EUROPEAN JOURNAL OF STEM EDUCATION

European Journal of STEM Education,
2024, 9(1), 12
ISSN: 2468-4368

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STEM Education in the STEM Centers in Ethiopia: Implementation Practices, Challenges and Prospects

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Citation: Tegegn, A. T. (2024). STEM Education in the STEM Centers in Ethiopia: Implementation Practices, Challenges and Prospects. *European Journal of STEM Education*, 9(1), 12. https://doi.org/10.20897/ejsteme/15131

Published: September 6, 2024

ABSTRACT

This study aimed to examine the implementation of STEM education in the university-based STEM centers in Ethiopia. To this end, a descriptive survey research method was employed, and data was collected from 11 coordinators of the STEM centers and 54 STEM educators through questionnaire, interview and observation. Data was analyzed by using both quantitative and narrative techniques. Results of the study uncover that there were variations among the STEM training centers in implementing the program, partly due to absence of a national scheme; irregular and uneven implementation of STEM initiative; inadequate support system; absence of regular monitoring and evaluation; absence of collaborations and commitments of key stakeholders, and the limitations of separate STEM disciplines taught in different classes. Recommendations, hence, call for developing a STEM national curriculum with implementation strategies, strengthening regular monitoring and evaluation of the implementation process, allocation of adequate resources and facilities, broadening of STEM pedagogy ecosystem, fostering collaborations and commitments of stakeholders who are key to the success of STEM initiative, strengthening preparation of STEM educators and teachers, integrating the STEM disciplines in K-12 education programs to stimulate students' passion and interest in science and technology from the earliest level of exposure.

Keywords: integrated STEM education, STEM curriculum, STEM centers, STEM competencies, STEM

INTRODUCTION

Background of the Study

In recent years, education and training for students in science, technology, engineering, and mathematics (STEM) and other domains has become a critical priority for countries due to its important role in global economic competitiveness (Sahin, 2015). Likewise, Mpofu (2019) noted that the recognition of STEM disciplines as economic drivers motivated the initiation of STEM education in both developed and developing nations. This is based on the thinking that an effective STEM education is a vehicle for developing in students the much-desired twenty-first century competencies.

The acronym STEM has been used to refer to the fields of science, technology, mathematics, and engineering. More recently, various iterations of the acronym (e.g., STEAM) have extended to encompass other domains such as social studies, English language arts, agriculture, the arts, environmental science, economics, education, and medicine as well (Srikoom et al., 2018; Bybee, 2010). The basis of STEM education, therefore; involves the integration of these subjects by breaking down the "silos" of discipline-independent teaching that students often encounter throughout the day and making connections to the context of the real world (Wieselmann et al., 2022;

Sutaphan and Yuenyong, 2019; Thibaut et al., 2018; Al Salami et al., 2017; Carmichael, 2017; Kelley and Knowles, 2016; NAE and NRC, 2014; Johnson, 2014, 2013; Nathan et al., 2013; The Global STEM Alliance, 2013; Stohlmann et al., 2012).

STEM education is a 'meta-discipline' and this means the creation of a discipline based on the integration of other disciplinary knowledge into a new 'whole' rather than in bits and pieces (Ejiwale, 2013; Brown et al., 2011b). It is an interdisciplinary approach, cross-disciplinary approach to teaching and learning by integrating different disciplines into one cohesive teaching and learning program (Shen, 2023; Thibaut et al., 2018; Srikoom et al., 2018; Rosicka, 2016; Lytras et al., 2017; Sahin, 2015; NAE and NRC, 2014; Ejiwale, 2013; Stohlmann et al., 2012; Tsupros et al., 2009).

The implementation of STEM education in schools is aimed to prepare the future workforce with strong scientific, mathematical, technological and entrepreneurial backgrounds by enhancing knowledge, skills and value developments across the STEM and other domains (Ejiwale, 2013).

Integration of STEM fields across the curriculum is one of the main consistent characteristics of STEM education. Integrated STEM instructional practices include a range of different experiences that involve some degree of connection and synthesizing lessons. The experiences may occur in one or several class periods, throughout a curriculum, be reflected in the organization of a single course or an entire school or be encompassed in an out-of-school activity. Each variant of integrated STEM education suggests different planning approaches, resource needs, implementation challenges, and outcomes (NAE and NRC, 2014).

STEM education has many benefits for students. Through STEM, students develop key skills like problem solving, creativity, critical analysis, teamwork, independent thinking, initiative, communication, and digital literacy (Ismail, 2018; Rosicka, 2016). These skills provide them with the foundation to succeed at school and beyond. STEM also empowers individuals with the skills to succeed and adapt this changing world.

Likewise, NAE and NRC (2014) note that teaching STEM in a more connected manner can make the STEM subjects more relevant to students and teachers. This in turn, can enhance motivation for learning and improve student interest, achievement, and persistence (Anderson et al., 2004).

Many studies suggest that STEM education must begin, and fundamental STEM knowledge and skills should be established at the earliest years (Kurup et al., 2019; English, 2017; Carmichael, 2017; Rosicka, 2016; NAE and NRC, 2014). It holds that children in the early years are curious and excited learners and, thus, they need to begin to develop the early foundational skills that will help them reason, think creatively, analyze data, and work collaboratively in the future.

