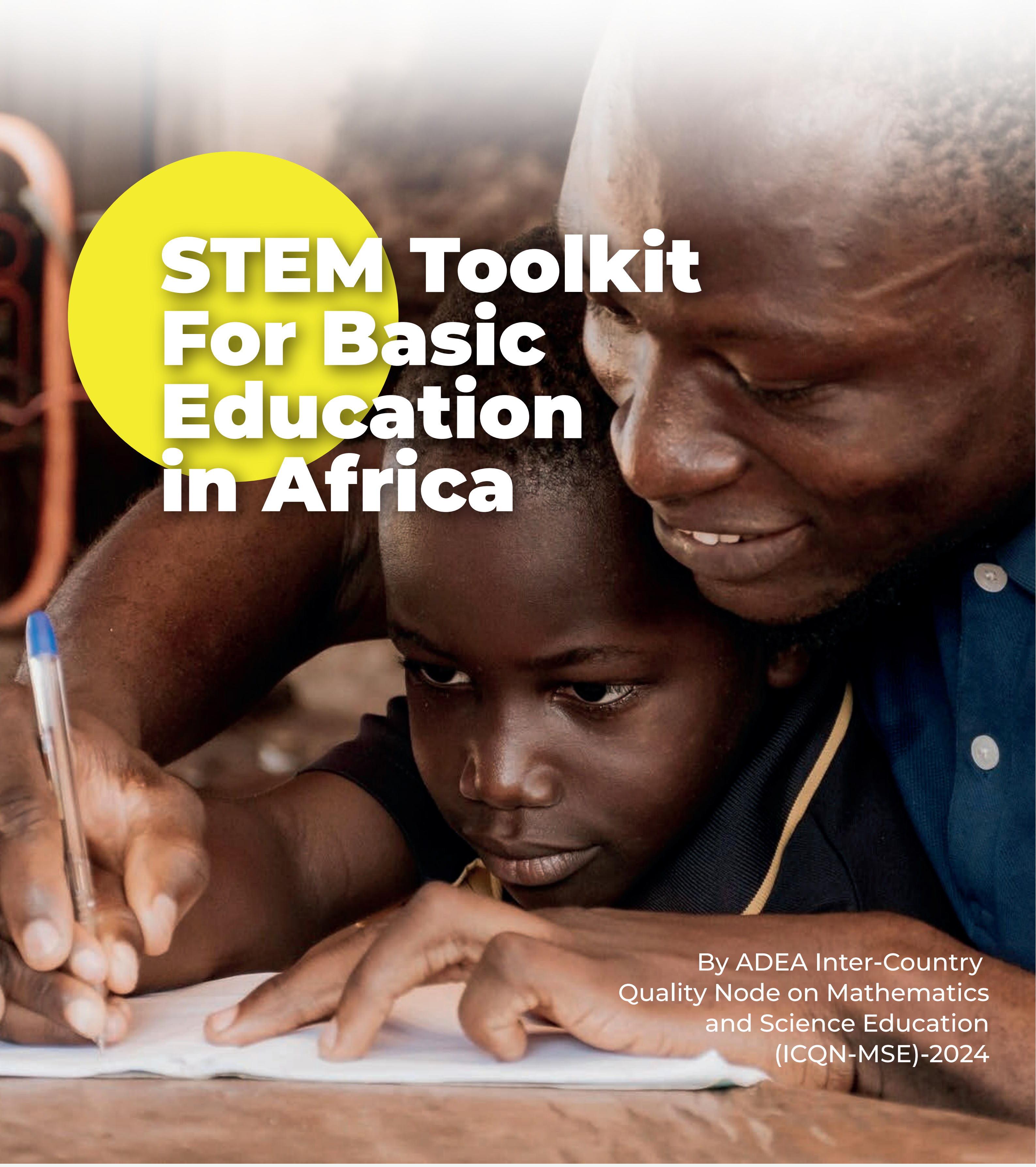
Association for the Development of Education in Africa

MINISTRY OF EDUCATION

REPUBLIC OF KENYA

ADEA Inter-Country Quality Node on Mathematics and Science Education

The LEGO Foundation
www.learningthroughplay.com



STEM Toolkit For Basic Education in Africa

By ADEA Inter-Country Quality Node on Mathematics and Science Education (ICQN-MSE)-2024

www.adeanet.org

ADEA

Association for the Development of Education in Africa (ADEA)
African Development Bank Group (AfDB),
Immeuble CCIA Plateau, Avenue Jean-Paul II
01 BP 1387, Abidjan 01 Côte d'Ivoire
Tel.: (+225) 2026 5674
Email: adea@afdb.org
Website: https://www.adeanet.org

Inter-Country Quality Node on Mathematics and Science Education
Secretariat Office, Host Institution
Centre for Mathematics, Science and Technology Education in Africa (CEMASTEA)
P. O. Box 24214 – 00502
Karen, Nairobi – Kenya
Tel.: 020 2044406 / 0706 722697 / 0780 797648
Email: ceo@cemastea.ac.ke
Website: http://www.cemastea.ac.ke

Developed with the support of the LEGO Foundation

…………………………………………………..

Citation

ADEA (2024). The STEM Toolkit for Basic Education in Africa.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

ADEA	Association for the Development of Education in Africa
BDL	Design-based Learning
CBC	Competence-Based Curriculum
CEMASTEA	Centre for Mathematics, Science and Technology in Africa
CESA	Continental Education Strategy for Africa
COVID	Coronavirus Disease
CPD	Continuous Professional Development
IBL	Inquiry Based Learning
ICQN-MSE	Inter-Country Quality Node on Mathematics and Science Education
ICT	Information Communication Technology
M&EF	Monitoring and Evaluation Framework
MEL	Monitoring, Evaluation and Learning
OSAA	Office of the Special Adviser on Africa
PBL	Problem-Based Learning or Play-based Learning
PCK	Pedagogical Content Knowledge
SDG	Sustainable Development Goals
SMASSE	Strengthening Mathematics and Science in Secondary Education
STEM	Science, Technology, Engineering and Mathematics
STISA	Science, Technology, and Innovation Strategy for Africa

DEFINITION OF TERMS

Term	Operational Definition
Integrated STEM education:	An approach to teaching content of two or more STEM education domains.
Interdisciplinary or Multidisciplinary STEM education:	An approach that integrates two or more disciplines within the fields of STEM to provide a more comprehensive and holistic learning experience.
Transdisciplinary STEM education:	Integration of knowledge and skills from multiple STEM subjects as well as from other disciplines such as the arts, humanities and social sciences.
Person oriented question:	Encourage learners to make connections between what they already know and what they are exploring. The questions give learners the space to answer in whatever way that makes sense. Person-oriented questions are useful when the teacher wants to increase the amount of conversation with and between learners or assess what learners know about a topic.
Play Based Learning:	A learning approach that incorporates playful and hands-on activities to engage students in the exploration and understanding of STEM concepts and skills.
Process Oriented Questions:	Extend learning by guiding the learners toward more meaningful conversation during a play-based STEM assessment/exploration. Responding to process-oriented question from a teacher is always preceded by an action by the learner.
Multidisciplinary STEM assessment:	An evaluation and assessment approach that measures and appraises the interconnectedness and application of knowledge and skills across different STEM disciplines.
STEM practices:	These are methodologies, approaches, and activities employed within the fields of STEM to investigate, understand, and apply knowledge, skills, values and attitudes.

ACKNOWLEDGEMENTS

Appreciation to all stakeholders that collaboratively supported the development of the STEM Toolkit for basic education in Africa. We acknowledge the Ministry of Education, Kenya led by the Cabinet Secretary for provision of strategic leadership in the implementation of the Inter-Country Quality Node (ICQN) on Mathematics and Science Education (MSE) activities that culminated in this piece of work. ADEA's thematic-based ICQNs such as the one on mathematics and science education serve as platforms that consolidate relevant information to inform education policy development in Africa. Regards to LEGO Foundation for funding the project on development of the STEM toolkit for Africa that will guide development of STEM education activities.

Gratitude to the board of governors and management of the Centre for Mathematics, Science and Technology Education in Africa (CEMASTEA) for hosting the ADEA ICQN-MSE Secretariat that oversaw the development of this valuable piece of work. Recognition to the leadership of the ADEA ICQN-MSE coordinator Dr. Mary W. Sichangi for expert translation of various ideas from member states into the STEM toolkit for Africa.

We acknowledge the valuable input of focal point officers in the ministries of education from the following countries; Kenya, Côte d'Ivoire, Angola, Botswana, Eswatini, Ghana, Ivory Coast, Malawi, Mauritius, Kingdom of Morocco, Mozambique, Namibia, Nigeria, Senegal, South Africa, The Gambia and Uganda; who validated the content of the toolkit and confirmed the need for harmonized meaning and interpretation of STEM education.

Appreciation to Dr. Herine Otieno the ADEA resource person for provision of professional expertise in the development of the STEM toolkit for Africa. Gratitude to Dr. Sudi Balimuttajjo and Dr. Evanson Muriithi the scientific review team of experts that comprehensively appraised the STEM toolkit for scientific soundness, accuracy of content, coherence and logical flow of ideas.

Acknowledgement to all that supported the development of the STEM toolkit for basic education in Africa towards harmonized meaning and interpretation of STEM activities in learning institutions.

Albert Nsengiyumva
Executive Secretary
Association for the Development of Education in Africa (ADEA)

EXECUTIVE SUMMARY

Recent studies by ADEA (2021, 2023) established critical gaps that exists in the provision of quality STEM education at the basic levels in Africa. These include lack of harmonised understanding of STEM education across countries in Africa; inadequate resources and facilities; students' lack of interest to pursue STEM careers; relevance of STEM curriculum; and insufficient number of STEM curriculum implementers.

As a step towards addressing the aforementioned gaps, the stakeholder forum organised by the ADEA Inter-Country Quality Node on Mathematics and Science Education (ICQN-MSE) in February 2022 recommended the development of a STEM toolkit mitigate the gaps. The toolkit developed will guide the implementation of countries' STEM policies and enhance understanding of opportunities that an interdisciplinary nature of STEM education presents in fostering knowledge, skills and interest of learners at the basic learning levels in STEM careers.

Designed to be flexible and adaptable to different contexts and needs of countries in Africa, this STEM toolkit will act as one of the key guides and resources for shaping a shared vision for STEM education and harmonised approach towards addressing the gaps in the provision of quality STEM education at the basic learning level.

Accordingly, referring to STEM education policies in some African countries, the first section of the STEM toolkit presents an outline of a process that countries may follow to formulate and continuously improve policies for STEM education at the basic learning level.

Similarly, the toolkit responds to the noted lack of coherence in understanding of and implementation of STEM education at the basic learning levels. It presents a framework for conceptualization of integrated STEM education and its related practices that individual countries may adapt in shifting from silo teaching of STEM disciplines to an inter-disciplinary approach to STEM education.

In step with recent reforms that have seen many countries adopt competency-based curricula, the STEM toolkit provides guidance on how integrated STEM education instructional practices such as play-based learning approaches, inquiry and problem-based learning and assessment may be tapped into, to explicitly foster both content knowledge and key 21st century skills.

Similarly, the STEM toolkit provides evidence-based guidelines on which countries may draw on, to shape programs that are responsive to respective contexts, needs and aspirations in developing training programs for teachers at the basic levels of learning.

