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Determinants of effective hands-on STEM education in higher education institutions in Mogadishu, Somalia

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The study investigates the influence of various factors on effective hands-on STEM education in higher education institutions, focusing on faculty expertise, training, pedagogical approaches, curriculum design, and resources. Using partial least squares structural equation modeling (PLS-SEM) with a significance threshold of $P < 0.05$, 10 hypotheses were tested. The data were gathered from 323 academic staff members in Mogadishu through an online survey employing a stratified random sampling technique. Strata were defined based on faculty specialization (STEM vs. non-STEM) and gender to ensure diversity, and the sample size was justified by power analysis Bootstrapping with 10,000 subsamples was used to assess the statistical significance of the paths. The results show strong support for the majority of the hypotheses. Faculty expertise significantly influences effective hands-on STEM education (H1), with a path coefficient (β) of 0.177, *t*-value of 2.301, and a 95% confidence interval (CI) between 0.026 and 0.330. Additionally, STEM pedagogical approaches (H2) and curriculum design (H3) significantly impact effective hands-on STEM learning, with path coefficients (β) of 0.165 and 0.121, respectively. The strongest relationship was found between STEM resources and facilities (H4) and effective hands-on education, with a path coefficient (β) of 0.367, *t*-value of 4.374, and a 95% CI ranging from 0.193 to 0.522. The study further highlights indirect effects, such as the mediation of pedagogical approaches (H8) and curriculum design (H9) on the relationship between faculty expertise and effective hands-on STEM education. The findings suggest that enhancing faculty expertise, pedagogical strategies, curriculum design, and resources will significantly contribute to improved hands-on STEM education outcomes. These insights can guide educators and policymakers in creating more engaging and effective STEM learning environments.

KEYWORDS

STEM education, hands-on learning, higher education institutions, pedagogical approaches, faculty expertise and training

1 Introduction

STEM education (Science, Technology, Engineering, and Mathematics) is pivotal in developing a nation's workforce and its ability to adapt and innovate in an increasingly complex and technologically driven world (Sharma and Yarlagadda, 2018). In the 21st century, characterized by an era of innovation, digital literacy and complex problem solving skills, STEM education is seen as a starting point in equipping students with the skill set of today's global economy and technology requirements. The push for 21st-century skills, particularly critical thinking, creativity, communication, and collaboration, has fundamentally redefined how higher education institutions understand and engage with learning in STEM (Barcelona, 2014). The importance of STEM education in the 21st century has been widely recognized and debated, as various reports have highlighted how STEM fields are changing and how students' interests and career aspirations are lagging (Ancrossed d Signiæ and Mažar, 2023; De and Arguello, 2020). STEM education in higher education institutions aims to equip students with the skills and knowledge to face the challenges and opportunities of a dynamic world and contribute to the innovation and discovery that advance science and technology (Le et al., 2021; Tytler, 2020). STEM education promotes the development of critical thinking, problem-solving, creativity, and collaboration skills vital for lifelong learning and success (Ancrossed d Signiæ and Mažar, 2023; Idris et al., 2023).

Globally, hands-on STEM education has evolved to become a learner-centered approach that emphasizes active engagement through laboratory work, simulations, and real-world problem-solving. This pedagogical shift has been supported by studies in developed countries, such as the U.S., Australia, and parts of Asia, where active learning environments have been shown to enhance students' STEM competencies and motivation (Kelley and Knowles, 2016). In the African context, however, especially in post-conflict and resource-constrained regions like Somalia, such approaches remain underutilized or poorly integrated.

Hands-on learning is a cornerstone of effective STEM education, fostering critical thinking, problem-solving, and practical skills essential for success in the 21st century. However, in Somalia, where STEM educational infrastructure and resources have faced numerous challenges, the quality and accessibility of hands-on STEM education in higher education institutions remain significantly underdeveloped. This poses a critical challenge, as a skilled and innovative STEM workforce is crucial for the country's economic and social development.

Therefore, this article examines the factors influencing the availability and quality of hands-on STEM education at higher education institutions in Somalia, such as faculty expertise, training, pedagogical approaches, curriculum design, and resources.