STEM pedagogy concurs active learning environments like project-based learning and problem-based learning (Wieselmann et al., 2022; Sahin, 2015; Ejiwale, 2013; Capraro et al., 2013), inquiry-based learning (Rosicka, 2016), hands-on activities in STEM laboratories and workshops, dialogue; technology-driven instruction, internship and cooperative learning (Lytras et al., 2017; European Schoolnet, 2016; Ejiwale, 2013) and performance-based assessment (Sahin, 2015; Ejiwale, 2013).

Though strengthening STEM education has been recognized globally as embedding solutions to many socio-economic problems and as a vehicle for developing in students the much-desired twenty-first century competencies, yet its operationalization has remained a great challenge in many nations (Mpofu, 2019).

One of the biggest educational challenges for K-12 STEM education is that few general guidelines or models exist for teachers to follow regarding how to teach using or applying STEM integration approaches in their classroom. Furthermore, research into teachers' current integrated STEM teaching practices can inform STEM education stakeholders and assist in identifying barriers as well as determining best practices (Srikoom et al., 2018).

Barriers to successful implementation of STEM education are many, like poor preparation and shortage of qualified STEM educators, lack of investment in teachers' professional development, lack of research collaboration across STEM fields, poor preparation and inspiration of students, lack of support from stakeholders, poor content preparation and content delivery and method of assessment, poor condition of laboratory facilities and instructional media, lack of hands-on training for students (Costello et al., 2020; Lee et al., 2019; Gandhi-Lee et al., 2015; Ejiwale, 2013).

In Ethiopia, STEM education has been regarded as a corner stone for the economic and social transformations, and thus, the quest for STEM education for primary, secondary and tertiary students has been reflected in various reform plans and programs, and legislations, such as the Education Sector Development Programs (ESDPs I-V), which were a series of rolling five-year strategic plans put in in to action 1997 to 2020; the Growth and Transformation Program (GTP-I & II, 2005–2010); the General Education Quality Improvement Programs (GEQIP, 2008–2018); Education Development Roadmap (2018–2030), and the Higher Education Proclamations (2009 and 2019).

The need for a shift from traditional course offering to STEM education is considerably stipulated in the currently issued Education Development Roadmap (2018–2030). It has discussed at length about the challenges facing the country in building relevant and quality education systems across levels, disciplines, and trades including

Figure 1. Foka STEM Center

Science and Technology. Accordingly, emphasis to Science and Technology has become legitimate, and STEM as a program of intervention was introduced to secondary schools for reinforcing education of Science and Technology.

The Education Roadmap also underscores the need for STEM curriculum and ICT-supported instruction at primary education. Moreover, it clearly accentuated the need to develop experience of working with laboratory materials by the secondary schools and higher education preparatory schools as a way to increase the quality of higher education in the country.

In the same vein, the HE Proclamations (2009 and 2019) have also given greater emphasis on Science and Technology education through 70:30 placement policy (70% of HEIs students in STEM). The 70:30 national policy of admitting university students in the Science and Technology fields can be seen as a good indicator of the Ethiopian Government's aspiration to capacitate the generation in the STEM fields.

In 2009, the initiative to introduce training in STEM disciplines was taken by a foreign NGO called STEM-*power*, under the motto *'Inside Every Child is a Scientist',* with the objective of maximizing the number of STEM students. In this light, the first STEM center, a model STEM hub, was established in 2009 at Foka area of Bishoftu town, 40 km southeast of the capital, Addis Ababa (**Figure 1**). The data obtained from this center reveals that it has contained four laboratories: electrical, mechanical, optical and computer. It was established as a main resource center for the subsequent STEM centers across the country. Currently, the number of STEM centers exceeded 40, which are operating with varying degrees, at every regional state across the nation. Most of them are located on a university campus and are expected to become a university resource centers or assets.

The STEM centers are specialized learning facilities that are meant to offer hands-on science and ICT experiences to local areas where students voluntarily enroll in various age-appropriate programs offered, at no tuition fee. Usually, talented students in grade 7-12 were selected for the training, conducted most often at summer times (July to September). Accordingly, university teachers in the four STEM disciplines and lab technical assistants are responsible to mentoring the trainee students in their learning activities. The centers are also supposed to serve as venues for local gatherings and hubs for Science Fairs (MOE, 2018).

Science Fair is a competitive program through which students get access to develop their creative skills in STEM fields. It was especially open to students in grades 7-12 where they present their projects under the supervision of their mentors. This is believed to unleash their creativity, achievement, public speaking, and healthy competition (MOE, 2018).

In this regard, this study set out to examine implementation practices of the STEM training initiatives at selected STEM centers across the country and simultaneously bringing challenges and shortcomings into light that would help in figuring out future actions accordingly.

Objectives of the Study

This study aimed to:

- examine the state-of-arts-of the implementation of STEM program initiatives,
- explore the factors affecting the STEM implementation process,
- identify the gaps in STEM education, and
- suggesting some possible ways of improving STEM educational practices.

Statements of the Problem

The Government of Ethiopia acknowledges the importance of STEM subjects in achieving Millennium Development Goals and in the attainment of the Vision 2030 as would provide the necessary manpower to steer the country into new technological and industrial development. Nonetheless, the low performance in the subjects has persisted despite the desperate attempts to provide enough teachers, facilities, and in-service training for teachers and provision of other necessary materials posing a lot of concerns to all stakeholders in education.