In the same vein, the STEM toolkit reinforces the importance of monitoring, evaluation and learning by individual nations, and collectively as a continent. It provides a guideline that countries can leverage to shape national monitoring, evaluation and learning systems for quality STEM education.

While recognising the need to understand the cultural and contextual nuances that each country needs to pay attention to in providing quality STEM education at all levels, the spirit of the STEM toolkit echoes the continent's conviction espoused in Agenda 2063: The Africa We Want. The success in all our aspirations, including preparing learners for STEM-based careers and demands of the future job market, depends on the ability to demonstrate a unity of purpose and willingness to address any identified gaps in a timely manner.

CHAPTER ONE
Introduction to the STEM Toolkit

This chapter is organised into three main sections:

- Introduction
- Objectives of the STEM toolkit
- Rationale for the STEM toolkit

1.1 Introduction

Africa is faced with several challenges including a rapidly increasing population currently estimated to 1.2 billion people, limited STEM-based skills among the 11 million youth, less than 25 years of age, who join the labour market every year. The COVID-19 pandemic further amplified the socio-economic challenges in Africa, and this may continue to be felt for many years to come. A strategic response to these challenges is to accelerate investment in quality STEM education at the basic learning levels to equip the youth with relevant skills to take up emerging opportunities in STEM-based careers in Africa.

Towards achieving this goal, the stakeholder forum organised by ICQN-MSE in February 2022 recommended that ADEA should support the development of a STEM toolkit to advance policies on integration of STEM education, play and technology in Africa. The toolkit is a guide for implementation of STEM education policies in African countries considering the interdisciplinary nature of the subjects.

1.2 Objectives

The STEM toolkit for basic learning levels in Africa seeks to achieve the following objectives:

- Harmonise understanding of STEM education at the basic learning level across the continent.
- Enhance understanding and capacity for using learner centred pedagogies including play-based approaches to facilitate learning.
- Serve as a reference for formative assessment on the progress being made by individual countries in the provision of quality integrated STEM education.

1.3 Rationale for the STEM Toolkit

In the past decades, African governments have put a lot of effort to promote STEM education particularly mathematics and science. Increasingly there is a growing awareness and advocacy for an integrated approach to STEM education to better position it as an enabler for development and peace. Indeed, a recent policy paper by the UN-Knowledge Network of the Office of the Special Adviser on Africa (OSAA), highlights the critical role of interdisciplinary STEM education in creative development of solutions and innovations for real-life issues spanning sectors such as health, energy, food production and cohesive societies (Adebayo et al., 2022).

Nevertheless, Africa is still facing challenges of drawing on STEM education to develop relevant skills amongst its citizens. ADEA et al., (2021) reported inadequate resources and facilities for integration of STEM subjects, students' lack of interest to pursue STEM-based careers, relevance of the curriculum for STEM, and insufficient number of curriculum implementers. Additionally, ADEA et al., (2023) reported a lack of harmonised understanding of STEM education across countries in Africa.

The STEM toolkit is one of the key guides and resources for shaping a shared vision for STEM education. It also presents a harmonised approach to address gaps in the provision of quality STEM education at the basic learning level. The toolkit is designed to be flexible and adaptable to different contexts and needs of countries in Africa.

1.3.1 Purpose of the STEM Toolkit

Countries are encouraged to use the STEM toolkit as one of the key references in formulating country and context specific STEM education interventions. Specifically, countries may draw on the STEM toolkit as a reference and guide when:

- Reforming national curriculum and standards to foster STEM competences and promote interdisciplinary learning,
- Planning and implementing continuous professional development and mentoring programs for curriculum implementers.
- Supporting curriculum implementers to create an inviting learning environment and resources that foster inquiry, problem solving, exploration and collaboration among students.
- Establishing collaborative network of stakeholders such as academia, industry, government, and non-governmental organisations to support integrated STEM education.

1.3.2 STEM Needs Assessment

The studies on the status of STEM education in primary and secondary education in Africa (ADEA et al., 2021, 2023) and play-based learning identified gaps that need to be addressed to improve the quality of STEM education in Africa. Given the contextual and cultural nature of learning and teaching, the findings are deemed representative and cannot therefore be generalised for each country in Africa.

In step with ADEA's efforts, each country is therefore encouraged to carry out a national STEM education assessment to identify the actual needs for improving STEM education at the basic learning level. The needs assessment findings will inform the development of key national STEM education frameworks and policies.

1.3.3 STEM education policy and strategy

Based on the needs assessment findings, each country is encouraged to develop a STEM education policy and strategy to entrench the national vision and commitment in addressing identified gaps towards quality STEM Education at the basic learning levels. A sample outline of the STEM Policy

(Annex 1) is attached to guide countries to adapt to respective contexts based on the needs assessment findings.

1.3.4 National adaptation program guide for STEM Education policy and strategy

In order to facilitate effective and efficient operationalization of STEM education policies, Countries are encouraged to develop national adaptation guidelines to act as key references for STEM education policy implementers at all levels. Guides provide both technical, norms and standards for operationalizing key components of national STEM education policies. The national guides for STEM Education will be living documents, developed and continuously improved through a consultative and collaborative process with key stakeholders.

1.3.5 National STEM monitoring, evaluation and learning framework

National STEM monitoring, evaluation, and learning (MEL) frameworks will help countries to track and monitor the implementation of policies. The frameworks are informed by the key policy areas designed based on the identified needs. To facilitate efficient reporting at the continental level, countries may align the structure and format of their national STEM MEL frameworks with the Continental Monitoring and Evaluation System (M&ES) for STEM Education.

CHAPTER TWO
Integrated STEM Education at Basic Learning Level

2.1 Background

One of the key findings of the study on the status of STEM education in primary and secondary schools (ADEA et al., 2021, 2023) is divergence in conceptualization of STEM education in Africa. Similarly, the studies established a growing interest in the continent in integration of STEM subjects at the basic learning level and gaps in use of innovative learner-centred pedagogies such as play-based approaches (Ibid).

The STEM toolkit contributes to addressing the above-mentioned guided by the following specific objectives:

1. To harmonise the understanding of integrated STEM education at the basic learning level in Africa.
2. To provide a rationale for the implementation of integrated STEM education at the basic learning level.
3. To enhance understanding of the integrated STEM education instructional and assessment practices.

This chapter is organized into the following key sections:

- Integrated STEM education in Africa
- Rationale for integrated STEM education at the basic learning level
- Framework for Integrated STEM education at the basic learning level
- Implications for policy and practise.

2.2 Integrated STEM Education in Africa

Integrated STEM education emphasises the interdependence between STEM subjects. It requires teaching the content of two or more STEM subjects bound by related practices within an authentic real-life context (Ismail, 2018). The curriculum for integrated STEM education is characterised by integrating cross-cutting concepts of the different subjects (Han et al., 2023).

In concurrence with a number of countries from the Global North (Thibaut et al., 2018) and the Asian continent (Cheng, 2022), there is growing attention in Africa (Ismail, 2018) towards integrated STEM education. Countries such as Ghana, Kenya, Mauritius, Mozambique, and Zambia are transiting towards 'integrated' curriculum for STEM at the basic level of learning. The teachers from these countries are expected to apply hands-on, minds-on, real-life activities to explicitly help learners appreciate the interdependence between different STEM subjects.

2.3 Rationale for integrated STEM Education

The growing interest in integrated STEM education is foundationally premised on the understanding that the complex problems that the world seeks to solve through STEM are not disciplinary in nature (Kelley & Knowles, 2016; Ong et al., 2023). Accordingly, the emerging and emergent problems facing the African continent cannot be solved by single STEM disciplines. Solving complex problems at any one time requires application of knowledge and skills from more than one STEM subject.

At the basic learning level, the emphasis on the interconnection between the STEM subjects, exemplification of the practices through hands-on and minds-on real life activities in integrated STEM education have the following benefits (Han et al., 2023; Ismail, 2018):

1. Increase learners' interest and engagement in STEM subjects
2. Enhance students' interest and awareness of STEM-based careers
3. Foster STEM literacy amongst all learners
4. Develop 21st century skills such as creativity, critical thinking, collaboration and communication, adaptability and resilience.

2.4 Framework for integrated STEM education

The framework (Figure 1) is a guide to the national and continental process of building consensus on how integrated STEM learning, teaching and assessment need to be conceptualized. The framework is informed by findings on STEM education in Africa (ADEA et al., 2021, 2023); extant global research findings on integrated STEM education (Kelley & Knowles, 2016; Ong et al., 2023) and existing education policies in Africa that espouses learning as a shared experience rather than an individual experience.

A breakdown of the five principles (Thibaut et al., 2018) that underpin the framework is presented below. The five principles guiding integrated STEM education are supported by the demand for 21st century skills and competencies, learner-centered approaches such as play-based learning, and social construction.

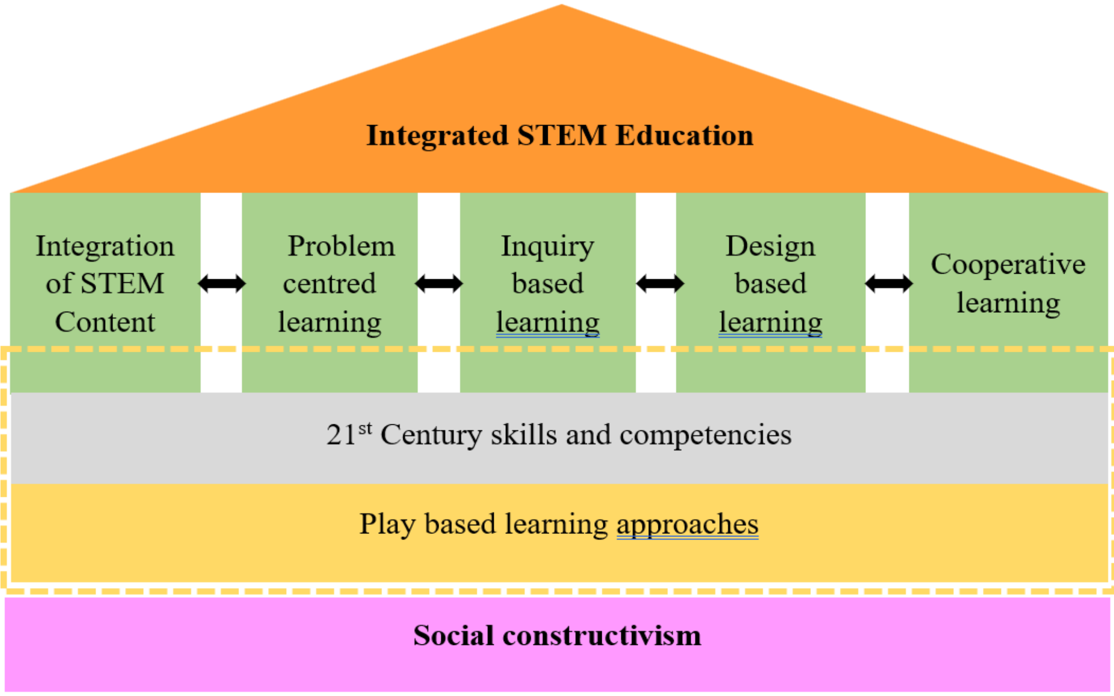


Figure 1: Framework for integrated STEM Education (Adapted framework from Thibaut et al. 2018 on integrated STEM instructional practice)

a. Principle Number One: Integration of STEM content

The curricula and instruction approach to involve explicit assimilation of learning goals, content and practices from the different STEM subjects. At the basic level of education, it is advised that the integration is inter-disciplinary (two or more STEM disciplines) and not transdisciplinary.

b. Principle Number Two: Problem Centred

Meaningfulness of the content learned is enhanced through learning environments that involve learners in solving authentic, open-ended, structured real-world problems.

c. Principle Number Three: Inquiry Based Learning

To discover new concepts and develop new understanding, learners are engaged in questioning, hands-on, minds-on and discovery learning activities.

d. Principle Number Four: Design -based learning

Opportunities for learning about engineering design, processes and practices is provided through open-ended, hands-on and minds-on design challenges.

e. Principle Number Five: Cooperative learning

Communication and collaboration amongst learners during the learning process is fostered and emphasised.

