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Recontextualizing Science, Technology, Engineering, and Mathematics Education through Chemistry: A Pathway to Global Sustainable Development

***Ogunmade, T. O., Braimoh D. S., & Saibu, S. O.**
College of Science Education, Lagos State University of Education, Oto/Ijanikin, Lagos, Nigeria

***Correspondence author email:** ogunmadeto@lasued.edu.ng

Abstract
Science education research in recent times has reported students' involvement and engagement in scientific inquiry, discovery and exploration. In particular, studies have shown that in Science, Technology, Engineering and Mathematics (STEM) education, learners are afforded the opportunity to understand the world around them and proffer appropriate solutions to many of the societal problems facing humans and society at large. Thus, this call for the recognition of STEM education as an 'economic driver' has motivated its inclusion in the school curriculum framework worldwide, both in developed and developing nations. This is based on the premise that effective STEM education is a vehicle for developing in students the much-desired 21st-century competencies towards the attainment of sustainable global development. However, despite the importance of STEM education for sustainable global development, its curriculum implementation in many countries of the world still remains ineffective and a great challenge to educators' lack of a cohesive understanding of how STEM education informs classroom practices. This paper therefore presents the potential of chemistry as a sub-set of STEM education with its various innovative teaching approaches through which nations could engage in achieving a successful sustainable global development for the 21st century.

Keywords: Classroom Practice, Global Economy, Innovative Strategies, STEM Education, Sustainability

Introduction

STEM education, an acronym for Science, Technology, Engineering, and Mathematics, has evolved to address the need for a more integrated and practical approach to these fields. According to Beers (2015), STEM education aims to prepare students with the skills needed for the 21st century, emphasizing problem-solving, critical thinking, and interdisciplinary learning. This concept has expanded beyond traditional subject boundaries to include more comprehensive and real-world applications, promoting a holistic understanding of how these disciplines interrelate. DeBoer (2019) described Science, Technology, Engineering and Mathematics Education as the strongest drivers of competitive national economies and the most important aspect of the Quality Education for Sustainable Development Goals (SDGs). Recent studies have continued to refine the STEM approach by integrating elements such as design thinking and computational skills into the curriculum. For instance, Binns and Campbell (2020) discussed the adaptation of STEM curricula to better align with evolving educational goals and industry demands, focusing on the inclusion of interdisciplinary methods and practical problem-solving skills. Chemistry as a subset of Science Technology Engineering and Mathematics (STEM) education plays a pivotal role in STEM education by providing foundational knowledge and practical applications that connect various STEM disciplines (Braimoh et al., 2023; Stohlmannm et al., 2012).

Additionally, Chemistry has been described as the study of properties and composition of matter, its chemical reactions, structure and associated changes and which provides students with many transferable skills that can be applied to any career in their work life (Nkiko, 2021; Chukwu & Adophus, 2022). The integration of chemistry into STEM curricula helps foster a deeper understanding of the chemical principles that underpin technological advancements and engineering solutions (Bianchi & Toms, 2017). According to Ogunmade et al. (2020), integrating chemistry into STEM curricula provides students with a comprehensive understanding of material properties and chemical processes, which are essential for technological and engineering innovations. This integration helps students appreciate the relevance of chemistry in solving practical problems and driving advancements across various STEM fields.

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Further, research by Chukwu and Adolphus (2022) underscored the importance of chemistry in developing critical thinking and problem-solving skills. They argued that chemistry education facilitates interdisciplinary learning, allowing students to apply chemical principles to diverse STEM challenges. This interdisciplinary approach not only enhances students' understanding of chemistry but also strengthens their overall STEM competencies. Pahnke et al. (2019) however affirmed that chemistry teaching and learning essentially helps learners to develop the competencies necessary for the attainment of Sustainable Development Goals (SDGs). Recent research by Hodge and Jones (2018) on *Green Chemistry* explored how advances in chemistry have led to the development of new materials with improved properties, such as lightweight composites and advanced polymers. These materials are crucial for technological applications, including aerospace and electronics, demonstrating the importance of chemistry in driving engineering innovations as in Nanochemistry. Moreover, chemistry plays a vital role in addressing global challenges such as sustainability and environmental impact (Saibu, 2023).