On the top of this, secondary school students' poor experience of working with laboratory and workshop materials and technology (MOE, 2018) and the perennial problem inherent with quality of science and technology teaching that has been compromised by serious shortage of qualified academic staffs and lack of sufficient and well-established laboratories and workshops in the area in most of HEIs in the country (MOE, 2009) are deriving forces to conduct this study.

Research Questions

This study intended to answer the following two basic questions:

To what extent the STEM program was implemented at the centers?

- What forms of STEM learning activities were organized at the centers?
- What teaching strategies and methods were applied in the STEM classes?
- What educational materials and technological tools were used by STEM educators to facilitate student learning?
- How was the implementation process of STEM initiative managed?

What factors affected adversely the implementation of STEM program?

- What were personal and contextual factors that affected the implementation of the STEM initiative?

METHOD OF THE STUDY

Research Design

Descriptive research design was used to guide the entire process of this study and describe the-state-of-the-art of the topic under consideration. This type of research design allows for a variety of methods to recruit participants, collect data, and utilize various methods of instrumentation (Creswell, 2012). Thus, the descriptive survey design was assumed a good fit to the purpose of this study and the type of research questions to be answered.

Data Sources

The target population of this study was 41 university-based STEM centers. Out of 41 STEM centers, 11 centers with more than three years of experience in running the program and that had certain considerable performance in implementing the program were purposefully selected and included in the study. They were Foka (Bishoftu) STEM hub, Bahir Dar University STEM center, Kotebe Metropolitan University (KMU) and Menelik-I Science Shared campus, Gondar University STEM center, Wellega University STEM center, Addis Ababa Science and Technology University (AASTU) STEM center, Asayita STEM center, Hawassa University STEM center, Jigjiga University STEM center, Leqa STEM center, and Jimma University STEM center. Data was collected through questionnaire from 54 STEM educators and 11 Coordinators on face-to-face and online modes.

Table 1. Responses of center coordinators on the types of STEM learning opportunities organized at the STEM centers

STEM learning activities	Very much		Much		Little		None		Total	
	f	%	f	%	f	%	f	%	f	%
After-school sessions	4	36	4	36	2	18	1	9	11	100
Summer sessions	8	73	-	-	3	27	-	-	11	100
Week-end sessions	4	36	6	55	1	9	-	-	11	100
Field trips to STEM-focused firms	-	-	4	36	6	**55**	1	9	11	100
Semester break sessions	2	18	2	18	3	27	4	**36**	11	100
Science TV shows	2	18	1	9	4	**36**	4	**36**	11	100
Science fairs	8	73	-	-	3	27	-	-	11	100
Virtual Lab sessions	2	18	1	9	4	**36**	4	**36**	11	100
Visits to the STEM centers	2	18	2	18	7	**64**	-	-	11	100

Data Collection Techniques and Instruments

A questionnaire consisting of different items were designed and administered to the STEM center coordinators and educators. A questionnaire was chosen as main data collection tool in order to reach a significant number of research participants, and other stakeholders across the country. Moreover, interview and observations were conducted at the main STEM hub (Foka STEM center) and at other STEM centers.

Data Analysis Techniques and Procedures

A statistical and a narrative analysis techniques are used to analyze the data collected. As such, data collected through the questionnaire are analyzed by using descriptive statistics, while data collected through interviews and observation are analyzed by using narrative techniques.

DATA PRESENTATION AND ANALYSIS

Implementation of STEM Education

The first basic question of this study dealt with how STEM education program had been managed or supported. The data obtained through interviews at the main STEM hub in Bishoftu town and STEM-power at the MOE disclosed that the management of the program is found to be very weak, and the program was run arbitrarily. The only support given to the STEM centers was some financial amount, which came as an operational fund of two years, and material (lab equipment) support from the initiator of the program, the STEM-power. Nonetheless, other enabling supports, like provision of substantial professional development trainings; establishment of partnership with schools; arrangement of experience-sharing activities among STEM centers; periodic assessment of the implementation practices; evaluation of program's outcomes; development of STEM-based curriculum guide were minimal or non-existent.

STEM learning activities

When it comes to the forms of STEM learning experiences, two modes or arrangements of learning opportunities are cited most often in the academic literatures: the formal STEM learning (that are school-based activities) and the informal STEM learning, which are carried at out-of-school settings (OST). The latter was the focus of this study, and comprises different learning opportunities, like afterschool sessions, summer sessions, week-end sessions, semester break sessions, etc.

In this light, questionnaires were developed and administered to STEM center coordinators to examine the type of STEM learning opportunities that were organized at the centers. The responses are presented in **Table 1**.

As to the responses of the center coordinators shown in **Table 1**, *summer sessions* and *science fairs* followed by *after-school sessions*, and *week-end sessions* are common forms of STEM learning experiences executed by the centers. Other relevant forms of STEM learning experiences, such as *visits to the STEM centers* and *STEM-focused firms*, *virtual Lab sessions, Science TV shows,* and *semester-break sessions* were rarely practiced, which are indicative of areas of intervention in the future practices of the STEM centers.

Moreover, the interview conducted at Foka STEM center also confirmed that *summer sessions, science fairs* and *week-end sessions* are the common forms of STEM learning activities arranged across the STEM centers.

With regard to the essence of STEM center activities, data obtained suggest that there is variation across the STEM centers. In the case of Foka STEM center (the first, model STEM hub), *week-end sessions* (on Saturday &

Figure 2. Trainee students in Science Lab-I

Figure 3. Trainee students in ICT Lab

Sunday) had been conducted for 3 to 4 hours; *lab sessions* (ICT and Science) for about 4 hours; and *summer sessions* had been conducted for 3 months (July to September).