2.5 Supporting features of integrated STEM Education

a. Play-Based Learning

Play-based approaches in their characteristic provide opportunity for practise and fostering of each of the elements of integrated STEM education presented in the abovementioned principles. In addition, given that learning involves an inextricable interplay of cognition and emotions (Pyle & Danniels, 2016; Otieno, 2017), a play-based approach allows for reinforcement of role of emotion in learning and enhancement of students' affect (interest, engagement, attitude and motivation) towards STEM content, practices and careers (Gao et al., 2020).

b. Inter-relationship between the principles

The instructional practices underpinned by the aforementioned principles work together to facilitate learning. Figure 2 illustrates the interplay of the above principles in facilitating learning during an integrated STEM lesson. The communities of practice enhance cooperative learning; engineering design support design learning; mathematical thinking facilitates problem-centred learning; technological literacy enhances design and problem-centred learning; while scientific inquiry facilitate inquiry based learning.

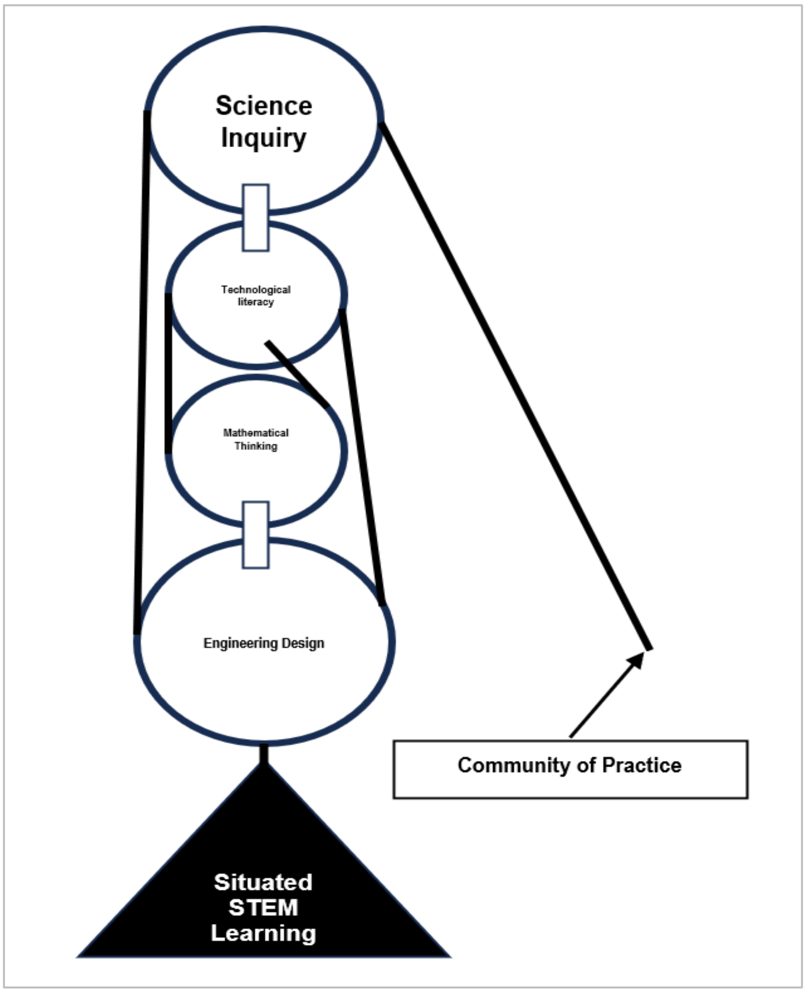


Figure 2: Conceptual framework for integrated STEM learning (Kelley & Knowles, 2015)

c. Fostering of 21st century skills

Depicted in the adapted conceptual framework for integrated STEM Education (Thibaut et al., 2018) fostering of key competencies or 21st century skills as emphasised in competence-based curriculum is a key learning outcome for integrated STEM education. Indeed, both integrated STEM education and competence-based education puts equal emphasis on content knowledge and key processes or soft skills such as creativity, critical thinking, collaboration, communication, and problem solving. These competencies are discipline specific and hence integrated STEM education uniquely fosters them in the context of STEM.

d. Social Constructivism

In tandem with a social constructivist view on learning, integrated STEM education is characterised by shared learning rather than individual experience and active learner' construction of knowledge.

2.6 Integrated STEM Assessment

In order to achieve the objectives of integrated STEM education, countries are encouraged to employ integrated STEM assessments. The assessments are classroom-based (Pellegrino et al., 2023) and play a formative role in improving instruction and learning. Formative assessment of integrated STEM education involves the application of a variety of tools, and guidelines. They include assessing learning linked to the affective domain in terms interest and motivation, psychomotor domain in regard to observing, imitating and adopting and cognitive domain such as application of knowledge from multiple subjects, disciplinary content knowledge, and skills by way of experimental skills, creativity and collaboration (Gao et al., 2020; Han et al., 2023).

Capturing the complex nature of interdisciplinary STEM learning, assessments are guided by learning objectives regarding knowledge, skills, and affective domains as well as practices for each subject as illustrated in Table 1 below.

Table 1: Assessment of learning objectives and integrated STEM

Nature of Disciplines \ Learning Objectives	Knowledge (K)	Skill (S)	Practice (P)	Affective Domain (A)
Transdisciplinary (TD)	TDK	TDS	TDP	TDA
Interdisciplinary (ID)	IDK	IDS	IDP	IDA
Monodisciplinary (MD)	MDK	MDS	MDP	MDA

Learning objectives linked to a specific learning area or knowledge may be assessed using disciplinary or inter-disciplinary strategies that involve conventional assessment activities such as answering multiple choice questions, answering open ended questions and essay type responses.

On the other hand, cognitive and psychomotor skills and practices, and attributes from the affective domain such as interest and motivation may be assessed through specific rubrics. An example of a rubric for assessing a cognitive skill such as critical thinking (Reynders et al., 2020) during an integrated STEM lesson is provided in Table 2.

Table 2: Rubric for assessing critical thinking

Critical thinking	**Evaluating, analysing, and or synthetizing relevant information to form an argument or reach a conclusion supported with evidence**					
Category	0	1	2	3	4	5
Evaluating		**Minimally** determined the relevance and reliability of information that might be used to support a conclusion or argument		**Partially** determined the relevance and reliability of information that might be used to support a conclusion or argument		**Extensively** determined the relevance and reliability of information that might be used to support a conclusion or argument
Analysing		**Inaccurately** interpreted information to determine meaning and to extract relevant information		Interpreted information to determine meaning and to extract relevant evidence **with some errors**		Made a claim and provided **complete** evidence to support it
Synthetizing		**Inaccurately** connected or integrated information to support an argument or reach a conclusion		Connected or integrated information to support an argument or reach a conclusion **with some errors**		**Accurately** connected or integrated information to support an argument or reach a conclusion
Forming arguments (Structure)		Made a claim and provided **incomplete** evidence to support it.		Made a claim and provided **partial** evidence to support it.		Made a claim and provided **complete** evidence to support it.
Forming Arguments (Validity)		The claim, evidence and reasoning were **minimally** consistent with accepted disciplinary ideas and practices		The claim, evidence and reasoning were **partially** consistent with accepted disciplinary ideas and practices		The claim, evidence and reasoning were **fully** consistent with accepted disciplinary ideas and practices
Comments:						

Source: Reynders et al., (2020)

If the integrated STEM education lesson is presented in a play-based format, the teacher may overtly or covertly assess the students on specific learning outcomes in terms of cognitive and affective domains using a set of rubrics. The teacher may also join the learners during play-based learning and ask open-ended person oriented and process-oriented questions to gain information learners' understanding of individual concepts and or process of STEM learning activities (Grady & Dusing, 2015). The information gained during play-based assessment by teachers can be used to plan appropriate activities for more effective teaching and or to address misconceptions or identified knowledge gaps.

2.7 Implications for Country-Based Policy and Practice

The foregoing discussions on integrated STEM education have implications for policy and practice in different countries as discussed in the sections below.

a. Vision and Mission for STEM Education

Integrated STEM education requires a shared vision and commitment from key stakeholders to operationalize a mission that provides opportunities for all learners at basic learning level to attain STEM-related goals.

b. Teacher training

Countries are encouraged to initiate the process of reviewing relevant policies towards integrated STEM education at pre- service and in-service teacher training levels.

c. School practices

Implementation of integrated STEM education is influenced by the structure and culture of the school. The lesson plan structure needs to provide adequate time for implementation of an integrated STEM lesson. Similarly, the time available for teachers to prepare for the lessons may influence the quality of an integrated STEM lesson. Equally, countries need to evaluate the current school culture in terms of the teachers' pedagogical practices and students' expectations on lessons and schoolwork in the context of role diversification. School development plans need to prioritise investments that directly improve the quality of STEM education, especially teaching and learning resources, pedagogical leadership, inviting school climate and culture.

d. Curriculum and Standards

The review and reform of the curricula content and set learning objectives for STEM subjects need alignment to the core purpose of an integrated STEM education. Curricula for integrated STEM education need to encompass; resources, model lessons, and assessment designs.

e. Assessment policy

Countries may need to review assessment policies towards integrated STEM assessment. This includes enriching instructional time with formative assessments that encourage creativity, innovation, and integrated forms of learner-centred pedagogy. In addition, the assessment measures to include a system of assessment to cover all the three domains namely cognitive, affective and psychomotor.

f. Resourcing of schools

Countries to consider mobilising and coordinating the distribution of resources including technology that are needed for implementation of integrated STEM education.

g. Partnerships and collaboration

Strengthening partnerships and linkages between the ministries of education and non-state actors, industries, academia, for profits, non-profit organisations, and schools in the implementation of integrated STEM education will foster knowledge dissemination, peer learning, synergy in resource utilisation and sustainability of interventions.

CHAPTER THREE
Learner-Centred STEM Education

3.1 Introduction

Learner-centered pedagogy views learners as active participants in own learning, with education shaped by respective interests, prior knowledge and active investigation. In spite of its prominence in education policies, implementation of learner-centered pedagogy has been challenging, and changes to classroom practice have been limited (Bremner et al., 2022). Studies have highlighted different instructional frameworks that are learner-centred to support STEM education (Kelley & Knowles, 2016; Thibaut et al., 2018). These instructional frameworks include integration of STEM content, problem-based learning, project-based learning, inquiry-based learning, design-based learning, cooperative or collaborative learning and other relevant learner centred approaches. The foregoing framework has been improved to include play-based approach as a reinforcement for each components of integrated STEM education at the basic learning level. The interrelated instructional practices are discussed in this chapter under the following sections; integration of STEM content, problem-based learning in STEM education, inquiry-based learning in STEM education, design-based learning in STEM education, cooperative learning in STEM education, and play-based learning in STEM education.

