CHAPTER EIGHTEEN

SCIENCE TEACHING AND LEARNING FOR THE 21ST-CENTURY: UTILIZING INTEGRATED STEM EDUCATION

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Objectives

This chapter aims to discuss students' learning for the 21st century through integrated STEM education. The specific learning objectives include:

1. Explain 21st-century learning and its components
2. Highlight the components of the 21st-century skills; core subject skills, learning and innovative skills, career and life skills, and digital skills
3. Explain STEM education
4. Explain the components of STEM education
5. Highlight the integrated STEM approach
6. State the role of the teacher in the 21st-century classroom

Introduction

The quest to help learners develop knowledge and skills that are relevant to the 21st century using innovative instructional strategies is at the forefront of educational discourse globally. Innovative strategies that have the potentials to develop the human resource needed for this century. The human resource that responds to the environmental and economic problem of the world through scientific reasoning, critical and innovative thinking. These can be achieved through the adoption of instructional strategies that can be guaranteed the acquisition of these skills. However, the observed educational delivery structure is characterized traditionally by the teacher as the giver of knowledge while learners are the recipient. Traditional instructional strategies dominate most classrooms in developing countries such as Nigeria which focus on lower thinking skills (Olokundun et al., 2018). The world and the society are evolving and becoming more complex. The skills, competences and knowledge needed by citizens to circumnavigate the intricacies of life and work in the society must also evolve. This implies that the status quo in the processes of education must not remain. The students need to be prepared for the now and future with comprehensive skills and competencies that will help them thrive in our rapidly evolving 21st-century global world through 21st-century learning. World Economic Forum (2016) observed that because of the present changes, it is important to consider the way education is being provided today and seek better ways to enhance the process of education to enable learners' transition from school to the world of work. Education is a veritable tool for advancing sustainable development and frontiers of knowledge. Hence, the process of education should be geared towards equipping students with relevant skills. Because the global society of the twenty-first century is facing multidisciplinary problems, finding solutions to these problems require both pieces of knowledge of the disciplines of STEM and 21st-century skills.

Given the proceeding, the global economy has shifted from the industrial era to the information and knowledge-based economy era which requires the transformation of classroom instruction and experiences to reflect the demands of the information and knowledge-based economy era.

Literature has suggested the implementation of integrated STEM education which could provide the learning environment that will equip learners with the needed skills for the 21st-century (Koula, Frasera, & Nastitiaa, 2018; Retnowati, Riyadi, & Subanti, 2020). Providing more understanding of these skills becomes a vital endeavour.

Twenty-first Century Learning Outcomes

In the last decade, there is advocacy for educators globally to engage students with learning that is relevant to the 21st century (Teo, 2019). This is in response to the need to equip students with skills to circumnavigate and take advantage of available resources and opportunities in the present globalized world and interdisciplinary educational landscape. The 21st-century skill is a buzzword for researchers, governments, and other stakeholders. Therefore, the status quo in classroom instruction and curriculum must not remain. It is important to note that the demand for 21-st century skills and knowledge framework is built on the premix that education has failed to prepare learners for the demand of the present age. Therefore, the need to re-engineer classroom teaching and learning to help learners develop 21st-century skills and competencies through 21st-century learning. Advocates of 21st-century learning believe that the world is evolving, and learners must be prepared for today and the future through meaningful and deeper learning which emphasize skills such as digital, critical thinking, creative, collaborative, and communicative skills. Others include adaptability, flexibility, and problem-solving skills. Furthermore, skills such as empathy, social and cross-cultural skills, accountability, and leadership, among others. In addition to these skills, students should also master the content of science, technology, engineering, and mathematics because STEM content knowledge drives innovation in this digital age. The 21st-century framework is highlighted in Figure 1