One exceptional STEM center is Bahir Dar University STEM center, established in 2011, which is the best performing STEM center with 12 laboratory rooms (Physics, Optics, Space Science, Chemistry, Biology, Biochemistry, Electronics, Mathematics, ICT Rooms). STEM teaching-learning activities at this center include *outreach programs* (since 2011, every summer for 45 days for 500 talented students), *STEM Projects* (STEM project training and coaching), *STEM short term trainings* (for primary and secondary school students and teachers), *Camp programs*, especially for girls (once a year for 7–15 days), *Science Shared Campus program* (full STEM course provision for the whole year at the STEM Center), *STEM Fair Programs* (twice a year at the STEM center and once a year at a region level), *STEM Gardening* (practical and demonstrative garden practices), and *STEM Visiting* (both institutions and individuals). The outreach programs typically involved hands-on practical laboratory experiment followed by students' presentations, report writing and project works. Projects can be done in any field of study. Subject wise, the outreach programs included Science (Physics, Chemistry, Biology), Mathematics, ICT, Electronics, Technical Drawing, and English language improvement (**Figure 2**, **Figure 3**, and **Figure 4**).

Support system of the STEM program

For a successful STEM education, the implementers require a lot of support in terms of guiding frameworks, professional development, material development and many other resources as well as financial incentives (Mpofu, 2019). Regarding these issues, coordinators of the centers were asked to comment on it, and their reactions are presented in the ensuing **Table 2**.

The responses of the STEM center coordinators in **Table 2** depict that support that had to come in the form of *finance, curricular materials, experience sharing activities and technical support* are found to be insignificant, and it implicates the need for more supportive activities in these areas by the concerned body.

Moreover, as to the interview conducted at Foka STEM hub, an operational fund for two years and material support, like lab equipment with installation services were the only supports given to each STEM center by the founding organization, the STEM-power. Nonetheless, it was reported that supervision activities were not carried out at all to check the way the materials had been used at the Centers and the way trainee students were taught.

Figure 4. Trainee students in Science Lab-II

Table 2. Responses of the STEM coordinators on the support given to the centers

Support type	Very much		Much		Little		None		Total	
	f	%	f	%	f	%	f	%	f	%
Professional training & workshops	6	55	4	36	1	9	-	-	11	100
Financial support	2	18	1	9	8	**73**	-	-	11	100
Educational resources (lab equipment)	4	36	4	36	3	28	-	-	11	100
Technical support (monitoring & evaluation)	4	36	2	18	4	36	1	9	11	100
Arrangements of experience-sharing programs among the STEM centers	-	-	4	36	6	**55**	1	9	11	100
Provision of curricular materials	-	-	4	36	6	**55**	1	9	11	100

Table 3. STEM educators' response on instructional methods applied

Type of instructional method	Very much		Much		Little		None		Total	
	f	%	f	%	f	%	f	%	f	%
Lab-based instruction	8	18	28	**52**	18	33	-	-	54	100
Project-based instruction	20	**37**	16	**30**	16	30	2	3	54	100
Inquiry-based instruction	20	**37**	18	**33**	16	30	-	-	54	100
Peer teaching instruction	15	**28**	23	**43**	14	26	2	3	54	100
Flipped classroom instruction	5	9	16	30	15	**28**	18	**33**	54	100
Personalized instruction	5	9	16	30	15	**28**	18	**33**	54	100
Integrated instruction (connections across the STEM disciplines)	11	20	10	19	13	**24**	20	**37**	54	100

Utilization of instructional approaches and strategies

Regarding STEM teaching-learning context, STEM teachers need to create a learning context that is meaningful, motivating, linked to the real world and STEM-related jobs and STEM contents Srikoom et al. (2018). In this light, STEM educators and center coordinators were asked to react to the instructional approaches and strategies used by STEM educators in the STEM classes. Their responses are presented in **Table 3** and **Table 4**.

The responses of STEM educators presented in **Table 3** suggest that *lab-based*, *project-based instruction, inquiry-based instruction*, and *peer teaching approaches* were considerably employed in the instructional processes. Nonetheless, the *integrated instructional approach*, *flipped classroom model and personalized teaching approach*, which are highly valuable for the development of STEM competencies, were used seldom by the educators. So, these three teaching methods are found to be major areas of focus in the future STEM teaching and learning practices.

According to the responses presented in **Table 4**, the coordinators of the STEM centers testified that most of the instructional methods and strategies were employed considerably by the educators in their classes. But, *the field trip instruction approach* was applied rarely.

It is possible to infer from the two data sets that *lab-based instruction*, *project-based learning (PBL)*, and *problem-based instructional approaches,* are the prominent instructional approached applied typically across the centers.