3.2 Integration of STEM content

Integration of STEM content refers to the explicit assimilation of learning goals, content, and practices from different STEM disciplines (Thibaut et al., 2018). It is a unification of content and concepts from multiple STEM fields (Roehrig et al., 2021). However, integration of STEM content lacks specific strategies (Thibaut et al., 2018). It is both a multidisciplinary and interdisciplinary approach to teaching STEM content using practices within an authentic context that connect these fields for enhancing learning (Thibaut et al., 2018). This connection between the four disciplines, namely science, technology, engineering, and mathematics, to real-world problems happens in one classroom, one unit or lesson.

The open-ended nature of integrated tasks requires curriculum implementers to play a role of facilitation in the learning process by helping learners to understand the STEM practices in which they are engaging and reflecting on the process. Moreover, learners are required to engage in data practices and evidence-based reasoning to justify design decisions.

3.3 Problem-Based Learning in STEM Education

Problem based learning refers to the environments that involve learners in authentic, open-ended and structured real-world problems to increase the meaningfulness of the content they are learning (Thibaut et al., 2018). In this approach, learners engage in an extended process of asking questions, finding resources, and applying information. Learners are encouraged to control the questions asked, use resources, and developed outcomes. The process encourages learners to be actively engaged in lesson activities, pursue their interests, gain insights from real-world context and draw upon intrinsic motivation to inform learning (Johnstone, 2022). This type of learning enables learners to further develop critical thinking and problem-solving skills which are transferable to future needs (Hope & Allen, 2009).

When curriculum implementers focus learners on finding answers rather than developing questions, they fail to develop imagination, creativity, and critical thinking skills. Holloway et al. (2017) suggests that providing learners with opportunities to interact with problems or questions kinaesthetically, it increases the ability to grasp concepts that are more abstract. Nevertheless, the success of these approaches relies on students' prior knowledge and skills to ably tackle the provocations and presented problems. Subsequently, it is essential for students to be supported to build curiosity, resilience, and independence by designing an overarching culture within the classroom that fosters and nurtures these qualities (Rais et al., 2021).

The implementation of problem-based learning at the classroom level requires adequate preparation to realize effective STEM lessons. The preparation steps are discussed below:

- ***Establishing learning outcomes***: desired capabilities that students need to acquire after participating in the learning process.
- ***Creating a relevant scenario or a real-world problem***: think of problems that students may encounter in real life or future careers.
- ***Forming small groups of students*** that are effective by establishing rules, assigning roles and responsibilities to maximise learning.
- ***Guiding students*** to explore the problem, research information and generate solutions.
- ***Guide students to present solutions*** and reflect on learning process.
- ***Establish formative assessment*** process that requires students to engage in self and peer assessment based on the learning level.

3.4 Inquiry-Based Learning in STEM Education

The inquiry-based learning (IBL) is among contemporary approaches that are increasingly being promoted in STEM education. Concurrent to trends in STEM education in the world, African countries are increasingly promoting inquiry based learning (Mugabo & Nsengimana, 2020; Ramnarain, 2014; Mkimbili & Odegaard, 2020). For instance, the revised South African school science curriculum espouses learning that is characterised by exploration of objects, situations and events in the learners environment, collection of data, recording of information and drawing of accurate conclusions (Ramnarain, 2014) aimed at advocating for an inquiry-based education.

The foregoing aspirations echoes globally identified tenets of inquiry-based learning that engages learners in questioning, experiential learning and hands-on activities that encourage discovery of new concepts and new understandings (Thibaut et al., 2018). Findings from studies in the use of IBL in teaching different STEM subjects in African classrooms, also suggest positive impact on learners attitude (Manishimwe et al., 2022), learners self-concept (Gathage et al., 2021) and conceptual understanding (Mkimbili & Odegaard, 2020).

The potential of inquiry-based learning is largely determined by the teacher's role in terms of time frames, content covered, and amount of information given to learners to stimulate inquiry. Table 3 below provides an outline of possible variations in learner and teacher engagement during different stages of inquiry-based learning.

Table 3: Essential features of classroom inquiry and related variations

Essential features	**Variations**			
1. Learner engage in scientifically oriented question	Learner poses a question	Learner selects among questions, poses new questions.	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source.
2. Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner is given data and asked to analyse	Learner given data and told how to analyse
3. Learner formulates explanations from evidence	Learner formulates explanations after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner is given possible ways to use evidence to formulate explanation	Learner provided with evidence
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner is given possible connections to sources of scientific knowledge	Learner is provided with sources of scientific knowledge
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to sharpen communication	Learner given steps and procedures for communication

Source: (Barrow, 2010)

Based on the levels of engagement of learners, an inquiry-based STEM lesson may fall into one of the following categories:

- **Open (Level 5):** The lesson is entirely inquiry-based. The learners decide on the problem and question to investigate and the method on how to solve the problem.

- **Guided (Level 4):** In guided inquiry, the teacher provides the question that needs to be answered. The learners decide on the best method to answer the question to realize the expected outcome.
- **Structured (Level 3):** In structured inquiry, the teacher provides the learners with both the question and the method on how to answer the question but omits the expected outcome.
- **Confirmatory (Level 1):** The lessons are not inquiry-based. In confirmatory exercises, the teacher tells the learners the expected solution to the question at the beginning of the lesson and then gives instructions on how to conduct the experiment to confirm the answer.

Table 4 may be drawn on as a rubric to establish the levels of inquiry in STEM lessons in individual African countries.

Table 4: Levels of inquiry in STEM lessons

Inquiry Level	Questioning	Planning	Implementing	Concluding		Reporting	Applying
			Carrying out plan	Analyse Data	Draw Conclusions		
0	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher
1	Teacher	Teacher	Students/ Teacher	Teacher	Teacher	Students	Teacher
2	Teacher	Teacher	Students	Students/ Teacher	Students/ Teacher	Students	Teacher
3	Teacher	Students/ Teacher	Students	Students	Students	Students	Students
4	Students/ Teacher	Students	Students	Students	Students	Students	Students
5	Students	Students	Students	Students	Students	Students	Students

Models of inquiry-based learning

There are different models of inquiry-based learning, including the Engage, Explore, Explain, Elaborate and Evaluate (5E) model (Duran & Duran, 2004), the Elicit, Engage, Explore, Explain, Elaborate, Evaluate and Extend (7E) model (Eisenkraft, 2003) and the Elicit, Engage, Explore, Explain, Elaborate, Echo, Evaluate, Emend and E-search (9E) model (Kaur & Gakhar, 2014). A number of countries in Africa have adapted the 5E model of inquiry-based learning (Nkundabakuara et al. 2023). Across the different models, inquiry-based learning processes are made up of four distinct and interrelated (Figure 4) inquiry phases namely, orientation, conceptualisation, investigation, and conclusion.

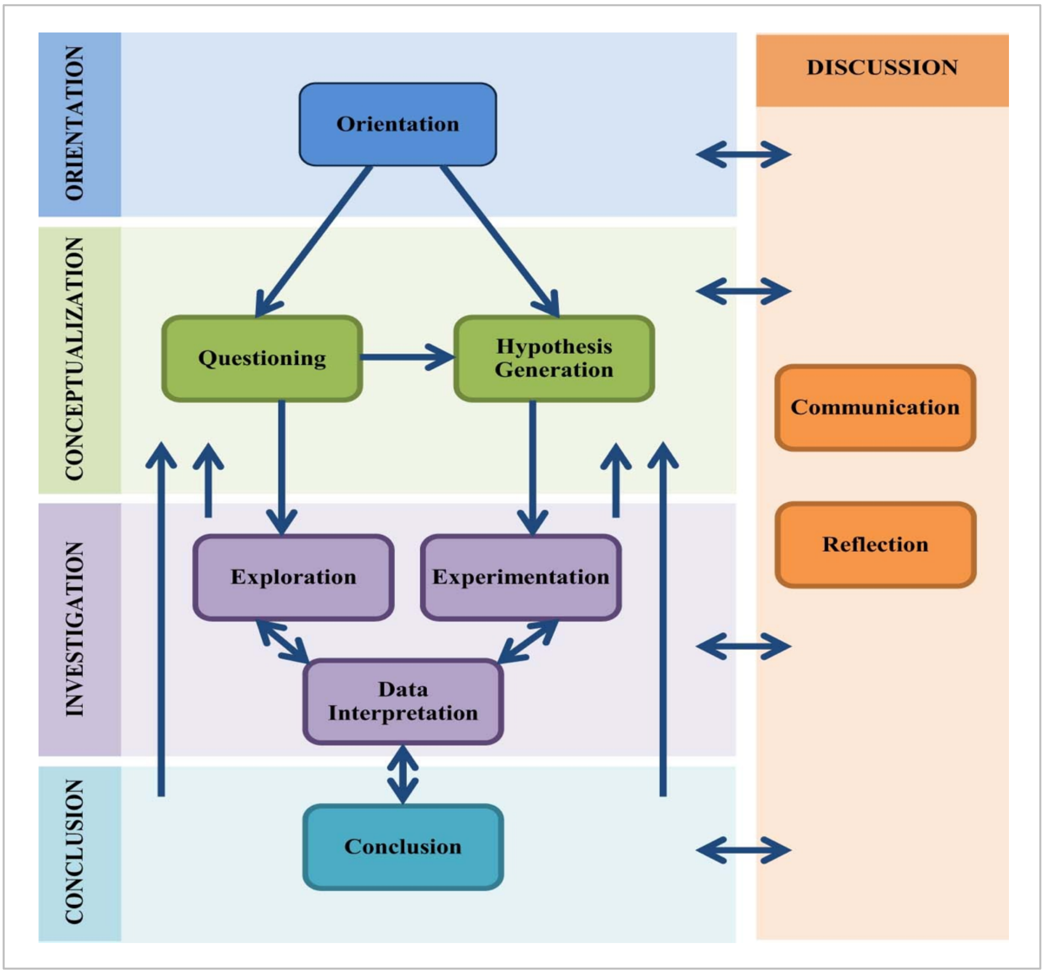


Figure 3: Phases of inquiry-based learning (Pedaste et al., 2015)

3.5 Design-Based Learning in STEM Education

According to (Thibaut et al., 2018), design-based learning (DBL) provides students with the opportunity to learn about engineering design processes and engineering practices. It entails the use of open ended, hands-on design that challenges students to use theoretical knowledge to tackle real-life problems.

Design based learning emphasizes real world application, more hands-on and interactive learning experiences. More importantly, the DBL connects theory and practices to enable students identify projects' needs, develop ideas by engaging in a range of thinking.

There are various ways of implementing DBL in the classroom based on the level, subject and context of learning as explained in the steps below:

- Identify a problem or challenge that is relevant and meaningful to the learners,
- Research and brainstorm possible solutions,
- Design and prototype a solution,
- Test and evaluate the solution,
- Reflect and communicate the results.

Design-based learning corresponds to project-based learning which has gained more traction in Africa (Twahirwa & Ntivuguruzwa, 2021). A key difference is that design-based learning in STEM education emphasizes the convergence of engineering and scientific practices. Specifically, design-based learning in STEM education is characterised by using reasoning processes as navigational devices to bridge the gap between the problem and the solution; leveraging uncertainty as a starting point to catalyse cognitive effort; and promoting learning by doing (Kelly & Knowles 2016).