Unlike earlier studies that focused mainly on general STEM implementation or science achievement in Somalia, this study uniquely examines the determinants of effective hands-on STEM education, which remains a neglected area in Somali higher education research. By employing PLS-SEM on academic staff perspectives, it not only identifies key influencing factors but also models their direct and mediated effects, offering a novel contribution to both local and international STEM education literature.

By identifying and addressing the key factors that hinder the implementation of effective hands-on STEM education, this research aims to contribute to the development of more effective and engaging learning experiences for students, ultimately fostering a more skilled and innovative STEM workforce in Somalia.

This study, therefore, fills a significant gap in both empirical data and theoretical modeling concerning hands-on STEM pedagogy in post-conflict settings, offering practical insights for curriculum designers, faculty trainers, and policymakers.

There is still little knowledge about how different elements like faculty experience, pedagogical approaches, curriculum design, and resources affect the efficacy of STEM learning, despite the growing significance of experiential STEM education in higher education institutions, especially in Mogadishu, Somalia. These elements' effects on students' engagement and achievement in STEM disciplines have not been fully investigated in the context of Somalia, where educational resources and infrastructure are still in the early stages of development. In order to improve the caliber and accessibility of experiential STEM education—which is crucial for creating a knowledgeable and creative workforce in the area—this study attempts to investigate these important variables.

The purpose of this study is to examine how curriculum design, pedagogical approaches, faculty expertise, and resources affect the implementation and efficacy of experiential STEM education at Mogadishu, Somalia's higher education institutions. This project will investigate how these elements work together to improve students' STEM learning experiences by encouraging critical thinking, problem-solving, and practical skills through an empirical analysis. To support the long-term growth of STEM jobs in Somalia, the findings will offer insightful information to institutions, educators, and policymakers on how to enhance STEM education methods, curriculum design, and resource allocation.

This research is crucial as it targets higher education institutions in Mogadishu, where hands-on STEM education faces challenges due to limited resources, outdated teaching methods, and insufficient professional development for faculty members. By addressing these issues, the study will contribute to the development of more effective STEM education strategies in Somalia and similar contexts.

The study also discusses the potential benefits of expanding STEM education for Somalia's social and economic development. This study investigates the relationships between faculty expertise, pedagogical approaches, curriculum design, STEM resources, and the overall effectiveness of hands-on STEM education in higher education institutions in Mogadishu, Somalia. By exploring these connections, the research aims to provide actionable insights into how Somalia can address key barriers, such as limited resources, outdated teaching methods, and insufficient faculty training, and ultimately improve the quality and accessibility of hands-on STEM education, contributing to the development of a skilled and innovative workforce.

The authors constructed the proposed research model, shown in Figure 1, which illustrates the relationship between the independent variables (faculty expertise, pedagogical approaches, curriculum design, and STEM resources), the mediating variables (pedagogical approaches, curriculum design, and STEM resources), and the dependent variable (effective hands-on STEM education).

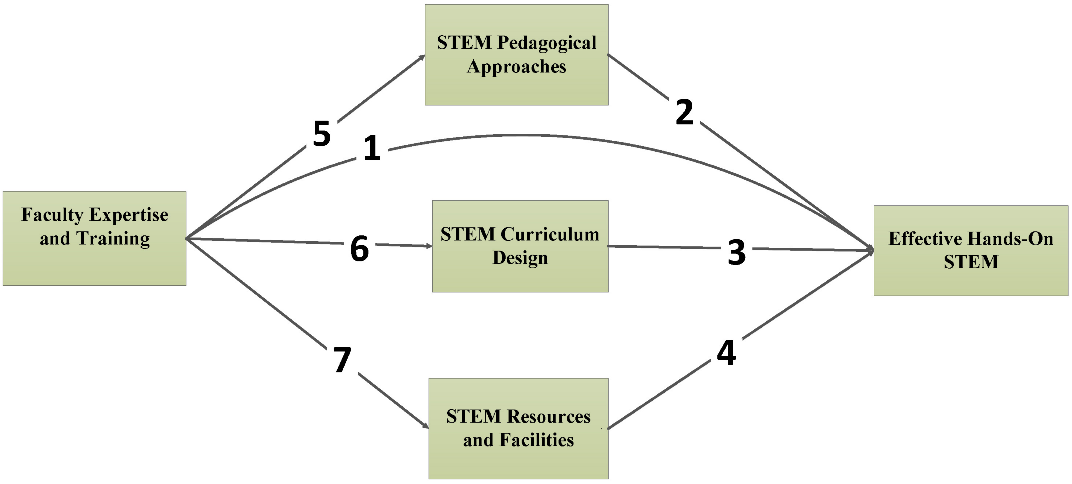

FIGURE 1
Research model.