According to Kumar et al. (2022), green chemistry practices are essential for developing eco-friendly technologies and reducing environmental harm. By integrating green chemistry principles into STEM curricula, educators can prepare students to tackle environmental issues and contribute to sustainable global development. Similarly, Hodge and Jones (2018) discussed how green chemistry principles aim to reduce environmental impacts by designing processes and products that minimize waste and energy use. This approach aligns with broader sustainability goals by promoting eco-friendly practices and innovations. The application of green chemistry extends to various sectors, including manufacturing and energy production, where it drives the development of sustainable materials and processes. Thus, chemistry's contributions to environmental sustainability are significant, as it provides the tools and knowledge necessary to address environmental challenges. This focus on sustainability helps learners to have a better understanding of how to address global issues such as climate change and resource depletion.

Goals of Education for Sustainable Development

Education is a crucial part of the SDGs, not only due to its role as a specific goal (Goal 4: Quality Education), but also because it is essential to the possibility of progress on all other goals in ensuring that all learners acquire the knowledge and skills to promote sustainable development as explicitly addressed in SDG 4.7. Scholars have described Education for Sustainable Development (ESD) in diverse ways according to their understanding. ESD is conceived by Berlin and White (2010) as an interdisciplinary learning methodology covering the integrated social, economic, and environmental aspects of formal and informal curricula.

ESD is further described by Kanga (2016) as an education that aims to help people develop their attitudes, skills and knowledge in order to make informed decisions for the benefit of themselves and others, now and in the future, and to act upon these decisions. This in essence connotes that ESD is hoped to meet the needs of the present without compromising those of the future.

Moyo and Berdut (2017) however provided five essential attributes that learners need to acquire the Goals of Education for Sustainable Development (ESD). These include:

- **Motivation:** To develop interests, for example in climate issues or social justice, and to experience self-efficacy, for example in engaging with these issues at the local level.
- **Understanding and knowledge:** To understand basic concepts and to build up knowledge.
- **Reflection and evaluation:** To recognize problems (e.g. non-sustainable development), understand perspectives, and engage in constructive discussions.
- **Values and moral options:** To experience values and the negotiation of and reflection on value standards, thereby initiating the development of a reflective attitude of critically examining and applying moral norms and, in the long term, the ability to make ethical judgments.
- **Action:** To participate in decisions, negotiate solutions, and change something in their everyday lives.

Essentially, through community-based STEM education for Sustainable Development, students would be able to discover for themselves their identity and the identity and perspectives of their peers and community members as it relates to the socio-scientific issue; and then act on the issue directly in their community through civic engagement.

Relevance of STEM Education in the Attainment of Sustainable Global Development

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Research in the last decade has examined the field of sustainability in relation to economic growth and development and as such the word "sustainability" has been defined in many different forms (Carter & Easton, 2011). To a layman, sustainability is seen as the avoidance of depleting natural resources to meet today's needs without sacrificing access to those resources in the future. In a clearer form, sustainability is defined as "offering the potential for reducing the long-term risks associated with resource depletion, fluctuations in energy costs, product liabilities, pollution and waste management (Shrivastava, 1995, p. 955). However, one of the most acceptable descriptions was presented in the Brundland World Commission (1987) report which described sustainability as "the development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (p. 634).

In recent times, the physical realities of the climate crisis the world experiences have made the relevance of sustainable development impressively recognizable. Thus, STEM education for Sustainable Global Development (SGD) encourages learners and youth to draw on their STEM education competencies and the process of science as a key basis for decision-making and for taking reasonable action in this modern world. For instance, in September 2015 a set of Sustainable Development Goals was launched by the United Nations as a result of growing urgency for sustainable development at the global scale with a view to equip students with the appropriate knowledge and competencies needed for ba etter understanding of SDGs and to engage as informed citizens in bringing about the necessary transformation in the world at large. (United Nations Education, Scientific and Cultural Organisation, UNESCO, 2017)**.** From the foregoing, it has been found that STEM education plays a significant role in advancing the United Nations Sustainable Development Goals (SDGs) by providing the knowledge and skills needed to address global challenges. In their research, Diercks and Peterman (2019) explored how STEM education can be aligned with SDGs by integrating sustainability principles into curricula and fostering interdisciplinary collaboration. They emphasised that by incorporating sustainability themes into STEM education, educators can help students understand the connections between scientific knowledge and global challenges, preparing them to contribute to sustainable solutions.