3.6 Cooperative Learning in STEM education

The principle of cooperative learning indicates that students need an opportunity to communicate and collaborate with each other to deepen their knowledge base (Thibaut et al., 2018). In cooperative learning, students collaborate on a task in small groups to resolve differences in opinion, share responsibilities, consider one another's ideas, and working to achieve common goals. This process reveals learning gaps among learners, making them feel part of a team rather than isolated due to the synergy created between low, average and high achievers. In this symbiotic relationship, high achieving learners improve understanding of concepts by teaching peers.

Research has shown that students participating in cooperative learning programs outperform those in conventional learning programs at basic and tertiary levels. In addition, cooperative learning has been shown to result in increased social skills, improved learner's confidence and relevance of the learning material (Boling & Robinson 2021).

3.7 Play-Based learning in STEM Education

Play-based learning also referred to as learning through play pedagogies is a way of teaching that uses play as a primary means for learners to explore the world, investigate its properties and build an understanding of how the world works (Parker et al., 2022). Play-based learning occurs in a continuum that involves a range from learner-directed to adult-directed (Weisberg et al., 2013; Pyle & Danniels, 2016) activities.

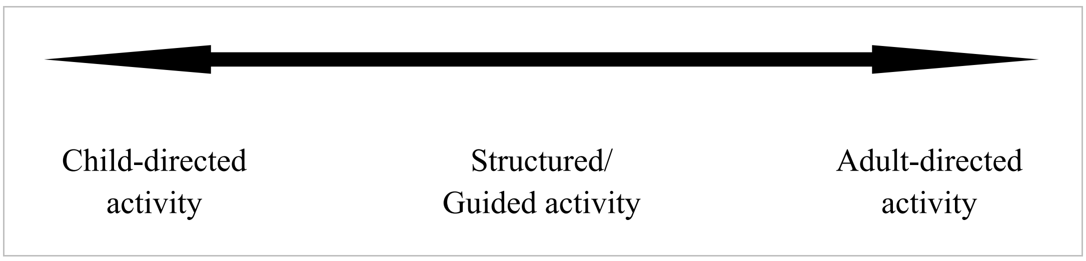


Figure 4: The play and power continuum (Briggs & Hansen, 2012)

The continuum suggests a power balance between the learner and the teacher such that learning is achieved through guided activities with the power of child or adult that increases on each corresponding side as you move away from the Centre of balance (Briggs & Hansen, 2012). A play-based integrated STEM education as depicted by the conceptual framework is premised on the understanding of resonance between key features of play-based learning and integrated STEM education.

Indeed, the five characteristics that have been found to embody educational play experiences (Zosh et al., 2017) depicted in figure 6 below, mirror key attributes of STEM integrated learning:

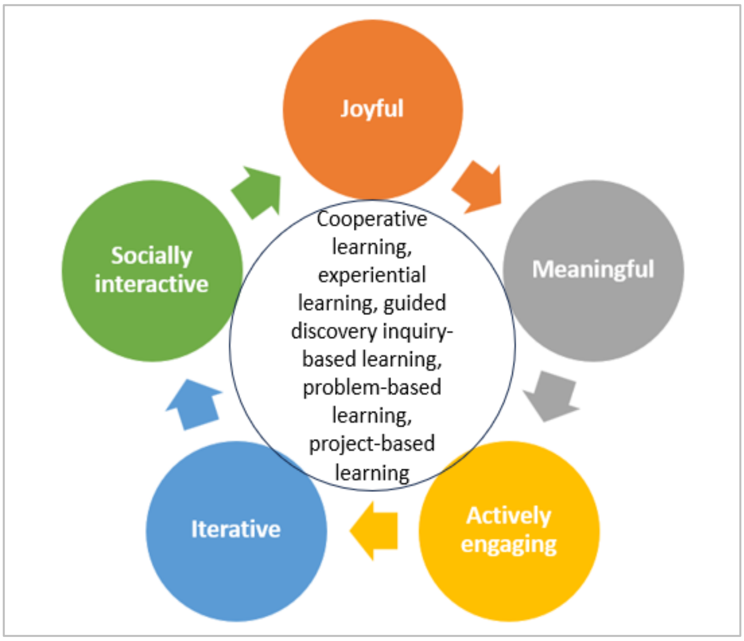


Figure 5: Characteristics of educational play experiences

- The meaningful feature of play-based learning resonates with the emphasis in integrated STEM education on connecting STEM concepts to real-life contexts that are meaningful to the learner.
- The actively engaging feature of play-based learning resonates with the emphasis in integrated STEM education on fostering of engineering and scientific practices through design learning that involves learning by doing.
- The joyful feature of play-based learning resonates with the focus on affective domain and aim to foster interest in STEM as one of the goals of integrated STEM education. Further, it enhances learning given the inextricable role of both emotions and cognition in learning.
- The iterative feature of play-based learning mirrors the scientific inquiry process of integrated STEM education, which involves questioning, 'experimentation' and investigation as provided for in integrated STEM education.
- The socially interactive feature of play-based learning resonates with cooperative learning a key feature of integrated STEM education.

In addition, a play-based approach to integrated STEM education at the basic learning level reinforces the fostering of key competencies such as creativity, critical thinking, collaboration and communication. An illustration of how a play-based STEM lesson may engender creativity is provided in figure 7 below.

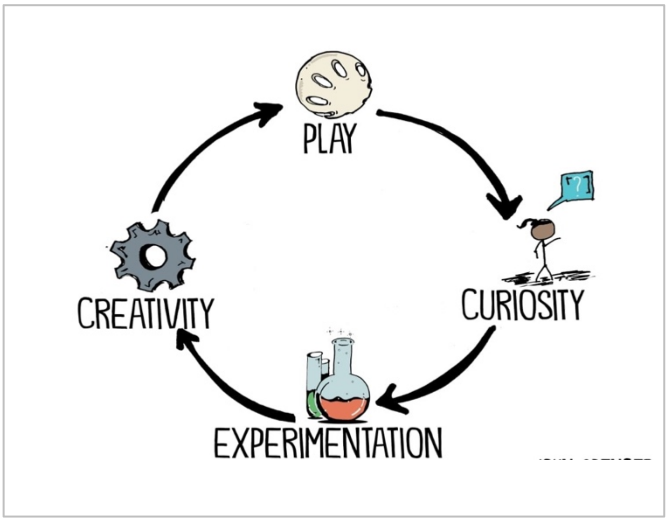


Figure 6: Educational Play Experiences (Spencer, 2018)

The afore-discussed resonance between play-based approaches and integrated STEM education notwithstanding, the context, purpose and learning outcomes of specific lessons inform the balance and type of play used by a teacher (Zosh et al., 2018).

CHAPTER FOUR
Teacher Training Guide

4.1 Introduction

Teacher capacity to deliver quality STEM education was identified as one of the gaps to be addressed to realize Africa's stipulated goals and aspirations for learners at the basic learning level (ADEA et al., 2021, 2023). The adaption of integrated STEM education in African countries require strengthening teacher-training programs both at pre-service and in-service levels. The training programs will respond to individual country' needs, context and aspirations for STEM education.

The guide seeks to harmonise understanding in Africa of the key tenets of an effective teacher-training program for integrated STEM education. Specifically, it outlines the process and areas of transformation that countries may target in teacher training, to support the process of complete transformation of learning STEM from a silo to an integrated approach. Countries are encouraged to draw on sections of this guide to develop teacher training manuals and training programs that are responsive to identified needs for successful implementation of integrated STEM education at the basic learning level.

The content of this chapter is organised under the following key sections:

- Framework for teacher professional growth
- Transformative teacher training program
- Teacher training program on integrated STEM education
- Teacher training approaches
- Teacher training techniques

4.2 Framework for Teacher Professional Growth

Integrated STEM education calls for an enhanced focus and effort on supporting teachers and curriculum implementers to be more adept at using specific learner-centred practices in teaching and assessment. Accordingly, teacher training and professional development programs instituted by countries are to be informed by evidence on factors that have been found to influence teachers' professional growth and uptake of new instructional practices. As depicted in figure 7 below, the factors may be categorised within three domains: personal domain, external domain, and domain of practice. Figure 7 depicts the expected shift in instructional practices influenced by teacher factors in terms of knowledge, skills, attitudes, beliefs and non-teacher factors such as policies, teaching and learning environment.

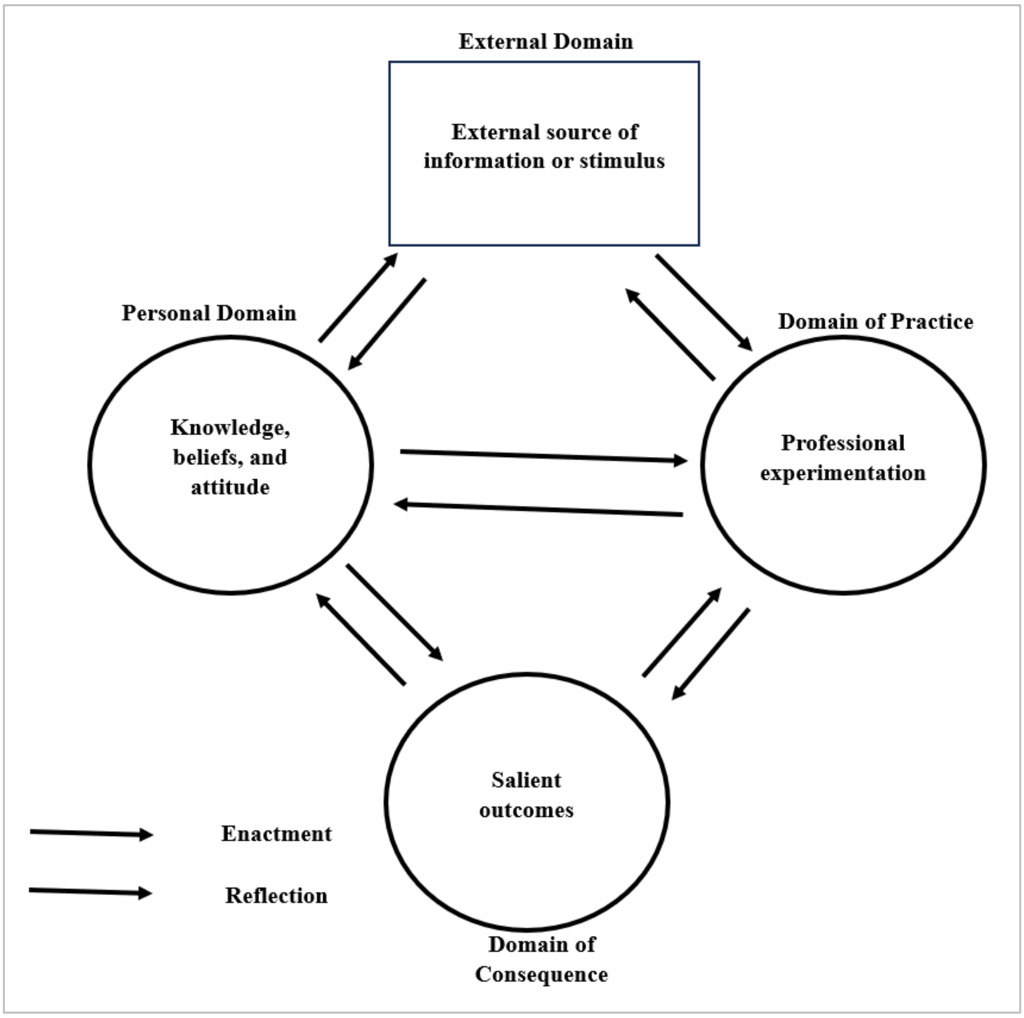


Figure 7: The Interconnected Model of Professional Growth
(Clarke & Hollingsworth 2002, p.951)

4.3 Transformative teacher training programs

Teacher training programs need to adopt a transformative approach to teachers' instructional practice for integrated STEM education. A transformative approach to training prioritizes the teacher's voice and agency by designing professional development programmes that enable teachers to continuously learn and re-learn to realise modified attitudes, knowledge, beliefs, and practices. The three key attributes of a transformative approach are:

I. Working WITH teachers and not ON teachers

Teacher agency and voice is central in implementation and monitoring of the training programs.