Additionally, the model examines the indirect effects of faculty expertise, pedagogical approaches, curriculum design, and STEM resources on the overall effectiveness of hands-on STEM education, focusing on how these factors interact to enhance the learning experience and promote student success in STEM fields.

2 Literature review

2.1 Faculty expertise and training

An educational institution's quality depends mainly on the expertise of its faculty and their on-going professional development. For STEM education, faculty members need to have strong academic credentials, industry exposure, and skills in teaching methods that promote experiential learning (Hasim et al., 2022).

One way to promote kinesthetic learning skills in STEM education is to use hands-on pedagogy, which involves learners actively exploring STEM concepts and their applications (Alrasheed and Hamdan Alghamdi, 2023; Kyere, 2017). Teachers can benefit from professional development (PD) activities led by faculty experts who can demonstrate how to design and implement hands-on activities that align with the curriculum and connect abstract ideas to real-world problems. Faculty experts can share their knowledge and skills with teachers and help them create engaging and meaningful learning experiences that bridge the gap between theory and practice in hands-on STEM education (Graha et al., 2023; Holstermann et al., 2010).

Educators need PD support to implement hands-on instructional methods effectively in the classroom (Ejiwale, 2012; Vedrenne-Gutiérrez et al., 2024). Teachers can benefit from participating in hands-on STEM education professional development programs and workshops, which help them design and deliver lesson plans that include tangible activities and projects. These learning experiences allow students to apply STEM concepts in real-world situations, enhancing their comprehension of the subject matter.

Teachers' instructional practices significantly impact students' engagement and achievement in STEM fields (Keith, 2018). Teachers who are confident and competent in delivering hands-on STEM activities can foster student curiosity and motivation (Chalmers, 2017). To improve teachers' self-efficacy in hands-on STEM education, targeted professional development that covers theory and practice is essential (Geng et al., 2019). Teachers also need continuous support, resources, and collaboration opportunities to facilitate hands-on STEM learning in their classrooms (Hasim et al., 2022).

2.2 Hands-on Pedagogical approaches

Pedagogical approaches with hands-on STEM education at higher education institutions are teaching and learning methods that involve students' active engagement in scientific, technological, engineering, and mathematical concepts and practices (Shernoff et al., 2017). Hands-on STEM education can take various forms, such as laboratory experiments, fieldwork, design projects, simulations, games, and maker spaces (Avendano et al., 2019). These approaches aim to foster students' curiosity, creativity, collaboration, critical thinking, and problem-solving skills, as well as their understanding of the relevance and applicability of STEM disciplines to real-world issues (Avendano et al., 2019).

In Somalia, the STEM field approach at high institutions faces many obstacles that hinder the effective implementation of STEM education at higher institutions. One of the significant challenges for higher education in Somalia is the lack of proper pedagogy, teachers and infrastructure to support the integration of STEM fields in the curriculum. College faculties use traditional teaching methods in the classroom (Salad, 2023). The College of Education, especially the science department, does not have enough teaching materials to make it easier for students to understand the subject and concepts of the course (Salad, 2023).

STEM education requires access to modern laboratories, equipment, materials, and qualified instructors, often scarce or unavailable in many institutions in Somalia. Moreover, the socio-cultural and political context of Somalia poses additional barriers to the promotion and acceptance of STEM disciplines, especially among female students and marginalized groups (Jama and Barre, 2019). Therefore, there is a need for more investment, advocacy, and collaboration to overcome these obstacles and enhance the quality and relevance of STEM education in Somalia.

Another advantage of hands-on pedagogy in STEM education is that it fosters collaborative learning. Many STEM fields involve interdisciplinary collaboration, reflecting the collaborative nature of real-world scientific and technological innovations (Tytler et al., 2023).