Table 4. Responses of STEM center coordinators on the types of instructional methods applied

Type of instructional method	Very much		Much		Little		None		Total	
	f	%	f	%	f	%	f	%	f	%
Integrated STEM instruction	2	18	6	**55**	3	27	-	-	11	100
Problem-based (PBL) instruction	4	36	6	**55**	1	9	-	-	11	100
Lab-based instruction	4	36	7	**64**	-	-	-	-	11	100
Project-based instruction	4	36	4	36	3	28	-	-	11	100
Design-based instruction	4	36	2	18	4	36	1	9	11	100
Technology-supported instruction	6	55	4	36	1	9	-	-	11	100
Personalized instruction	4	36	4	36	2	18	1	9	11	100
Constructivist instruction	2	18	8	**73**	1	9	-	-	11	100
Field trip instruction	2	18	2	18	6	**55**	1	9	11	100
Inquiry-based instruction	-	-	6	**55**	4	36	1	9	11	100
Team teaching	-	-	6	**55**	4	36	1	9	11	100

Table 5. Responses of STEM center coordinators on STEM educators' teaching practices and behaviors

Teaching practices/behaviors	SA		A		D		SD		T	
	f	%	f	%	f	%	f	%	f	%
Encouraged class discussion	11	100	-	-	-	-	-	-	11	100
Offered active learning experiences	11	100	-	-	-	-	-	-	11	100
Stressed theory as well as applications	10	91	1	9	-	-	-	-	11	100
Have good knowledge and skills associated with STEM disciplines	7	64	4	36	-	-	-	-	11	100
Have good lesson preparation	10	91	1	9	-	-	-	-	11	100
Excellent content delivery and method of assessment	10	91	1	9	-	-	-	-	11	100
Integrated emerging technologies to their instruction	7	64	4	36	-	-	-	-	11	100
Related STEM contents to students' lived experience.	10	91	1	9	-	-	-	-	11	100
Link concepts and skills through a real-world problem-solving	11	100	-	-	-	-	-	-	11	100
Utilized classroom-ready materials to simplify implementation	11	100	-	-	-	-	-	-	11	100
Encouraged students to explore new ideas	11	100	-	-	-	-	-	-	11	100
Engaged students to engage in the scientific process	11	100	-	-	-	-	-	-	11	100
Provided timely feedback to students' works	10	91	1	9	-	-	-	-	11	100
Applies both formative and summative assessments strategies	10	91	1	9	-	-	-	-	11	100
Uses tests and exams	10	91	1	9	-	-	-	-	11	100

Note. SA: Strongly agree; A: Agree; D: Disagree; SD: Strongly disagree; & T: Total

STEM educators/trainers characteristics

While the success of STEM education relies on many factors, the most important factor of this reform is educators'/teachers' classroom practices that foster the development in the students of the twenty-first century competences. This hinges on the quality of the teachers and their understanding, marriage to and competencies in STEM education (Mpofu, 2019; Kurup et al., 2019).

As such, competences expected of educators and teachers include, among other things, subject knowledge, presentation, classroom management, assessment and recording of pupils' progress and further professional development.

In light of this, STEM center coordinators were asked to rate STEM educators teaching characteristics, and the responses obtained are presented in **Table 5**.

As shown by **Table 5**, STEM coordinators strongly agreed with the application of almost all the instructional activities and methods mentioned. On the other hand, however; they reported the presence of several challenges and shortcomings to implement the program properly by the educators.

Utilization of educational technologies

The use of instructional technology in the classroom enhances learning and actually makes learning fun for students, which in turn motivates them to want to learn more (Eyyam and Yaratan, 2014). The use of emergent instructional technology tools enable students to relate what they learn in the classroom with the world in which they exist. Technology in the classroom changes how teachers and students communicate with each other. Today's schools are privileged to have an opportunity to integrate technologies during the learning process. The emergent educational technologies open up a classroom to the world enhancing personalized learning (Silton, 2015).

STEM education often requires different educational materials and technological devices such as Computers, ICT, Television, Multimedia, Interactive Whiteboards, Electronic Boards and other technological breakthrough which has made the art of teaching and learning to be pleasurable, interesting and resourceful.

Table 6. Responses of STEM educators on the utilization of educational technologies

Types of educational technologies used by educators	SA		A		D		SD		T	
	f	%	f	%	f	%	f	%	f	%
Paper-based materials	28	52	26	48	-	-	-	-	54	100
Audio-video materials	25	46	23	42	3	6	3	6	54	100
Projected media (slides, etc.)	5	9	29	54	13	24	7	13	54	100
Hyper media (web-based simulations)	2	4	18	33	19	**35**	15	**28**	54	100
Data sets/spreadsheets	3	6	13	24	22	**40**	16	**30**	54	100
Word processors (MS word)	10	18	20	37	14	26	10	18	54	100
Online collaborative tools	8	15	12	22	16	**30**	18	**33**	54	100
Manipulation in an experimental lab.	8	15	25	46	7	13	14	26	54	100
Calculators/graphic calculators	-	-	18	33	13	**24**	23	**43**	54	100
Resources for special need learners	-	-	10	18	16	**30**	28	**52**	54	100
Resources for personalized learning	-	-	21	39	10	18	23	**43**	54	100
Simulation & VR	7	13	8	15	13	**24**	26	**48**	54	100
Robots, sensors and data loggers	3	6	2	4	18	**33**	31	**57**	54	100

Note. SA: Strongly agree; A: Agree; D: Disagree; SD: Strongly disagree; & T: Total

Table 7. Responses of STEM center coordinators on the utilization of educational technologies

Types of educational technologies	Very much		Much		Little		None		Total	
	f	%	f	%	f	%	f	%	f	%
Hyper media (simulations, apps)	2	18	4	36	5	**45**	-	-	11	100
Audio/video materials	-	-	8	72	3	28	-	-	11	100
Projected media (Slides, etc.)	2	18	4	36	5	**45**	-	-	11	100
Robotic kits	8	72	-	-	2	18	1	9	11	100
3D designing and printing	4	36	2	19	1	9	4	**36**	11	100
Sketch-up	2	18	2	18	6	**54**	1	9	11	100
Unmanned aerial vehicles	2	18	2	18	3	27	4	**36**	11	100
Laser cutters	2	18	-	-	8	**72**	**1**	9	11	100
Mobile technology	2	18	1	9	4	**36**	4	**36**	11	100
Sensors	6	54	2	18	2	18	1	9	11	100
Data loggers	2	18	2	18	6	**54**	1	9	11	100

In this regard, both STEM educators and center coordinators were asked about educational materials and technological tools integrated into the STEM teaching and learning practices. The responses obtained from both STEM educators and center coordinators are presented in **Table 6** and **Table 7**, respectively.