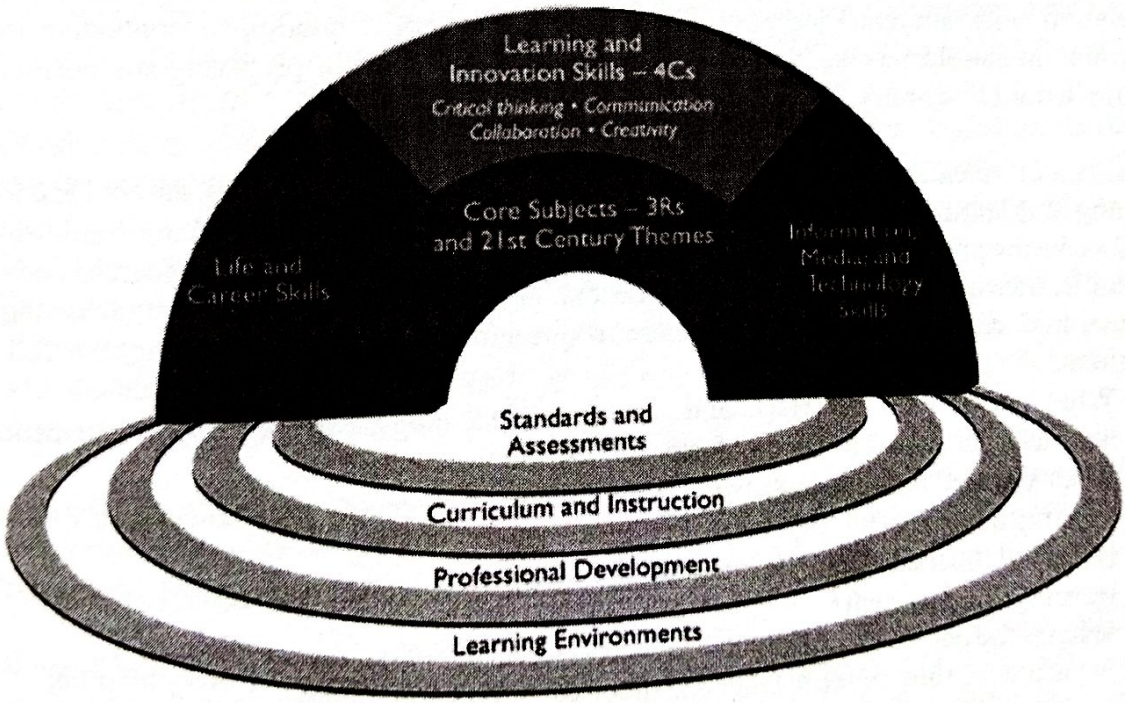

Figure : 21st Century Skills Framework (P21,2007)

These are key elements that can qualify 21st-century learning according to partnership for the 21st century (P21, 2015) which include; emphasis on core subjects, learning and innovative skills, and Information, media, and technology skills. These elements are highlighted in table 1.

Table 1 *Twenty-first Century Skills Domain*

Main Domain	21st-Century Essential Skills
Core Subject	• Reading • Writing • Numeracy
Learning and Innovative Skills	• Critical thinking • Creative and innovative • Problem-solving • Communication
Career and Life Skills	• Teamwork and collaboration • Adaptability and flexibility • Leadership and responsibility • Self-direction and Initiative • Social interaction • Productivity and accountability • Self-reliance and career learning
Information, media, and technology skills	• ICT literacy • Computer literacy • Information Literacy • Media literacy

Adopted from Trilling and Fadel (2009)

Twenty-first Century Learning Environment

The quality of the classroom environment is directly proportional to the quality of teaching and learning. Fraser, (2018) observed that classroom learning environment has a strong positive correlation with students' learning outcomes. Consequently, creating a conducive learning environment should be considered as an important endeavour for preparing students for work and life in the 21st-century.

Creating a 21st-century learning environment should begin with establishing the goal and focus of teaching and learning in the 21st-century. Perlman (2010) suggested a thinking framework that could assist the present learners to acquire relevant skills and competencies; expected knowledge and skills, instructional strategy and assessment, curricular activities, relevant technology, and instructional environment. Each of these could be achieved by answering the following questions.

1. What curricular materials and activities, pedagogy, technology, assessment, and instructional environment that foster 21st-century instruction?
2. What type of learning assessment that enhances students' engagement and 21st-century learning outcomes?
3. How will the technology be integrated to support pedagogy and assessment of 21st-century learning environment?
4. What is the nature of the physical environment that will foster 21st-century learning?
5. What are the roles of the teacher and the students in teaching and learning? (Perlman, 2010).

Therefore, there is the urgent need to move away from the status-quo in term of the traditional teaching and learning to the 21st-century instruction which will help learners acquire relevant skills. Saavedra and Opfer (2012) observed that "if we believe 21st-century skills are the keys to solving economic, civic, and global challenges and to engaging effectively in those spheres, then

we must act upon the belief that using those skills to overhaul our education systems is possible." They recommended the following for teaching and learning environment in the 21st-century;

1. Make teaching and learning relevant to the students by engaging them in authentic learning
2. Help learners develop thinking skills (critical thinking, creative, innovative, and problem-solving skill etc) by employing approaches and instructional strategies that engage learnersin higher-order thinking skills
3. Encourage transfer of learning to a novel situation, this can be achieved by providing the real-world problem that will be solved through the application of what is learnt
4. Encourage metacognition among learners (teach students how to learn)
5. Integrate relevant technology to enhance instruction
6. Adopt multidisciplinary instructional approaches and pedagogy such as Project-based learning, integrated STEM approach,
7. Provide the opportunity for students to collaborate (peer tutoring, team-work, pair teaching) and communicate their ideas and knowledge with each other and with the teacher.
8. The teacher facilitates the learning process through driving questions, open-ended questions, provision of clues and moderating the collaboration between the students.