2.3 STEM curriculum design

Curriculum design in hands-on STEM higher education institutions is a process of planning and implementing learning activities that engage students in authentic, inquiry-based, and collaborative experiences (Saliman et al., 2023; Yu et al., 2019). In Somalia, STEM subjects are often taught in a theoretical way without connecting them to real-life situations (Salad, 2023). STEM curriculum design in higher education institutions aims to change that by offering hands-on learning experiences that foster skills and creativity in STEM fields. However, STEM education in Somalia faces several challenges, such as gender biases, teacher understanding, resource insufficiency, and science anxiety by students (Mutsvangwa and Zezekwa, 2021).

Lab activities and real-world applications are essential components of STEM education. They enable students to learn by doing, to apply theoretical concepts to practical situations, and to enhance their problem-solving skills (Kelley and Knowles, 2016). A STEM curriculum that integrates these elements can stimulate students' creativity, innovation, and collaboration. Such a curriculum can prepare students for the challenges and opportunities of the 21st century (Barcelona, 2014).

Science education has recently emphasized the importance of inquiry and hands-on-based curriculum. This curriculum allows students to engage in observation and inquiry guided by teachers and develop scientific reasoning and logical thinking skills (Yu et al., 2019). STEM hands-on curriculum that involves practical experience with mechanical and electrical materials can help students achieve effective knowledge integration with the help and encouragement of teachers and peers (Jacobs et al., 2016).

2.4 Resources and facilities

The quality and effectiveness of STEM education in higher institutions depend primarily on the resources and facilities that are accessible to students and educators (Ejiwale, 2012). To learn STEM effectively, students need access to well-equipped laboratories and specialized equipment (Connor et al., 2016). However, many higher education institutions in Somalia face challenges in providing adequate resources and facilities for hands-on STEM education, such as laboratories, equipment, materials, and software.

Modern technology and tools, such as computers, software, and data analysis equipment, enhance the learning experience and allow students to apply STEM concepts in practice. These tools have enabled a pedagogical approach that fosters hands-on STEM education and enhances student and instructor engagement (Campbell and Damico, 2023).

Collaborating with industry partners can enrich students' learning experiences and outcomes, as they can access the equipment and methods that STEM professionals use in their fields (Klein and Schwanenberg, 2022). This can also help students develop relevant skills and insights for their future careers. Resources and facilities must be constantly maintained and updated to provide students with the best STEM education. This requires adequate funding and support from institutions that value the importance of STEM learning (Klein and Schwanenberg, 2022).

Despite the growing global emphasis on experiential and hands-on approaches to STEM education, there remains a significant gap in research examining how these practices are implemented in post-conflict and resource-constrained settings like Somalia. Existing studies primarily focus on general STEM awareness or performance in basic education, often overlooking the systemic barriers and enabling conditions specific to hands-on STEM pedagogy in higher education. Moreover, limited empirical work has investigated how faculty expertise, pedagogical methods, curriculum design, and resource availability interact to influence experiential learning outcomes in fragile contexts. This gap highlights the urgent need for localized, evidence-based research to inform policy and institutional practice. The present study responds to this need by systematically analyzing these determinants using structural equation modeling, thereby contributing valuable insights for improving STEM education in Somalia and similar environments.

3 Methodology

The primary aim of this study was to investigate the determinants of effective hands-on STEM education in higher education institutions in Mogadishu, Somalia. A cross-sectional research design was employed to assess the relationships between various factors influencing hands-on STEM education at a specific point in time. This approach is consistent with established practices in educational research and allows for a comprehensive evaluation of the effectiveness of pedagogical strategies (Abdi and Idris, 2024; Setiamurti et al., 2023).

3.1 Research hypotheses

The authors propose the following hypothesis:

H1: Faculty expertise and training significantly correlate with effective hands-on STEM education at higher education institutions.

H2: STEM Pedagogical approaches significantly correlate with effective hands-on STEM education at higher education institutions.

H3: STEM curriculum design significantly correlates with effective hands-on STEM education at higher education institutions.

H4: STEM Resources and facilities significantly correlate with effective hands-on STEM education at higher education institutions.

H5: Faculty expertise and training significantly correlate with STEM Pedagogical approaches

H6: Faculty expertise and training significantly correlate with STEM curriculum design

H7: Faculty expertise and training significantly correlate with STEM Resources

H8a,c: This hypothesis examines the multiple mediating roles of STEM Pedagogical approaches, STEM curriculum design, and STEM Resources and facilities between Faculty expertise and effective hands-on STEM education at higher education institutions.