II. Contextual

Considering the value of context in terms of knowledge, practices and resources in teaching and learning, attention to context is central to a transformative approach to teacher training. The importance of the contextual teacher training is captured in the excerpt; *'A simple transplant of western educational thoughts to the Chinese context cannot work well because it neglects the particularity of* *the Chinese context. Therefore, the effort of transforming the Chinese teacher-centred relationship needs a genuine understanding of Chinese context of teaching to access both its strengths & limitations'* (Li & Du, 2015).

An illustration of the importance of context in an effective and transformative teacher-training program is depicted in the model (Figure 8) below for effective professional development.

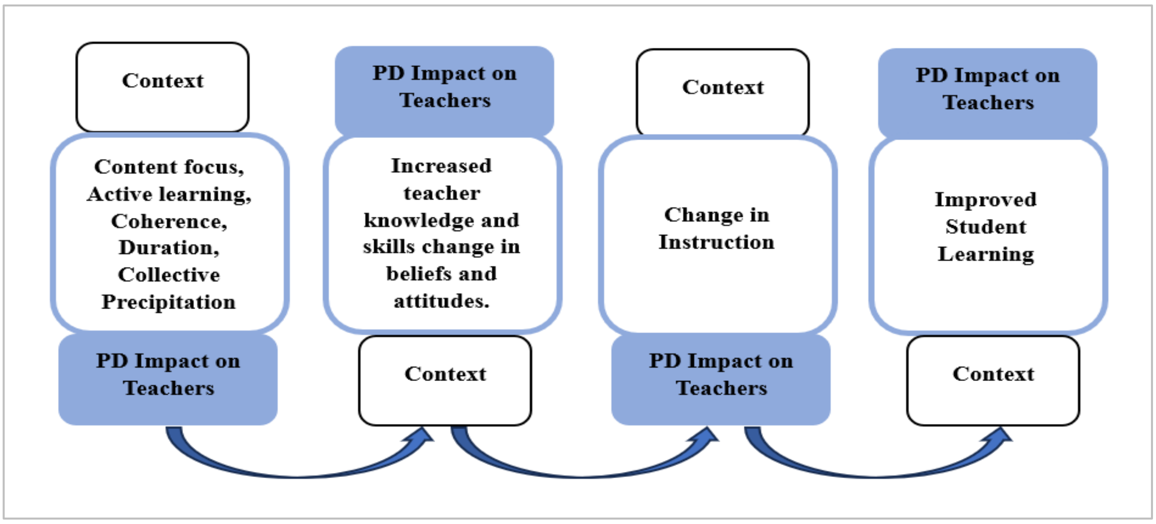


Figure 8: Contextual transformation of teacher training programs (Marey et al., 2022)

III. Foundational focus on teacher beliefs, attitudes, and values

Transformative professional development programs put effort in transforming teachers' values, attitude and beliefs as a foundation to transforming Pedagogical Content Knowledge (PCK).

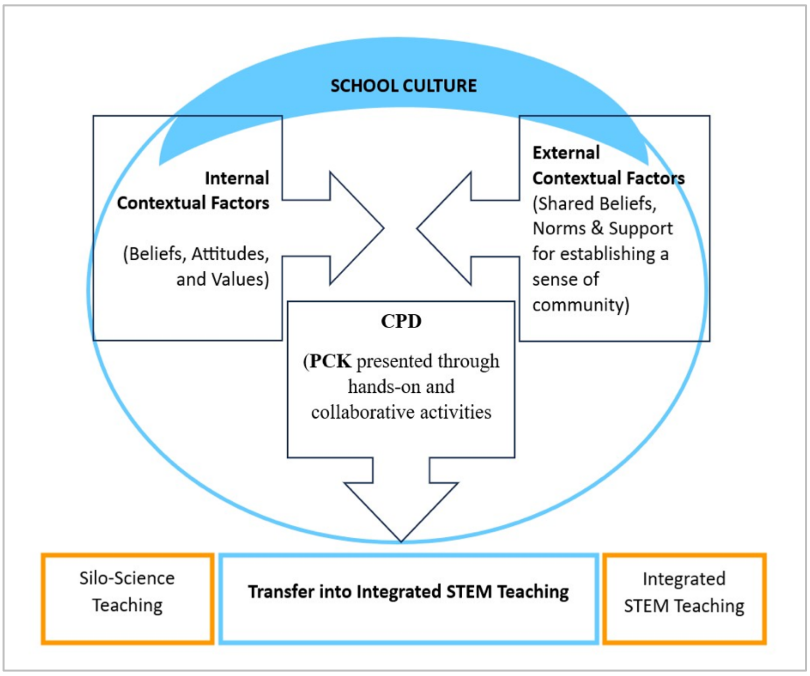


Figure 9: Adapted from El-deghaidy et al. (2017)

Lessons from SMASSE Program in Kenya

A qualitative study on factors that influenced Kenya secondary mathematics teachers' uptake of learner-centred practices after participating in the Strengthening of Mathematics and Science in Secondary Education (SMASSE) program identified the beliefs towards what constituted learning of mathematics to efficacy of learner-centred teaching as one of the mediating factors that influenced practice of learner-centred learning post training (Otieno, 2018).

4.5 Transformative teacher training process

In order to achieve the expected transformation in knowledge, skills and beliefs of teachers towards integrated STEM education, the training activities, content, mode of training and implementation of the training are underpinned by principles from; transformative learning theory, constructivist theory and reflective practice (Marey et al., 2022) as shown in Figure 10.

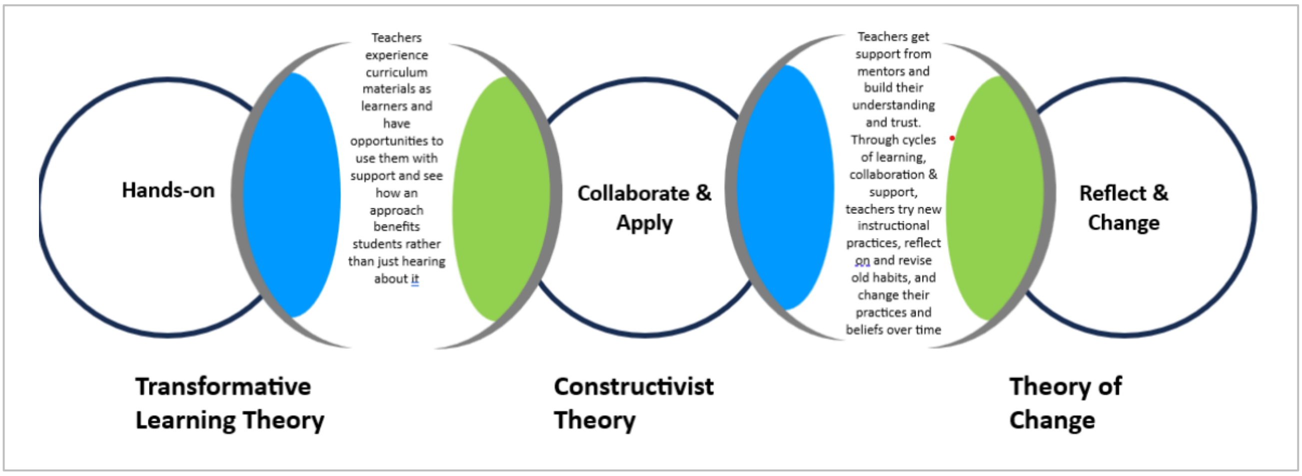


Figure 10: Transformative teacher training (Marey et al., 2022)

4.6 Transforming curriculum implementer's beliefs and attitude to integrated STEM education

The foregoing teacher professional growth framework reveals that beliefs, attitude and values towards teaching and learning play a significant role in determining practices. Specifically, as countries make steps towards integrated STEM education, it is important to establish curriculum implementer's beliefs on the nature of STEM knowledge, process of knowing and related key learning outcomes.

Teacher pedagogical practices are linked to the belief system on the nature of knowledge as depicted in (Figure 11). For example, teachers who believe that mathematics knowledge is about isolated facts, mostly formulae and numbers will teach differently from those who believe that mathematical knowledge is interconnected and is about inherent processes and competencies such as problem solving (Otieno, 2015b). In the same vein, teachers who believe that individual STEM disciplines are not interconnected may have difficulty adopting an integrated STEM education.

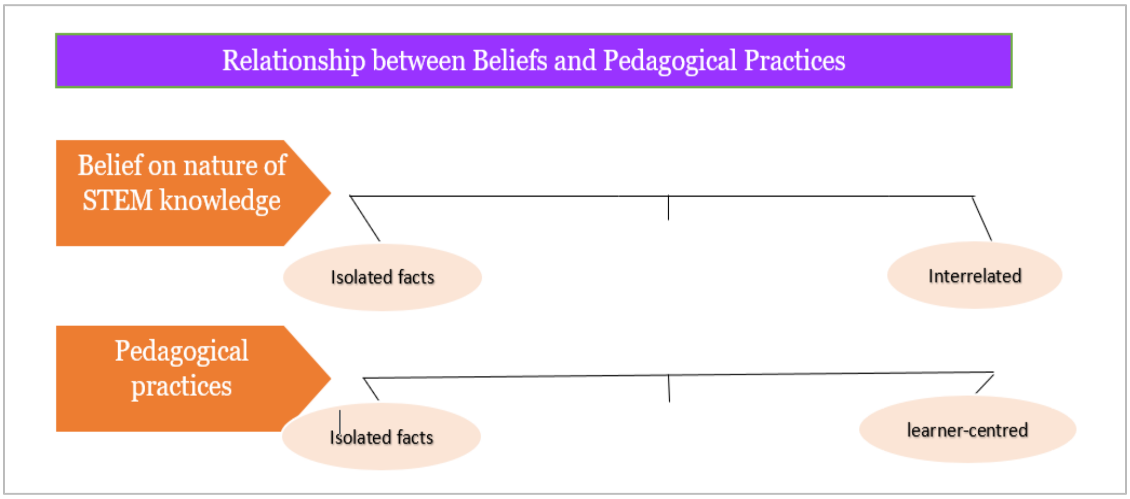


Figure 11: Belief and pedagogical practice

Similarly, training programs for curriculum implementers need to pay attention to beliefs on the ability to influence STEM learning outcomes or self-efficacy. Positive self-efficacy has been attributed to teachers' willingness to experiment and adopt innovative teaching and learning (Otieno, 2015a). Some self-doubt, surprise, and uncertainty, influence how teacher practitioners reflect on practice, and experiment with new instructional practices or changing practices (Otieno, 2015b).

The introduction of integrated STEM education to curriculum implementers especially teachers, need to reinforce self-efficacy towards influencing new learning outcomes and revealing the gap between status vis-à-vis the expectations.