Table 6 shows the type and the extent to which STEM educators make use of educational technologies of various kinds to enhance students' learning and achievement. Accordingly, it is evident that *Hyper media* like web-based or computer-based simulations and software*, online collaborative tools, graphic calculators, spreadsheets, simulations and VR, robots, sensors* and *data loggers*, and *resources for personalized learning* and *special need learners* are among the rarely used technologies by STEM educators in their teaching practices. So, it implies the need to give due attention to these educational technologies in the future practices.

Table 7 depicts responses obtained from STEM center coordinators regarding educational technologies used in the classes. Accordingly, *audio-video materials, robotic kits,* and *Sensors* are found to be major educational technologies used in the instructional processes. This indicates that the responses of the coordinators are indifferent with the responses of the STEM educator, except for audio-video materials.

Additionally, the interview data obtained from the Foka STEM hub show that *Robotic kits and sensors, science lab apparatus,* and *computer-based simulations* and *software's* were usually used in the STEM sessions.

The data shows a variation among the centers regarding the types of educational technologies used. For example, for KMU and Menelik-I Science shared campus, few of the mentioned technologies, like computer-based simulations, audio-video materials and projected media were used in the STEM classrooms while none of the others are used.

Professional development activities

For a successful STEM education to happen, educators require a lot of support in terms of guiding frameworks, professional development, material development and many other resources as well as financial incentives (Mpofu, 2019). STEM educators should be provided with adequate mentoring during the critical first few years in the classroom; proper instructional leadership and support; and opportunities for professional growth and enrichment of knowledge and skills. They also should have access to classroom resources that are required for effective STEM

Table 8. Responses of STEM educators on provision of professional development opportunities

Focus of the training	None		< 1 day		1-3 days		4-6 days		> 6 days		Total	
	f	%	f	%	f	%	f	%	f	%	f	%
Internet use and general application	41	**76**	3	6	3	6	-	-	7	12	54	100
Advanced courses on application	41	**76**	5	9	2	4	3	6	3	6	54	100
Equipment-specific training	41	**76**	5	9	5	9	-	-	3	6	54	100
The use of ICT for teaching-learning	38	**70**	5	9	5	9	3	6	3	6	54	100
Subject-specific training on learning applications (tutorials, simulations)	34	**63**	8	15	7	13	2	4	3	6	54	100
Multimedia (digital video, audio equipment, etc.)	35	**65**	3	6	8	15	3	6	5	9	54	100
Participation in professional discussions (in blogs, Twitter)	30	**56**	10	19	-	-	11	20	3	6	54	100
Personally-initiated learning about innovative STEM teaching	24	**44**	10	19	5	9	5	9	10	19	54	100
Cooperation with STEM-based industry	25	**46**	8	15	5	9	13	24	3	6	54	100
Internet use and general application	41	**76**	3	6	3	6	-	-	7	12	54	100

Table 9. Responses of STEM center coordinators on students' learning activities

Types of learning activities	Very much		Much		Little		None		Total	
	f	%	f	%	f	%	f	%	f	%
Participation in **project-based activities**	10	91	1	9	-	-	-	-	11	100
Participation in **discussions**	4	36	6	55	1	9	-	-	11	100
Participation in **collaborative problem-solving**	4	36	4	36	3	28	-	-	11	100
Giving presentations to the whole class	6	55	-	-	5	45	-	-	11	100
Participation in **scientific inquiry process**	6	55	4	36	2	18	-	-	11	100

teaching and learning, including, for example, textbooks, supplies and equipment for laboratory and/or field experiences, and technology resources. Teachers should also be motivated to participate in professional development to help them achieve deep STEM content knowledge and mastery of STEM pedagogy.

In this light, data was collected from the STEM educators and their responses are presented as follow.

As **Table 8** shows, professional development opportunities that could have helped STEM educators in their in-and-out of classroom practices were not promising. It is evident that training on the use of ICT for STEM teaching-learning and on innovative STEM teaching methods were seldom provided to the educators or were offered for a very brief time. By implication, absence of significant training on such relevant skills and topics could affected the quality of STEM education provided at the centers. So, this is one of the critical areas that needs attention in the future practice of STEM education.

Students' learning engagements

Student engagement requires students to be actively involved in the learning process, willing to attempt tasks at the border of their ability and exhibit positive emotions regarding the learning process. Student engagement has been connected to promoting school completion (Anderson et al., 2004). Chapman (2003) notes that children with a higher level of student engagement show sustained behavioral involvement in learning activities…select tasks at the boarder of their competencies, initiate action when given the opportunity, and exert intense effort and concentration.

In connection to this, STEM center coordinators were asked to describe trainee students' learning behavior in the program. The responses are described and analyzed as follows.