The specific mediation paths are:

Faculty expertise → STEM Pedagogical approaches → effective hands-on STEM education (5 → 2).

Faculty expertise → STEM Curriculum design → effective hands-on STEM education (6 → 3).

Faculty expertise → STEM Resources and facilities → effective hands-on STEM education C (7 → 4).

Each hypothesis is designed to fill gaps in the existing literature by providing a comprehensive understanding of the pathways through which Faculty expertise influences implementation of effective hands-on STEM education. The theoretical justification for these hypotheses is grounded in the SCCT framework and the empirical evidence reviewed. Through this research, we aim to provide insights that will inform strategies to enhance hands-on STEM education, thereby contributing to developing a skilled and innovative workforce in Somalia.

3.2 Participants and sample size

The study targeted academic staff employed at five research universities in Mogadishu, Somalia. The total population of academic staff across these institutions was identified, and a final sample size of 323 participants was determined. This sample was chosen to ensure representation across various academic disciplines and roles within the universities.

Participants were recruited through institutional email lists and faculty WhatsApp groups, coordinated with university registrars. An invitation message explained the study's purpose, assured confidentiality, and included a link to the online questionnaire. Participation was voluntary, and informed consent was obtained before data collection.

3.3 Sample size justification

A power analysis was conducted before data collection to justify the chosen sample size for Structural Equation Modeling (SEM). This analysis indicated that a sample size of at least 300 would provide sufficient statistical power (80%) to detect medium effect sizes, ensuring robustness in our SEM estimates. The sample was selected using a stratified random sampling method, with strata defined based on faculty and department to maintain representativeness. Stratified random sampling ensures representativeness by including distinct strata based on faculty and department. This method reduces bias, improves precision, and allows for detailed subgroup analysis, enhancing statistical power. It enables reliable conclusions, ensuring that all relevant subgroups are adequately represented in the sample for more valid research findings (Triveni et al., 2024).

3.4 Questionnaire design and validation

The research utilized an online questionnaire developed from established instruments and adapted from relevant literature on effective hands-on STEM education. The tool measured five key constructs—Faculty Expertise and Training, STEM Pedagogical Approaches, STEM Curriculum Design, Resources and Facilities, and Effective Hands-on STEM Education each with five items, rated on a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree).

Content validity and clarity were tested for the instrument using formative validation process with two steps of validation: the questionnaire was pretested with 20 academic staff members from a non-final sample university. The relevance, clarity and understandability of the items were checked with participants. Furthermore, the questionnaire having been developed was reviewed by three other STEM and Education faculties as subject specialists to ensure that it had content validity and was theoretically grounded against the constructs.

There was no item extracted or combined in this phase. Following pilots, wording was slightly modified to ensure clarity, however the content, form and number of items per construct remained consistent. This indicated that the constructs were well understood and interpreted consistently by respondents.

The pilot also revealed that participants broadly associated "hands-on STEM education" with lab work, real-world applications, and collaborative projects, confirming alignment with the study's conceptual framework.

3.5 Data analysis

The collected data were analyzed quantitatively using R version 4.3.1, with Structural Equation Modeling (SEM) conducted through the SEMinR software package. This software was selected for its robustness in handling non-normal data and its ability to model complex relationships among latent constructs using the Partial Least Squares (PLS) approach.

The evaluation process consisted of two main stages: assessment of the measurement model and the structural model. The measurement model was analyzed to verify internal consistency, indicator reliability, and convergent and discriminant validity of the constructs using Composite Reliability (CR), Average Variance Extracted (AVE), and factor loadings. Discriminant validity was assessed through the Fornell–Larcker criterion and the Heterotrait-Monotrait (HTMT) ratio.