Further studies also pointed to the fact that for sustainable development, students in a pedagogic STEM education integration classroom should be engaged to: solve problems, innovate, invent, think logically, be self-reliant and technologically literate (Johnson & Sondergeld, 2015). Johnson and Sondergeld (2015) and UNESCO (2017) however provided that engaging in pedagogical STEM-integrated classrooms would help teachers and educators in most instances to address problems that are related to subject conceptual understanding, poor achievements and loss of interest including enrolment declines among learners. From the foregoing, therefore, the fact remains that having knowledge, skills, and understanding of STEM education is vital to helping students understand global problems and to support their actions in society by addressing these challenges in a meaningful and knowledge-based way. This, in essence, provides that learners need to be considered active stakeholders in inquiry and sustainability issues in order for them to become problem-seekers and solvers through their engagement in the following activities as presented by Pahnke et al. (2019):

- Promote inquiry-based learning and scientific thinking and practice.
- Encourage interactive, learner-centred teaching that enables exploratory, action-oriented, reflective and transformative learning.
- Reinforce a whole institution approach that focuses on the systemic development of the educational facility towards quality education and sustainability.
- Foster independent thinking and responsible action that takes place in the learner context and involves the institution's social and natural environment,
- Providing the opportunity to implement and experience real changes in the learners' own community, which then strengthens their capacity for agency compatible with the goals of sustainable development.
- Strengthen evidence-based and reasoned argumentation, recognize complexity, promote diversity of opinion and change of perspectives, and encourage the critical reflection of values.
- Empower present and future generations to use science, technology, engineering, and mathematics (STEM) skills and reflective reasoning to solve complex sustainability problems and many complex scientific phenomena that exist within societies.
- Informed students demand that adults take into account the scientific findings about these phenomena and act accordingly to achieve sustainable solutions for global challenges such as the climate crisis.

STEM education has a significant impact on addressing global challenges by preparing students to tackle complex problems through innovative solutions. Ruggiero and Rothenberg (2021) reviewed current practices in STEM education and their contributions to sustainable development, highlighting the importance of

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interdisciplinary learning and real-world applications. They pointed out that integration of STEM principles into educational practices helps students develop the skills and knowledge useful to address pressing issues such as climate change, resource management, and public health. From the above, it can be deduced that when youths are actively engaged in STEM education and socio-scientific issues from a young age, in perspective-they would be equipped to proffer solutions to address the most complex issues of our time and for future generations.

Globalisation Issue in Re-Contextualizing STEM Education for Global Sustainable Development

The word globalisation is a difficult concept to define due to its shifting nature. According to Kolb (2021), globalisation is the word used to describe the growing interdependence of the world's economies, cultures, and populations, brought about by cross-border trade in goods and services, technology, and flows in investment. From these definitions, it can be deduced that globalisation indicates that the problems of one country affect everyone; therefore, educating all children to be responsive to the issues of the day is critical. A powerful and sustained implementation of future-oriented Science, Technology, Engineering, And Mathematics education focused on the issues of critical importance and potential solutions to those problems, will help to inoculate young people and their teachers and parents against societal and health problems that can adversely affect their lives.

Consequently, engagement with science, technology, engineering, mathematics, and computer science – in addition to languages, the arts or social-emotional learning are an integral part of future-oriented education which supports learners' independent thinking and responsible action, as well as the reflective engagement with technological and societal changes for the benefit of sustainable development (Ogunmade et al., 2020). Thus, STEM education helps students solve the global challenges of our generation. More so, Education for Sustainable Development (ESD) encourages changes in knowledge, skills, values and attitudes to enable a more sustainable and just society for all and also aims to empower and equip current and future generations to meet their needs using a balanced and integrated approach to sustainable development. The future-oriented STEM Education should therefore focus on engaging youth in both scientific investigation and action on the most pressing issues and challenges of our time.

The Impact of Inquiry-Based STEM Education on Global Sustainable Development

A worldwide rapid expansion of the nation's interest in STEM education has been reported in several studies in recent times. This is with a view to addressing the ills and challenges being faced by society, yet, these challenges remain even with the emergence of STEM education. Researchers have unequivocally pointed out that developing a skilled and successful workforce through STEM education is a complement to creating global scientists and problem solvers who often engage in science process skills involving exploring and observing, asking questions, discovering connections, discussing findings and their implications, and as well the limitations of methods and knowledge for them to understand phenomena in the world (Lai, 2018; Stohlmannm et al., 2012). In essence, Scientists engage in Inquiry-Based STEM education while carrying out these activities. STEM Education is referred to as a "scientific" or inquiry-based approach to natural phenomena which corresponds to exploring the learner's inquisitiveness and their desire to get to the bottom of things by asking questions, to appropriately understand the world around them (Lai, 2018). He believed the STEM disciplines involve participation in the social process of searching, learning, and shaping with the aim of solving global sustainability issues and critically reflecting on their contribution to support actions in society that address them in a meaningful and knowledge-based way. The application of inquiry-based STEM education proposes that having knowledge, skills and understanding of science, technology, engineering, and mathematics phenomena would help students to understand global problems and provide support actions in society to address those challenges in a meaningful and knowledge-based way. Thus, students' involvement in STEM subjects can help in instilling economic development driving skills such as problem-solving, critical thinking, collaboration and creativity in the students for future engagement.