As **Table 9** depicts, trainee students' involvement in the various learning activities that meant for achieving STEM skills is found to be promising. So, the training centers need to keep up this leaning engagements and STEM educators also prepare more engaging lessons and activities that will make trainees more active participants in the instructional processes.

Challenges and Shortcomings to the Implementation of STEM Education

Challenges and shortcomings to successful implementation of STEM program can be multidimensional. As such, one of the basic research questions concerned with barriers related to the implementation of STEM education program at the centers. The responses to the questionnaire are presented in **Table 10**.

As **Table 10** depicts, the implementation of the STEM program was affected much by multiple factors mentioned. This implies that challenges and shortcomings to implement the STEM program have had multiple dimensions. So, these are important areas that require serious attention and intervention in the future practice.

Table 10. Responses of STEM coordinators on factors affecting the implementation of the STEM program

Factors	Very much		Much		Little		None		Total	
	f	%	f	%	f	%	f	%	f	%
Teacher's lack of cohesive understanding of STEM education	4	36	6	55	1	9	-	-	11	100
Shortage of qualified STEM educators	2	18	9	82	-	-	-	-	-	100
Poor content preparation	1	9	6	55	4	36			11	100
Poor content delivery and method of assessment	1	9	10	91	-	-	-	-	11	100
Problem of curriculum integration	3	28	8	72	-	-	-	-	11	100
Poor leadership/management			8	72	2	18	1	9	11	100
Poor condition of resources and facilities	4	36	6	55	1	9	-	-	11	100
Low inspiration and engagement of students	-	-	8	72	2	18	1	9	11	100
Poor teachers' efficacy			8	72	3	28			11	100
Unfavorable attitudes &beliefs about STEM education	2	18	6	55	2	18	1	9	11	100
Lack of relevant support and training on STEM education	-	-	10	91	1	9	-	-	11	100
Insufficiency of instructional time	-	-	8	72	3	28	-	-	11	100
Absence of incentives for STEM educators	6	55	4	36	1	9	-	-	11	100
Problem of poor partnership patterns among stakeholders	4	36	7	64	-	-	-	-	11	100

In addition, the interview data obtained from Foka STEM center disclose that schools' uncooperative attitude to send trainee students to the center whenever they were required to attend STEM sessions and take part in the Science Fairs was one of the barriers to the effective implementation of the program at the center.

FINDINGS, CONCLUSION AND SUGGESTION

The main aim of this study was to examine implementation of STEM education program at 11 selected university and secondary school-based STEM centers across the country and suggest some possible ways of designing and implementing the program in the future.

Data was collected from 11 STEM center coordinators and 54 STEM educators mainly through online questionnaire. The summary of the results of the study is presented as follow.

Major Findings

The study comes up with the following major findings:

Management and support system of the STEM program

- ***Irregular and fragmented activities:*** There are significant variations among the STEM centers in implementing (organizing, managing, teaching) STEM training programs. Because review of documents and interviews conducted with major stakeholders discloses that the centers have no common guideline on which their implementation activities are based. Uneven implementation is also observed in the absence of coordination among the STEM centers.
- ***Inadequate support system:*** Except for certain material support (like lab equipment), and technical support in the installations of labs, support that had to come in the form of financial support, monitoring and evaluation of the implementation process, and provision of curricular materials are found to be insignificant, or nonexistent. Moreover, professional development activities related to educational ICT and STEM pedagogy were also minimal.

Types of STEM learning activities

There are various forms of STEM teaching and learning activities to be organized for students. Nonetheless, *Summer Sessions* and *Science Fairs* were the typical forms of STEM learning opportunities organized at the STEM centers.

STEM teaching and learning approach

- Normally, STEM pedagogy should be understood as an integrative approach that connects four different subjects and other relevant subjects into one (Wieselmann et al., 2022; Sutaphan and Yuenyong, 2019; Thibaut et al., 2018; Al Salami et al., 2017; Kelley and Knowles, 2016; Johnson, 2013, 2014; Nathan et al., 2013; The Global STEM Alliance, 2013; Stohlmann et al., 2012; Tsupros et al., 2009; Furner and Kumar, 2007). Nonetheless, results show that STEM disciplines have been in silos (taught as separate subjects) and the instruction seems unable to explore the intersection between STEM contents and contexts to optimize learning.

- Evidences from the two data sets suggest that *lab-based instruction, project-based learning (PBL), and collaborative instructional approaches* are common instructional approaches applied across the centers while other suitable approaches, like the *integrated instructional approach, personalized teaching-learning approach, formative and summative assessments techniques, and the field trip approach* were given little attention.
- Technology-supported instruction is also found to be insignificant as the STEM centers relied on very few instructional tools like s*cience lab equipment, projected media* like slides and overhead projectors. So, more emergent educational technologies need to be considered in future practice.

Challenges to the implementation of the STEM program are multiple

Implementation of the STEM initiative was affected by multiple factors, like educator's lack of cohesive understanding of STEM education; shortage of qualified STEM educators; poor content preparation and deliver; lack of meaningful connections across the STEM disciplines; poor leadership; lack of resources and facilities; lack of professional training; absence of incentives for STEM trainers, and absence of partnerships among stakeholders, and the like.

Conclusion

STEM initiative in Ethiopia is a recent phenomenon, introduced by a foreign firm. As such, the fate of the program, to be a sustainable educational enterprise, has been apparently relied on the aid of the initiator (the STEM-*power*), and the 'good wills' of the hosting universities, who viewed it as an additional burden and, hence, dealt with it half-heartedly.