Following the validation of the measurement model, the structural model was evaluated to examine the hypothesized relationships among the constructs. The model's path coefficients, t-values, and confidence intervals were estimated using a

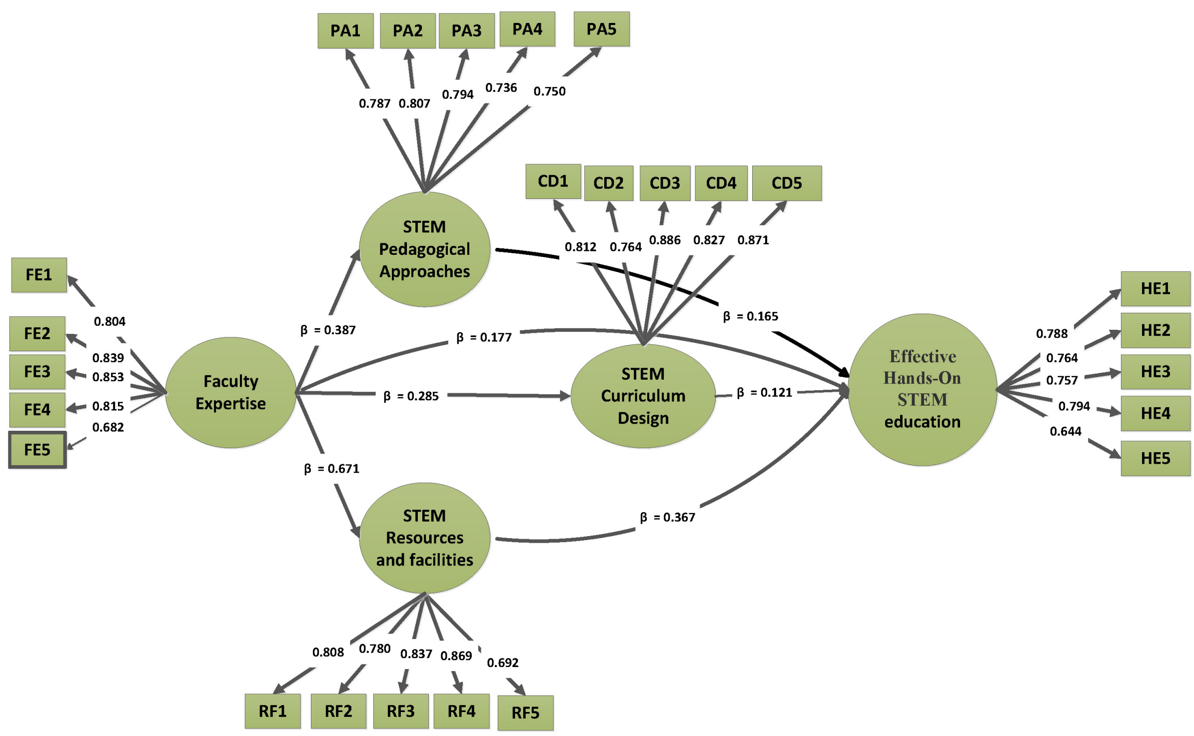

FIGURE 2
SEM analysis of conceptual model.

bootstrapping method with 10,000 subsamples, ensuring statistical significance was determined at the 0.05 level. Multicollinearity was assessed using Variance Inflation Factor (VIF) values, all of which were within acceptable thresholds, indicating no serious multicollinearity issues.

Figure 2 presents the results of the SEM analysis. It visually illustrates the relationships between faculty expertise, pedagogical approaches, curriculum design, resources and facilities, and their combined impact on effective hands-on STEM education. The path coefficients are displayed on the arrows, representing the strength and direction of the relationships among the constructs. The model also highlights indirect effects, showing how pedagogical approaches, curriculum design, and resources mediate the relationship between faculty expertise and the outcome variable. This comprehensive visual model supports the study's central argument and provides empirical backing for the theoretical framework developed.

4 Results

The sample's characteristics are delineated by utilizing demographic data obtained from respondents. This data is presented in a sequential manner in the initial section of the questionnaire, which focuses on gathering personal information.

The survey in Mogadishu, Somalia, reveals that the majority of respondents are male (79%), with 21% female. The majority are aged 34–44, with 49% aged 23–33. Most have master's degrees (84%), with 86% specializing in science in Table 1. This data suggests that institutions should tailor their programs to meet the specific needs of their students, promoting inclusivity and diversity in STEM education.

TABLE 1 Demographics of respondents.