Similarly, given this, The National Governors Association (2008) suggested the need to focus on global best practices and policies that have a high impact with regards to human capital development relevant to the 21-st century. Some of these global best practices with regards to STEM education include:

1. Reforming the curriculum using international benchmarks and standards especially in science, technology, and mathematics for secondary education level to ensure that students acquire knowledge and skills to compete effectively in the global market.
2. Developing a mechanism that will ensure that curricular, textbooks, digital resources and assessment among others align with international standards and benchmarks.
3. Ensuring accountability through adequate supervision, and monitoring, among others.
4. Ensuring adequate recruitment and development of teachers
5. Evaluating the performance of schools or education system by juxtaposing the achievement of students with the international context to ascertain that the knowledge and skills acquired will enable the students to compete favourably in the 21st-century global economy (National Governors Association, 2008).

Examples of such strategies that will provide such experiences will include integrated STEM approach, project-based learning, guided inquiry, designed-based learning, and problem-based learning, among others.

One of the recent strategies suggested for 21st-century learning in STEM education is relatively an innovative and most vital reform in science and mathematics education. STEM education has the potential to enhance students' higher-order thinking skills, creative skills, and critical thinking skills. Ritz and Fan (2014) opined that STEM education equips learners with competencies and skills to address the economic and environmental challenges in the world because it has the potential to develop the human resource needed for this century. Probably in recognition of this, many countries around the world have prioritized STEM education in their national agendas especially developed countries (Guzey, Ring-Whalen, Harwell, & Peralta,

2017). In the United State of America, STEM education is an important national agenda to provide the nation with a competitive spot as one of the best economies globally (Forman et al., 2015). Winn, Choi, and Hand (2016) opined that STEM education is the focus of policymakers in many nations in the world. Nevertheless, STEM education has not been given the needed attention by policymakers and other educational stakeholders in developing countries, and Nigeria in particular. This may have grave implication in the countries quest to develop a STEM workforce that will compete effectively in the global market. Hence, the need for this chapter.

STEM Education

The STEM education acronym was coined by Judith Ramley the director of the National Science Foundation (NSF) Education and Human Resource division 2001 – 2004 (National Science Foundation, 2012). Before this time, the National Science Foundation used the acronym SMET (science, mathematics, engineering, and technology). Some other researchers reported that through the National Science Foundation (NSF), STEM education acquired its name and has gained prominence all over the world for its perceived potential to improve K-12 education. STEM education is seen by researchers as the instructional process in the disciplines of STEM in an integrated manner (Kennedy & Odell, 2014). One of the goals of STEM education is to nurture a society that is STEM literate with knowledge and ability to identify a problem, provide a possible solution, solve the problem and communicate their findings that is evidence-based. Create consciousness of the influence of STEM disciplines on the economy, environment, and quality of life, as well as the willingness to participate in STEM-related issues and discourse.

Exhibit skills, attitudes and knowledge of STEM disciplines which will minimize the problem of workforce needs in the evolving nature of the global economy. Reduce the shortage of STEM manpower and educators around the world (Kennedy & Odell, 2014). Given this during the International Council of Association for Science Education (ICASE) world conference where 34 countries were represented. A declaration called the Kuching declaration was made calling on researchers and other stakeholders in STEM disciplines to consider as a matter of urgency the need to equip students with skills to be global citizens (ICASE, 2013).

Improving STEM education instruction that will break the barriers of traditional classroom practices is a global phenomenon because STEM education drives innovation (Kennedy & Odell, 2014). Worthy of note is the advent of technology and knowledge-based economy have made science and technology innovations essential elements of competing in the global market. It is recognition of this that President Obama in his Educate to Innovate initiative declare the need for the United State of America to focus on the ability to think critically, problem-solving, collaborative abilities among others which important in the 21st-century workforce (Dejarnette, 2012). STEM innovations are not possible without a workforce that is adequately educated and equipped with relevant skills in Science, Technology, Engineering and Mathematics.