4.7 Training strategies for transforming beliefs and attitude towards integrated STEM Education

a. Reflection

As depicted in the framework for transformative teacher training and framework on professional growth, continuous reflection of individual and collective beliefs during training and after implementation of an integrated STEM lesson is a critical component of the teacher training process. Reflection catalyses the process of questioning long held assumptions and beliefs on teaching as well as learning of STEM for validity and accuracy.

b. Exploration of educational theories underpinning teaching and learning.

How teachers' 'see' the classroom practice, make sense of daily experience, identify and solve Problems related to teaching and learning of respective STEM subjects is deemed to be informed by which of the educational theories they identify with (Otieno, 2015b).

c. Theorising education interventions and long-term scalable educational improvement

Teachers who understand the theoretical underpinnings of instructional and or assessment practice, are best placed to decide what aspects of the practice remain unchanged and those that need modification. Furthermore, understanding stimulates reflections on how and when to consider adapted practice for use in diverse STEM teaching and learning contexts.

d. Evidence on the impact of integrated STEM education: students' knowledge & competencies

Positive teacher beliefs and attitudes towards integrated STEM education including play-based approaches can be reinforced if teacher training mainstreams sharing of evidence (Clarke & Hollingsworth, 2002) from existing research and classroom experiences on its impact on the students' content knowledge, key competencies, motivation and interest to learn STEM subjects.

e. Shift from professional development mind-set to a professional learning mind-set

Countries need to consider transforming teachers' mind-set from that of professional development to a professional learning mind-set (Easton, 2008) right from the pre-service level. A professional development mind-set associate's professional development to structured and formal teacher training that occurs in one of the regular teacher training sessions. Formal training may comprise; workshops, conferences and webinars, often driven by parties such as school leadership, ministry of education and development partners.

On the other hand, a professional learning mind-set puts stronger emphasis on continuous formal and informal self-directed learning, inquiry-based approaches, and the development of a reflective and growth mind-set. In adopting a professional learning mind-set, teacher training on integrated STEM education encourages teachers to engage in reflective practice, collaborating with colleagues in designing and implementing integrated STEM lessons, engagement in action research, exploration of teaching approaches such as play-based teaching approach and engagement in independent study on integrated STEM education.

4.8 Training of teachers on knowledge and skills for integrated STEM education

In reference to needs assessment findings, each country is expected to develop and support training sessions that enhance teachers' knowledge and skills development for successful implementation of integrated STEM education. The teacher training programs may include key elements like content knowledge across STEM disciplines, experiencing STEM integration, collaboration among in-service and pre-service teachers, and collaboration of teacher training facilitators across content areas. The teacher training should equally focus on development and implementation of assessment activities for integrated STEM lessons.

School leaders and pedagogical leads need to be part of the teacher training programs to reflect on how the school structure and culture are improved to support integrated STEM education.

Drawing on the country's STEM education curriculum and insights from key stakeholders including teachers and school leaders key pedagogical support tools such as lesson observation protocol may be developed. An example of a lesson observation protocol for an integrated STEM lesson from Singapore (Ong et al., 2023) is shown below.

Table 4: Integrated STEM classroom observation protocol (iSTEM Protocol) & STEM task definitions

<table>
<tr><th>Lesson features</th><th>STEM Task Definitions</th></tr>
<tr><td>Recap</td><td>Recap of previous STEM lesson where previously known / shared ideas are discussed and repeated in class.</td></tr>
<tr><td>STEM phase: Problem Definition</td><td>i. Context: Introduce context that gives rise to STEM problem e.g., background of problem including who, where and when.
ii. Problem: Identify or state the STEM problem / challenge within the given context that students are required to solve. May include statement or identification of success criteria or solution constraints to be fulfilled by the final STEM solution.</td></tr>
<tr><td>STEM phase: Research</td><td>Gather information and / or empirical data to inform solution design. May include:
i. Search
• Search for existing information in online sources and given texts.
• Search for and /or evaluate existing responses such as, current product or possible solutions to the problem.
ii. Investigate
Gather empirical data to inform the solution, such as:
• Gather information from potential users to understand / specific problems pertinent to users (e.g., through interviews or surveys).
• Carry out investigations using Control of Variables (COV) approach or utilize given data to identify relationships among factors through scientific inquiry.</td></tr>
<tr><td>STEM phase: Development</td><td>Development of solution to STEM problem. May include:
i. Generate
• Describe (e.g., list of requirements or specifications) and/ or create a visual representation (e.g., drawing, diagram, flowchart) of possible solution(s) [technology/Design].
• Scaling and optimisation to determine resources required and size of product. [Mathematics].
• Include iterative re-generation of ideas.
ii. Concretize / Make
• Create or revise a design, model, prototype or other product (physical or computer-based) that can be tested [Technology]
• Include iterative re-concretize / re-make.
iii. Test
• Put design, prototype, model or other product to test (s) and analyse data from test (s) to evaluate whether the success criteria of the final STEM</td></tr>
</table>

	solution are met. Testing of design could utilise digital analysis tools such as simulations. Testing may also involve potential users. **iv. Feedback** • Present design solution (including final STEM solution) to other peers (not involved in one's solution design) or whole class for feedback • Reflect on recommended changes or improvements to design solution. • May occur after any other task.
Reflection	Summary of lesson or STEM activity; reflection on what is learnt from lesson or STEM activity.

Table 5: Integrated STEM Classroom Observation Protocol (Design Principles and Outcomes Descriptions)

Design Principles	Detailed Description	Observation Notes to Take (where observed)
Problematizing	Extent to which the STEM problem is meaningful to students and STEM communities. This is based on the context and nature of the STEM problem as presented to students.	The STEM problem, including its context.
Resources	Extent to which resources are provided to support students in solving the STEM problem. Resources include: • **Material resources** (e.g., information sources / reading; physical material; tools) to complete STEM. These include: o Materials such as; hyperlinks to information sources, readings and videos on context or problem o Tools such as; instruments for measurements or making product; apparatus for carrying out investigations; personal learning devices for making sketches. • Students are provided with support from teachers (or other adults) or written scaffold in worksheet (e.g., instructions or template for steps/ procedures) to complete STEM task. Support can be in the form of:	What and how materials, tools, or form of support are given to students. Note down if it is observed that students are given resources, but do not use them.

<table>
<tr>
<td></td>
<td>

Teacher does part of STEM task for student or demonstrates procedures/steps
Teacher gives verbal or written instruction on how to complete part of STEM task (e.g., certain procedures/steps) without showing how it is done.
Verbal or written options for how to proceed with or complete part of the STEM task, but students are not told what to do or to choose
Structured worksheet to record engineering design processes (e.g.; Ask, Plan, Create, Test or Improve)

</td>
<td></td>
</tr>
<tr>
<td>Authority</td>
<td>Extent to which students are given epistemic authority to construct the final solution to the STEM problem. This depends on:

Opportunities for students to propose own ideas for STEM task.
How teachers follow-up on students reported ideas.
How success criteria / solution requirements for evaluating final solution to STEM problem are decided.

</td>
<td rowspan="2">What happens after a student proposes an idea related to STEM task at hand or solution to STEM problem?

Who decides what to include examples of critique instances?

Who has a say on what the success criteria/constraints are and how they come about?

For instance, talk about a decision to be made for the STEM task at hand or contributes to solution of STEM problem.

An instance begins when a new decision is being discussed and ends when a decision is reached (including agreement to postpone decision-making or agree to disagree)</td>
</tr>
<tr>
<td>Accountability</td>
<td>Extent to which students’ ideas and actions are held accountable to STEM disciplinary concepts, Ways of Thinking and Doing (WOTD) and norms, by self and others (peers and the teacher). This depends on:

Who critiques students’ ideas put forward during STEM tasks?
Nature of critique (verbal, written or checklist): Based on STEM disciplinary concepts or WOTD, request for evidence / reasoning, or practical reasons.
Nature of success criteria or constraints for the final solution to the STEM problem.

</td>
</tr>
</table>

Outcomes	Description	Observation Notes to Take
Productive interdisciplinary engagement	Extent to which students are cognitively engaged in group-based interdisciplinary decision-making to progress towards a final solution to the STEM problem.	How decisions related to the STEM task at hand or solution to the STEM problem are reached by the group, including how groups justify their decisions.

4.9 Teacher training approaches

The goals of transforming teaching practice towards integrated STEM education are realizable if countries employ a combination of cascade, school-based and self-directed teacher training approaches. Affordances of technology including social media may be exploited to make the training more effective and efficient. For example, WhatsApp supported communities of practice may be formed to engender continuous learning, sharing of best-practices and sharing of training recordings to a larger group as a strategy of reducing leakage associated with the cascade approach to teacher training.

The choice of which form or combination of teacher training approaches at any one time is in part informed by the theoretical guide presented earlier on transformative teacher training. The selection of an approach for teacher training may also be informed by other contextual factors such as the population and distribution of STEM teachers in schools, the knowledge that teachers bring to the training, available resources including time for teacher training and teacher workloads across individual countries.

Further, the selection of teacher training approaches selected to train teachers should be gender responsive. Specifically, the content and delivery of teacher training on integrated STEM education should take into account the needs of both male and female STEM teachers at the basic level of education in the individual countries in Africa.

In the same vein, the teacher training approaches should be inclusive and should explicitly model pedagogical practices that teachers may employ to facilitate play-based learning of integrated STEM education in classrooms that have learners with special education needs and disabilities.

The overall goal of the training of teachers and therefore training approaches employed should be to make integrated teaching and learning of STEM disciplines at the basic level of education accessible and equitable.

4.10 Training Techniques

In essence, training programs need to prioritize experiential learning to allow teachers to explore and experience integrated STEM lessons. Furthermore, training programs should serve as models for integrated STEM instructional and assessment practices. This includes the integration of content from various disciplines and collaboration among trainers from different STEM fields when developing training content and activities. Additionally, these programs ought to explicitly address the challenges that teachers may encounter when using certain instructional practices and invite them to consider potential solutions.

CHAPTER FIVE
STEM Monitoring, Evaluation and Learning Framework

5.1 Introduction

In reference to the findings of the situational analysis conducted on the status of STEM education at the basic learning level in Africa, ADEA developed a Monitoring and Evaluation Framework (M&EF). The Monitoring and Evaluation Framework, provides a common reference for countries and key stakeholders to consistently track and report on progress towards quality STEM education at basic learning levels continentally. The chapter content is organised into two main sections:

- Continental STEM education indicators
- Modalities for STEM education reporting

5.2 Continental STEM education indicators

The Monitoring and Evaluation Framework relies on specific strategic objectives. The objectives aim to provide continental STEM education indicators. Countries and other stakeholders can refer to these indicators to monitor and track collective progress (Annex 2). The progress is towards achieving quality STEM education at basic learning levels in Africa.

- ***Strategic objective one***: Improvements in access and participation in STEM subjects for all learners, considering gender, learners with special needs, and students in both rural and urban areas at the foundational learning levels in Africa.
- ***Strategic objective two***: Strengthening the capacity of teachers at basic learning levels in Africa is developed to deliver quality STEM curriculum.
- ***Strategic Objective three***: Strengthening institutional capacity of education authorities and inter-country collaborations and partnerships to support delivery of quality STEM education in Africa.

5.3 Modalities of for STEM Education Reporting

Guided by the national STEM education policies and the continental M&EF, countries are encouraged to share annual reports with the Inter-Country Quality Node on Mathematics and Science Education (ICQN-MSE). The reports will include the strides made in strengthening the provision of quality STEM education at basic learning level in line with the foregoing strategic objectives.