More so, Inquiry-Based STEM Education is built on constructivist theories of learning developed by Piaget and Vygotsky, which believe that learners form their understanding of the world based on the prior knowledge that they acquire over time, and new knowledge augments previous understandings. This Constructivist theory has long been applied to many different education disciplines but has become particularly relevant to STEM Education. The Inquiry-based STEM education, in particular, gives children the opportunity to explore 'hands-on', to experiment, to ask questions, and to develop responses based on reasoning" in addition to solving

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problems and understanding the phenomena of the natural world around them, that is engaged in 'minds on' (Aniaku et al., 2020).

The goals of early science education comprise the dimensions of motivation, understanding of basic science concepts, procedural knowledge about, and skills in, scientific working methods, thus leading to "Scientific Literacy" (Goodrum et al., 2001). Scientific literacy has held a space somewhere between educating young people with deep scientific content knowledge and arming them with the skills and practices of science that are translatable to other disciplines (Ogunmade, 2006; Goodrum et al., 2001). Therefore, besides conceptual knowledge, an essential part of basic education in the STEM domains is the ability to acquire, expand, critically reflect on, and apply knowledge using suitable methods of thinking and acting (Ogunmade, 2006). This includes the ability to work out fundamental relationships for one, to evaluate these relationships, and to make decisions based on them. Thus, the evaluation of scientific results includes questions of value orientation. Hence, inquiry-based STEM Education should aim to comprehensively understand the world and to apply in a value-based way what has been learnt. Thus, modern STEM education pursues a critical-emancipatory understanding of education.

Case Studies of Successful Integration of Chemistry into STEM Education for Global Challenges

Case studies provide valuable insights into the effective integration of chemistry into STEM education. Choi and Lee (2021) presented examples of successful STEM programs that incorporate chemistry to address global challenges. These case studies demonstrated how interdisciplinary approaches can lead to innovative solutions and improved educational outcomes. For instance, programs that combine chemistry with engineering and technology have been shown to enhance students' understanding of complex systems and foster collaborative problem-solving skills. These examples highlight the potential of integrated STEM curricula to address real-world issues and prepare students for future challenges.

Research studies have shown that when learners are provided the opportunities to engage in a more sensible outlook of practical approach to real-life experiences, they tend to proffer solutions to problems confronting them and society at large (Hirst, 2019; Martin-Paez et al., 2019). This therefore implies the need for training teachers in a manner to achieve behavioural changes in the learners and to align curriculum reform with continuous teacher professional development (Eriksen, 2013). Many nations in recent times have regarded STEM education as an important ingredient for developing 21st-century competencies in learners such as creativity, problem-solving and entrepreneurship which are important prerequisites for further studies in STEM education areas (Colucci-Gray et al., 2006). This is with a view to engaging students in STEM education-related careers through their engagement in entrepreneurship and inventions. This paper therefore examines the place of chemistry as a pathway to global sustainable development.

Contemporary Pedagogical Approaches for Re-contextualising Chemistry into STEM Education for Sustainable Global Development

There is no gainsaying the fact that re-contextualising chemistry, a subset of STEM education for sustainable development, is germane towards addressing global environmental issues confronting mankind and the ecosystem. Therefore, learners' understanding of chemical concepts is best achieved by 'doing and engaging' in regular hands-on activities thereby connecting science to real-life activities and proffering appropriate solutions within the context of their immediate environment with the hope of grooming innovative minds of the learners to create a real impact of science in their daily life activities in order to spearhead the global sustainable development (Pahnke et al., 2019).

In today's contemporary world, several innovative approaches to teaching chemistry have been presented towards attaining sustainable global development. These innovative approaches include the following:

1. **Curriculum Design and Pedagogical Approaches**
   Integrating chemistry into STEM curricula which involves adopting pedagogical approaches that emphasise interdisciplinary learning and real-world applications. Nguyen and Loke (2019) described strategies for incorporating chemistry into STEM education, including project-based learning and inquiry-based methods. These approaches help students apply chemical concepts to solve complex problems and understand their relevance to global challenges. Thus, by designing curricula that integrate chemistry with other STEM disciplines, educators can enhance students' problem-solving

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skills and prepare them for careers that require a comprehensive understanding of scientific and technological principles.