Organization for Economic Co-operation and Development (OECD) observes that the educational systems of countries have an important responsibility to support innovation by raising highly skilled labour force in all sectors of the economy (OECD, 2011). Because quality education has become a vital element of economic success. This underscores the need for research on STEM approach to learning especially secondary schools to prepare students for higher education in STEM careers, increase their interest and motivation in STEM-related disciplines.

One of the major goals of STEM education is to make classroom learning similar to what professionals do in their daily work. This may help students to be able to transfer knowledge acquired in the classroom to a real-life situation. In a real-life situation, students need to make informed choices about the environment, genetically modified food, scientific policies, and the economy. These students may be able to successfully participate in these choices if they are exposed to STEM education. Consequently, STEM education is implemented in the classroom as an integrated instructional approach.

Components of STEM

STEM education has the potentials to help learners develop thinking skills such as critical thinking, creative, communitive, collaborative, and problem-solving skills, among others earlier (Kennedy & Odell, 2014). The components of science, technology, engineering and mathematics in this study were derived from the components of science and engineering practices, mathematics practices and technological practices from Literature (Parker, Stylinski, Bonney, Schillaci, & McAuliffe, 2015)

The Science (S) in STEM according to the Framework for K-12 science education is made up of scientific practices which include; formulating the problem, developing and using models, planning and carrying out investigations, analysing and interpreting data, and drawing a conclusion (National Research Council, 2012). The practices of scientist and engineers are discussed together because they are very similar (Parker et al., 2015). In this study, the following science and mathematics concept will be applied in engineering design. In this study, the concepts of science and mathematics are applied in the engineering design process.

The Technology (T) in STEM refers to technology design and technology as a learning resource. Most Literature sees the technology in STEM as applications which offer the potentials to align classroom activities with STEM practices in the real world and how professionals solve problems, therefore, they work hand in hand with engineering design. Because technology is the modification of the natural world to solve human needs, for instance, the emphasis on technology is on how to solve problems using hands-on tools. In this study, therefore, technology is seen as an instructional resource, its applications will help to deepen students' understanding of STEM by promoting active student-centred learning. As an instructional resource in this study, it can be achieved through using specific technological applications such as; computer modelling, computer simulation, digital animation, multimedia productions, and virtual exploration (Osman & Saat, 2014). The success story of STEM education around the world defines technology in STEM as information communication technology with regards to materials that are used to scaffolds learning (Parker et al., 2015).

Technology components employed in the teaching and learning process in genetics could help learners develop critical thinking skills. This will help students apply knowledge and skills in a real-life situation as against students reproducing what they have learnt in traditional classrooms (Jerald, 2009). The use of technology as a learning resource will enhance genetic learning, defining a problem, formulate hypothesizing, generating data, analysing and drawing of conclusions (Stohlmann, Moore, & Roehrig, 2012). They further observed that teachers need materials in integrated STEM approach to help learners carry out hands-on activities. The materials are those that are readily available or improvised, which include, but not limited to measuring devices, construction tools, glue, cardboard, construction papers and Styrofoam. Using these materials to carry an investigation to solve the problem, learners get a better understanding and use of technology. Given the foregoing, it is important to note that teaching

and learning process may not meet the yearnings of employers, without learners taking advantage of the 21st century's technologies. Because STEM professionals use some of them in real life to work.

The justification for adapting and adopting some of the components of the STEM components and practice is because it emphasizes the process of how an individual knows. It scaffolds student-centred learning that is characterized by hands-on and minds-on activities which engage learners in quality learning. These practices motivate the students to think scientifically, developing skills that will make the individual thrive in the 21st century, such as critical thinking and innovative skills. It also motivates students to learn because learning is student-centred. For instance, defining problems or driving questions stimulate curiosity and engage the sense of deduction and analysis, which are critical thinking skills employ to have a proper understanding of the problem and how it can be resolved by employing the most appropriate solution including qualitative analysis. Hypothesis formulation is an important process of investigation because it provides the route to navigate the problem through data collection, which can be analysed to obtain results which will provide the yardstick for concluding. Model construction is a fundamental tool in teaching and learning science because it simplifies the complex and abstract concept for better understanding as well as help learners investigate phenomena. STEM education is implemented in the classroom for teaching and learning as an integrated STEM approach.