The state of STEM training can be expressed as a *naïve experience or an embryonic enterprise* – in a sense that its practice across the various centers is found to be an evolving, immature process. In addition, a robust STEM program is lacking and the existing training program has no real owner who oversees its operations and patronizes it.

Thus, to provide Ethiopian students with the STEM knowledge, skills and values, existing gaps and challenges relating to national scheme, resources and facilities, ownership and leadership, implementation strategies, and monitoring and evaluation mechanisms must be considered seriously by the federal government and all key stakeholders, especially by higher education institutions and schools.

Recommendations/Implications

For the success of STEM initiative, the following actions are recommended as a way forward. The recommendations in this study, taken together, will be an important first-step in the transformation of STEM education or training in the country.

Developing STEM education national policy and strategic plan

Developing STEM education national policy and strategic plan to be updated every five years. The Ministry of Education, in collaboration with the universities and regional education bureaus (REBs), has a key role to play and bear the ultimate responsibility in developing STEM education policy and strategic plan by working in partnership with stakeholders at all levels. So, there should be a country-wide consultation and collaboration with REBs, schools, HEIs, employers and the like.

Most importantly, universities are required to dedicate infrastructure and facilities like laboratories, workshops, classrooms, museums, etc. that can be used for promoting STEM education.

Developing a national STEM content guideline

To overcome the existing problems of fragmentations and irregularities, a National Council for STEM education should be established and develop a framework that defines a harmonious national STEM content guideline for K-12 education program. These guidelines should define the essential knowledge, skills and values needed at each grade level for each STEM discipline and metrics for assessing and evaluating students' performance that are aligned with the new national STEM content guidelines.

Adopting an integrated STEM pedagogy

STEM pedagogy must move beyond discipline-specific design and approach. Many studies suggest that true STEM education is an integrated program of study that includes cross-curricular real-world learning experiences for students (Wieselmann et al., 2022; Sutaphan and Yuenyong, 2019; Thibaut et al., 2018; Al Salami et al., 2017; Kelley and Knowles, 2016; Johnson, 2013, 2014; Nathan et al., 2013; The Global STEM Alliance, 2013; Stohlmann et al., 2012; Furner and Kumar, 2007). Accordingly, using an interdisciplinary or integrated STEM program provides opportunities for more relevant, less fragmented, and more stimulating experiences for learners; improves problem solving and higher-level thinking skills, and retention; makes students better problem solvers, innovators, inventors, self-reliant, logical thinkers, and technologically literate.

STEM integration can be viewed in many ways. As to Brown et al. (2011a), one appealing method of creating an integrated STEM pedagogy is establishing a networking system among STEM teachers or educators so that they can align classes to build STEM challenges or projects together and better integrate STEM into their required curricula. They noted that there are common characteristics or natural overlapping of subjects and contents that unite the STEM disciplines which establishes the need for collaboration and ways for these teachers to work together within schools.

Likewise, Stohlmann et al. (2012) suggested that teachers of different disciplines should work together to ensure they are maximizing student learning and reinforcing similar concepts and information in different classes. Thus, teachers should work together as a team to make STEM instruction authentic, rather than in individual classrooms.

Creating effective ecosystem of STEM education

Creating effective ecosystem of STEM education developing increased engagements within and outside a formal educational setting; arrangements of various forms of STEM learning opportunities, such as week-end sessions, semester-break sessions, field visits to STEM-related firms, virtual lab sessions, televised STEM programs, STEM clubs, and the like.

Infusing innovative technological devices and tools into school STEM curriculum and instruction

These would include hyper media (Web-based or computer-based simulations, software's), manipulation of apparatus in experimental lab, simulation & virtual reality, audio-video materials, projected media, robotic kits, mobile technology, Internet-of-things (IoT), and the like. Such knowledge and skill will be useful to build school students' interest and passion for science and technology.

Strengthening regular monitoring and evaluations of the implementations process and feedback mechanisms

Furnishing the STEM programs with all essential resources and facilities

Furnishing the STEM programs with all essential resources and facilities—because effective STEM teaching-learning requires a set of enabling factors.

Developing STEM teacher preparation programs

Effective STEM programs also must place an emphasis on teacher preparation (National Research Council, 2011, 2012). Sustained professional development programs are reported to have a positive effect on teacher instruction and student achievement. Professional development offered to and sought out by teachers enables them to acquire new knowledge and skills, apply it to their practice, and reflect on the results with colleagues.

Different types of professional development can help better prepare teachers by increasing their confidence and efficacy for teaching STEM, as well as their perceptions. Professional development programs can simultaneously help existing teachers develop deeper understanding of the subjects they teach while exploring mechanisms for integration across STEM and non-STEM disciplines.

By the same token, Ejiwale (2013) notes that for a pool of educators that will be dedicated to teaching in STEM fields, being equipped with deep content knowledge in STEM and strong pedagogical skills for teaching their students are two essential attributes they should possess to be able to help students achieve deep understandings of STEM for later utilization in their lives and careers.

So, teachers prepared for K-12 education levels should be provided with sufficient STEM content knowledge or skills for teaching this content during their pre-service preparation. Moreover, for those on the job, improving STEM educator's pedagogical knowledge, skills and attitudes through continuing professional development opportunities becomes necessary.

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