2. **Project-Based Learning (PBL)**
   This is a hands-on approach which encourages students to get involved in real-world problems in order for them to have an in-depth understanding of STEM concepts. Students, through these projects, apply what they learn in class to solve complex questions, design solutions, and collaborate with peers, thereby making learning relevant and exciting (Larkin & Lowrie, 2023).
3. **Incorporate Technology and Digital Tools**
   This involves using technology in the classroom such as simulations, coding exercises, and online laboratories. These can provide interactive and immersive learning experiences for the learners. The use of tools like virtual reality (VR) and augmented reality (AR) would help bring abstract concepts to life and make learning for students more understandable and engaging (Lowrie & Larkin, 2020). Innovative teaching practices and technologies offer new possibilities for integrating chemistry into STEM education. These technologies provide interactive and engaging learning experiences that can help students better understand complex chemical concepts and their applications (Chui, 2021).
4. **Flipped Classroom Model**
   This approach involves the use of traditional learning models and is inverted. For deeper understanding, students first explore new content at home through videos or readings and then apply the concepts in class through discussions, projects, and problem-solving activities. This allows for more active, hands-on learning during class time.
5. **Cross-disciplinary Approaches**
   This approach involves integrating STEM subjects with arts, humanities, and social sciences. This can help demonstrate the interconnectedness of knowledge and foster a holistic understanding of concepts being learned. For example, linking chemistry or physics with environmental science can show the practical applications of STEM in diverse fields.
6. **Gamification**
   This involves incorporating game elements into learning. This strategy can make STEM subjects more engaging and fun. Students' involvement in educational games, competitions, and challenges would help motivate them to learn and can also improve their problem-solving skills and persistence (Dichev & Dicheva, 2017).
7. **Real-World Connections**
   Exposing students and highlighting them on how STEM subjects apply to everyday life, current events, and future careers can make learning more relevant and inspiring. Through the invitation of Guest speakers from STEM professions, field trips, and partnerships with local businesses or universities, students can be provided with practical insights and career inspiration (Bybee, 2010).
8. **Student-Centred Learning**
   Empowering students to take charge of their own learning, through choices in projects, self-paced learning modules, or inquiry-based activities would foster their independence and a deeper engagement with the material. Also encouraging questions and allowing students to explore areas of interest can lead to a more personalised and meaningful learning experience.
9. **Cultivate a Growth Mindset**
   Teaching students that intelligence and abilities in STEM can be developed through effort, practice, and learning from failures can encourage persistence and resilience. Celebrating progress and effort rather than just correct answers or grades helps build a positive learning environment.
10. **Collaborative Learning Environments**
    Promoting teamwork and collaboration among students through group projects and lab activities can enhance communication skills, foster a sense of community, and allow students to learn from each other's perspectives and strengths.

Conclusion

This paper has examined the relevance of chemistry as a subset of STEM education with an emphasis on the application of innovative approaches to build students capacity for sustainable global development through the knowledge of scientific and technological innovations for future generations. Such approaches would add value to educating young people since it provides the fundamentals to understanding how to develop sustainability mindsets and use reflective STEM knowledge for societal good.

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Furthermore, integrating the STEM curriculum framework would encourage teachers to adopt research, discovery and problem-based approaches in teaching specific STEM subjects. In addition, the adoption of these student-centred approaches in teaching STEM education like chemistry should be able to develop creative and innovative minds in students and as such classroom practices emanating from pedagogical STEM integration should be able to meet the criteria for effective STEM instruction towards sustainable global development.

Recommendations

Based on the aforementioned benefits of chemistry learning towards the attainment of sustainable development for nations, the study recommends the following:

1. There is a need for the integration of chemistry into STEM education curricula worldwide, emphasising practical applications and real-world examples.
2. Efforts should be geared towards encouraging collaborations between educational institutions, industry, and governments to promote STEM education and sustainable development.
3. Emphasis should be geared toward the provision of professional development opportunities for educators in order to enhance their chemistry knowledge and teaching skills.
4. The government should help to support research initiatives that explore innovative chemistry-based solutions to global challenges.
5. There should be need for the development of interdisciplinary teaching resources and materials that showcase chemistry's role in sustainable development.

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