Item	Characteristics	Percentage (%)
Gender	Male	79
	Female	21
Age Group	23-33	43
	34-44	49
	44 +	8
Qualification	Masters	84
	PhD	16
Specialization	Arts	14
	Science	86

4.1 Measurement model assessment

The primary objective of the initial assessment of the measurement model was to ascertain the idea's factor loadings, reliability, and validity, as defined by Hair et al. (2020). The methodology primarily encompassed a set of 25 factors. In evaluating the measurement model, it was determined that no items required elimination, as all factor loadings surpassed the acceptable level of 0.600 (see Figure 2; Mokhtar et al., 2018).

TABLE 2 Factor loadings, reliability, and convergent validity.

Variable	Items	Loadings	Alpha	rhoC	AVE	rhoA
Faculty expertise and training	FET1 FET2 FET3 FET4 FET5	0.804 0.839 0.853 0.815 0.682	0.859	0.899	0.642	0.873
STEM pedagogical approaches	PA1 PA2 PA3 PA4 PA5	0.787 0.807 0.794 0.736 0.750	0.834	0.883	0.601	0.836
STEM curriculum design	CD1 CD2 CD3 CD4 CD5	0.812 0.764 0.886 0.827 0.871	0.890	0.919	0.694	0.899
STEM resources and facilities	RF1 RF2 RF3 RF4 RF5	0.808 0.780 0.837 0.869 0.692	0.857	0.898	0.639	0.865
Effective hands-on STEM education	HSE1 HSE2 HSE3 HSE4 HSE5	0.788 0.764 0.757 0.794 0.644	0.808	0.866	0.565	0.823

Consequently, all inquiries were integrated into the final measuring technique (see Table 2). The Average Variance Extracted (AVE) and composite dependability of all the constructs are more significant than and equal to the respective thresholds of 0.50 and 0.70 (Binheem et al., 2021). Therefore, the presence of convergent validity and dependability is apparent. Furthermore, the results of discriminant validity using the Fornell and Larcker (1981) approach are displayed in Table 3. According to Mohamed and Hassan (2023), a construct is considered acceptable when its diagonal values surpass its non-diagonal values inside the respective columns and rows.

The evidence of discriminant validity is demonstrated by the higher values on the diagonal compared to the non-diagonal values, as indicated in Table 4. The discriminant validity of each construct is demonstrated by the diagonal bold numbers, which indicate the square root of the average variance extracted (AVE). According to Dotzel et al. (2022), all constructs exhibit values that surpass the threshold of 0.50. Subsequently, a comprehensive analysis was conducted. Table 3 demonstrates that the values of the constructs do not exceed 0.85 or 0.9, indicating that they possess discriminant validity in terms of the HTMT ratio (Mokhtar et al., 2018).

TABLE 3 Discriminant validity (Fornell-Larcker Criterion).

	FET	PA	CD	RF	HSE
Faculty expertise and training	0.801				
Pedagogical approaches	0.387	0.775			
STEM curriculum design	0.285	0.326	0.833		
Resources and facilities	0.671	0.421	0.341	0.800	
Effective hands-on STEM education	0.522	0.428	0.350	0.597	0.7516

FET, Faculty Expertise and Training; PA, STEM Pedagogical Approaches; CD, STEM Curriculum Design; RF, STEM Resources and Facilities; HSE, Hands-on STEM education.

TABLE 4 Heterotrait monotrait ratio (HTMT).

	FET	PA	CD	RF	HSE
Faculty expertise and training					
Pedagogical approaches	0.459				
STEM curriculum design	0.320	0.374			
Resources and facilities	0.770	0.502	0.392		
Effective hands-on STEM education	0.608	0.514	0.404	0.698	

FET, faculty expertise and training; PA, pedagogical approaches; CD, STEM curriculum design; RF, resources and facilities; HSE, hands-on STEM education.

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TABLE 5 Collinearity.

	Variance inflation factor (VIF)
Faculty expertise training	1.869
Pedagogical approaches	1.296
STEM curriculum design	1.188
Resources and facilities	1.989

4.2 Structural model by SEMinR

Estimating a set of regression equations is used to derive the coefficients of the structural model, which depict the interactions between various components. The assessment of potential collinearity concerns in the regressions of the structural model is crucial because it might lead to skewed point estimates and standard errors. These issues arise from high correlations among the predictor components (Kline, 2018). The methodology employed bears similarity to the assessment of formative measurement approaches. In this particular case, the scores of the predictor constructs are utilized within each regression of the structural model to calculate the variance inflation factor (VIF) values (Table 5).