The Engineering (E) in STEM Engineering is the application of science and mathematics principles, concepts, and theories to designing a product or process and modify existing ones to meet human needs. The engineering design process (EDP) is iterative. The EDP is made up of several phases or steps of an iterative process that help an individual think out of the box. The stages have been presented severally by researchers; identify problem, brainstorm, develop an idea, create a plan, develop, and test the prototype, improves prototype (Lottero-Perdue, Roland, Turner, & Pettitt, 2013). Imagine, design, create, test, and improve. Think, make, and improve (Martinez & Stager, 2013). The engineering design process is a problem-solving process, a platform that will help learners have a deeper understanding of complex abstract concepts, enhance understanding and the acquisition of 21st-century skills.

The Mathematics (M) in STEM is made up of a list of mathematical practices that will help learners acquire skills during problem-solving and deepen their understanding of science and engineering. The mathematical practices include; Make sense of the problem and persevere in solving them, reason in an abstract manner and quantitatively, construct arguments and question the reasoning of other participants or students, Model with mathematics, Use appropriate tools strategically, Attend to precision and make use of structures (Rockland et al., 2010). In this work, the mathematical components such as Make sense of the problem, Reason in an abstract manner and quantitatively (statistics), construct arguments and question the reasoning of other participants or students and use appropriate tools strategically.

Integrated STEM Approach

The basis for STEM integrated instruction is built on the premise that individual or single subject learning provide unconnected facts, concepts, and principles that students may not be able to transfer the knowledge obtained in the classroom to a real-life situation. Proponents of STEM-based instruction observed that teaching and learning STEM disciplines in an integrated manner especially in real-world context will enhance students' meaningful learning (Pearson, 2017).

The integrated STEM education approach is an instructional approach that is not intended to deal with the instruction of the individual disciplines, but STEM disciplines or subject taught in an interrelated manner or collectively (Dugger, 2010). Teaching and learning in the field of science, technology, engineering, and mathematics presented enhanced the transfer of knowledge across STEM disciplines and to a real-life context.

The integrated STEM educational approach is a holistic approach to teaching and learning that links the different disciplines together such that learning becomes relevant to the learners' needs of the 21st century, which is in line with the characteristics of the integrated STEM education approach. There is a lack of agreement about how STEM-based instruction should look like. However, from literature, the following may be considered in designing integrated STEM-based instruction;

1. Students learn an instructional content of one or two disciplines in the context of another discipline (Kertil & Gurel, 2016);
2. Integrated STEM should include the engineering design process (Dailey, 2017);
3. It must involve an authentic or real-world problem, implemented in a problem-based and project-based learning environment
4. Learning should be characterized by hands-on and minds-on activities which will target both science process skills and Higher Order Thinking Skills (HOTS).
5. Use 21st-century tools, 21st-century instructional context, teaching and learning 21st-century content and adopting 21st-century assessment.

Teacher Role

The role of the teacher shifts from teaching to a facilitator in the 21st-century classroom. As a facilitator, the teacher is required to be able to understand the facilitating techniques and characteristics of each student so that they can facilitate more individually. Learning that prepares students for the challenges of the 21st century is done by teachers who understand and know what to do (North Carolina State Board of Education, 2007), namely:

i) Teachers make learning content interesting, relevant, and meaningful to the students' lives.
ii) Teachers with students build learning competencies that incorporate critical thinking skills, problem-solving, and information and communication technology literacy (ICT).
iii) The teacher facilitates learning by encouraging all students to be able to find ways to learn (metacognition), innovate, collaborate, and convey ideas.
iv) Health, financial literacy, awareness as citizens, global society, and environmental awareness become one of the learning materials.
v) Teachers reflect on learning, assessment, and provide adequate feedback to students.
vi) The teacher encourages students to lifelong learning by driving the learning process through question prompts, leaning clues, encourage, and drives the process of classroom collaboration, among others.

Conclusion

This chapter focused on students' learning for the 21st century through an integrated STEM approach. Given the importance of STEM education for preparing learners for the 21st-century labour market, it is of paramount importance to explore STEM education to position students appropriately to take advantage of the employment opportunities. Hence, developing countries

like Nigeria will need to double their efforts to raise a STEM competent workforce that will compete favourably in the global market. This can be achieved through the implementation of STEM-based instructional approaches and creating a 21st-century learning environment. From the Nigerian perspective, the basis of STEM education research (in senior secondary school) is to improve the dwindling student academic achievement in science, improve youth interest in pursuing STEM careers and foster students' development of higher-order thinking skills.

Given that the role of the teacher has changed, there is a need for training and retraining on how to facilitate students learning using innovative strategies. The government should provide support services to help teachers keep up to date with current instructional developments which could help them create 21st-century teaching and learning environment. It was recommended that teachers at all levels of education should be trained and provided with the instructional materials to implement innovative instructional strategies such as integrated STEM approach.

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