Accordingly, in order to facilitate cross-pollination of ideas amongst countries, peers, and actualization of the continental vision of quality STEM education, the reports will cover highlights of lessons learnt, best practices, challenges and recommendations in the provision of quality STEM education.

CONCLUSION

As an outcome of a collective process involving senior STEM education experts and policy makers from 14 African countries, the STEM toolkit provides context specific, relevant and afro-centred evidence that may guide countries in the efforts towards shaping and implementing STEM education polices. This will lead to improved learning outcomes, STEM skills and competencies, and interest in STEM-based careers amongst Africa's learners at the basic learning level.

The process (spirit and vision) that guided the development of the STEM Toolkit is of equal importance to the practical knowledge and guidelines for implementation and coordination of STEM education on the continent.

Indeed, both the process of its development and the content within its covers embody the firm commitment by the ministries of education through ADEA's ICQN-MSE to transform the continent's STEM education landscape. The outcomes will herald the importance of foundational STEM skills and ensure that teachers are equipped with necessary knowledge, skills, attitude and resources as a critical step towards enhancing quality education and empowering Africa's youth for the 4th industrial revolution.

Specifically, governments and educational institutions are encouraged to draw on guidance provided in the STEM toolkit as they prioritize retraining of teachers in play-based pedagogy to create more effective and engaging learning environments in primary schools in respective countries.

ADEA ICQN-MSE commits to work with and support countries in the efforts towards adapting and implementing the STEM toolkit to address the country specific gaps in STEM education. Taking note of the evidence and practical insights from the 14 African countries' participants, we are persuaded that the STEM toolkit provides an invaluable opportunity for a coordinated and improved implementation of STEM education at the basic level. The STEM toolkit is in tandem with Agenda 2063, on "The Africa We Want" because it symbolizes and echoes the commitment to a shared vision and mission for STEM education at the basic learning level.

REFERENCES

ADEA, B., Node, I. Q., & Education, S. (2023). *The Status of Play-Based STEM Education in Primary Schools in Africa*.

ADEA, B., Node, I. Q., Education, S., & Node, A. I. Q. (2021). *Situational Analysis on the Status of STEM Education at Basic Learning Levels in Africa* (Issue May).

Adebayo, I., Oladejo, A. I., & Okebukola, P. A. (2022). Examining the Relative Effectiveness of CTCA in Improving Secondary School Students ' Achievement in Genetics. *Proceedings of the NARST 95th Annual International Conference: Unity and Inclusion for Global Scientific Literacy: Invite as a Community. Unite as a Community, Vancouver, BC, Canada (Pp. 27-30).*, *April*, 27–30.

Barrow, L. H. (2010). Encouraging Creativity with Scientific Inquiry. *Creative Education*, *1*(1), 1–6. https://doi.org/10.4236/ce.2010.11001

Cheng, M. M. H. (2022). *An Overview of STEM Education in Asia STEM Education in Asia*. Springer Nature Singapore. https://doi.org/10.1007/978-981-19-2596-2

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education*, *18*(8), 947–967.

Duran, L. B., & Duran, E. (2004). The 5E Instructional Model : A Learning Cycle Approach for Inquiry-Based Science Teaching. *The Science Education Review*, *3*(2), 49–58.

Eisenkraft, A. (2003). *Expanding the 5E Model*.

El-deghaidy, H., Mansour, N., Mohammed, A., & Alhammad, K. (2017). Context of STEM Integration in Schools : Views from In-service Science Teachers. *EURASIA Journal of Mathematics Science and Technology Education*, *8223*(6), 2459–2484. https://doi.org/10.12973/eurasia.2017.01235a

Gao, X., Li, P., & Shen, J. (2020). Reviewing assessment of student learning in interdisciplinary STEM education. *International Journal of STEM Education*, *7*(24), 1–14.

Gathage, J. K., Embeywa, H., & Koech, P. (2021). The Effect Of Inquiry-Based Science Teaching Approach On Self- Concept Of Secondary School Physics Students In Kitui County, Kenya. *African Journal of Educatio and Practice*, *7*(2), 18–29.

Grady, M. G. O., & Dusing, S. C. (2015). Reliability and validity of play-based assessments of motor and cognitive skills for infants and young children: a systematic review. *Physical Therapy*, *95*(1), 25–38.

Han, J., Kelley, T., & Knowles, J. G. (2023). Building a sustainable model of integrated stem education : investigating secondary school STEM classes after an integrated STEM project. *International Journal of Technology and Design Education*, *33*(4), 1499–1523. https://doi.org/10.1007/s10798-022-09777-8

Holloway, K., Arcus, K., & Orsborn, G. (2017). Training needs analysis – The essential first step for continuing professional development design. *Nurse Education in Practice*. https://doi.org/10.1016/j.nepr.2017.09.001

Hope, J. T., & Allen, W. J. (2009). *Student Competitive Events : A Strategy for Integrating a STEM Block in Public Schools*. 3852–3856.

Ismail, Z. (2018). *Benefits of STEM Education* (Issue September).

Johnstone, A. (2022). An inquiry into teachers ' implementation of play-based learning aligned approaches within senior primary classes. *Kairaranga*, *23*(1), 17–34.

Kaur, P., & Gakhar, A. (2014). 9E Model and E-Learning Methodologies for the Optimisation of Teaching and Learning. *2014 IEEE International Conference on MOOC, Innovation and Technology in Education (MITE)*, 342–347.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*. https://doi.org/10.1186/s40594-016-0046-z

Li, H., & Du, X. (2015). Teachers ' Perspective of their Role and Student Autonomy in the PBL Context in China. *International Journal of Learning, Teachinga and Educational Research*, *10*(2), 18–31.

Manishimwe, H., Shivoga, W. A., & Nsengimana, V. (2022). Effect of Inquiry-Based Learning on Students' Attitude Towards Learning Biology at Upper Secondary Schools in Rwanda. *Journal of Baltic Science Education*, *21*(5), 862–874.

Marey, R., A, M., Magd, A., Eldeghaidy, H., Tidswell, A., & A, M. (2022). A transformative professional development model in current Egyptian reforms : A mixed-methods study Social Sciences & Humanities Open A transformative professional development model in current Egyptian reforms : A mixed-methods study. *Social Sciences & Humanities Open*, *5*(1), 100233. https://doi.org/10.1016/j.ssaho.2021.100233

Mkimbili, S. thomas, & Odegaard, M. (2020). Inquiry-based science teaching in community secondary schools in Tanzania: role played by the language of instruction. *Curturak Studies of Science Education*, *15*, 1121–1142.

Mugabo, L. R., & Nsengimana, T. (2020). The Impediments of Inquiry-Based Learning in Rwanda Lower Secondary Education and Ways of overcoming them. *Southern African Association for Research in Mathematics, Science and Technology Education*, *257*.

Ong, Y. S., Koh, J., Tan, A., & Ng, Y. S. (2023). Developing an Integrated STEM Classroom Observation Protocol Using the Productive Disciplinary Engagement. *Research in Science Education*, *0123456789*. https://doi.org/10.1007/s11165-023-10110-z

Otieno, H. (2015a). *' Towards a hermeneutic inquir y into the uptake and implementation of student center ed teaching by Kenya secondar y schools mathematics teacher s '.*

Otieno, H. (2015b). *Understanding Mathematical activity " from self-consciousness into social consciousness."*

Otieno, H. (2017). *Shaping a digitally supported- ecosystem of emerging African scholars: My exploits, dreams and nightmares*. *February*.

Otieno, H. (2018). *Improving Kenyan Secondary School students' relationship with mathematics through self-regulated learning*.

Pedaste, M., Mäeots, M., Siiman, L. A., Jong, T. De, Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning : Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47–61. https://doi.org/10.1016/j.edurev.2015.02.003

Pellegrino, J. W., Grover, S., Harris, C. J., & Wiebe, E. (2023). *Classroom-Based STEM Assessment : Contemporary Issues and Perspectives.*

Pyle, A., & Danniels, E. (2016). A Continuum of Play-Based Learning : The Role of the Teacher in Play-Based Pedagogy and the Fear of Hijacking Play A Continuum of Play-Based Learning : The Role of the Teacher in Play-Based Pedagogy and the Fear of Hijacking Play. *Early Education and Development*, *00*(00), 1–16. https://doi.org/10.1080/10409289.2016.1220771

Rais, M., Yahya, M., Jamuluddin, & Purnamawati. (2021). Comparing project-based learning and problem-based learning to foster 21st-century learning skills in agricultural seaweed product Muhammad. *Cypriot Journal of Educational Sciences*, *16*(3), 1217–1230.

Ramnarain, U. D. (2014). Teachers ' perceptions of inquiry-based learning in urban , suburban , township and rural high schools : The context-speci fi city of science curriculum implementation in South Africa. *Teaching and Teacher Education*, *38*, 65–75. https://doi.org/10.1016/j.tate.2013.11.003

Reynders, G., Lantz, J., Ruder, S. M., Stanford, C. L., & Cole, R. S. (2020). Rubrics to assess critical thinking and information processing in undergraduate STEM courses. *International Journal of STEM Education*, *7*(9), 1–15.

Roehrig, G. H., Dare, E. A., Ring-whalen, E., & Wieselmann, J. R. (2021). Understanding coherence and integration in integrated STEM curriculum. *Nternational Journal of STEM Education*, *8*(2), 1–21.

Thibaut, L., Ceuppens, S., Loof, H. De, Meester, J. De, Goovaerts, L., & Brussel, V. U. (2018). Integrated STEM Education : A Systematic Review of Instructional Practices in Secondary Education. *European Journal of STEM Education*, *3*(1), 1–12.

Twahirwa, J. N., & Ntivuguruzwa, C. (2021). Effect of Project-Based Learning : Learners ' Conceptualization and Achievement in Science Education. *African Journal of Educational Studies in Mathematics and Science*, *17*(1), 17–35.

Weisberg, D. S., Hirsh-pasek, K., & Golinkoff, R. M. (2013). Guided Play : Where Curricular Goals Meet a Playful Pedagogy. *Mind, Brain and Education*, *7*(2), 104–112.

Zosh, J. M., Hirsh-pasek, K., Hopkins, E. J., Jensen, H., Liu, C., Neale, D., Solis, S. L., Whitebread, D., & Flynn, R. M. (2018). Accessing the Inaccessible : Redefining Play as a Spectrum. *Frontiers in Psychology*, *9*(August), 1–12. https://doi.org/10.3389/fpsyg.2018.01124

Zosh, J. M., Hopkins, E. J., Jensen, H., Liu, C., Neale, D., Hirsh-pasek, K., Solis, S. L., & Whitebread, D. (2017). *Learning through play : a review of the evidence* (Issue November).

Ushirika wa Maendeleo ya Elimu Barani Afrika
الرابطة لأجل تطوير التربية في إفريقيا
Association for the Development of Education in Africa
Association pour le développement de l'éducation en Afrique
Associação para o Desenvolvimento da Educação em África

Association for the Development of Education in Africa (ADEA)
African Development Bank Group (AfDB)
Immeuble CCIA Plateau, Avenue Jean-Paul II, 01 BP 1387
Abidjan 01, Côte d'Ivoire
Tel: (+225) 27 20 26 39 64
Email: adea@afdb.org - Website: www.adeanet.org