Variance Inflation Factor (VIF) values exceeding 5 indicate the presence of potential collinearity issues among the predictor variables. Nevertheless, it is crucial to acknowledge that collinearity may also become apparent at lower Variance Inflation Factor (VIF) values, typically falling within the range of 3 to 5, as emphasized by (Hong and Sullivan, 2013).

4.2.1 Hypothesis test

To examine the proposed correlations, the study used partial least squares structural equation modeling (PLS-SEM) at a significance threshold of $P < 0.05$. Strong support for the majority of the offered hypotheses is provided by the standardized path coefficients, as shown in Table 6. The statistical significance of the path coefficients was assessed using the bootstrapping technique with 10,000 subsamples. A path coefficient is deemed significant in this technique if its 95% confidence interval (CI) excludes zero (Miethlich et al., 2020; Table 6).

The present study employed statistical analysis to derive various significant findings, encompassing the confidence interval, t-statistics, path coefficient, and a significance threshold of 5%. The results of a comprehensive validation process of ten hypotheses offer robust support for each.

H1: Faculty Expertise and Training → Effective Hands-on STEM Education (HSE)

The hypothesis that Faculty Expertise and Training (FET) influences implementation of effective Hands-on STEM Education (HSE) is supported by the data. The standardized path coefficient (β) is 0.177, with a *t*-value of 2.301, and a 95% CI between 0.026 and 0.330. This confirms that faculty expertise positively impacts the effectiveness of hands-on STEM education.

H2: STEM Pedagogical Approaches → Effective Hands-on STEM Education

This hypothesis is also supported. The path coefficient (β) is 0.165, and the *t*-value of 2.915 indicates statistical significance. The 95% CI is between 0.055 and 0.276, confirming that pedagogical approaches significantly influence the implementation of hands-on STEM learning.

H3: STEM Curriculum Design → Effective Hands-on STEM Education

A significant relationship was found between STEM Curriculum Design (SCD) and Hands-on STEM Education. The path coefficient (β) is 0.121, with a *t*-value of 2.411 and a 95% CI ranging from 0.027 to 0.223, indicating that a well-designed STEM curriculum positively influences hands-on education outcomes.

H4: STEM Resources and Facilities → Effective Hands-on STEM Education

The strongest relationship was found between Resources and Facilities (RF) and Hands-on STEM Education, with a path coefficient (β) of 0.367, a *t*-value of 4.374, and a 95% CI ranging from 0.193 to 0.522. This demonstrates the critical importance of resources and facilities in supporting hands-on learning experiences.

H5: Faculty Expertise and Training → STEM Pedagogical Approaches

The path from Faculty Expertise and Training to Pedagogical Approaches (PA) is highly significant. The coefficient (β) is 0.387, with a *t*-value of 7.223, and a 95% CI from 0.285 to

TABLE 6 Summary of hypothesis testing.

Hypothesis	Path	Original Est.	Bootstrap mean	T-V	2.5% CI	97.5% CI
H1	FET- > HSE	0.177	0.177	2.301	0.026	0.330
H2	PA - > HSE	0.165	0.166	2.915	0.055	0.276
H3	SCD - > HSE	0.121	0.125	2.411	0.027	0.223
H4	RF - > HSE	0.367	0.367	4.374	0.193	0.522
H5	FET - > PA	0.387	0.391	7.223	0.285	0.493
H6	FET - > CD	0.285	0.288	4.774	0.169	0.404
H7	FET - > RF	0.671	0.673	14.792	0.579	0.758
H8a	FET - > PA- > HSE	0.064	0.065	2.605	0.020	0.117
H8b	FET - > CD - > HSE	0.034	0.036	2.047	0.007	0.072
H8c	FET - > RF - > HSE	0.246	0.246	4.345	0.131	0.355

FET, faculty expertise and training; PA, STEM pedagogical approaches; CD, STEM curriculum design; RF, STEM resources and facilities; HSE, effective hands-on STEM education.

0.493, indicating that faculty expertise substantially influences pedagogical approaches in STEM education.

H6: Faculty Expertise and Training → STEM Curriculum Design

This hypothesis is supported by a significant path coefficient (β) of 0.285 and a *t*-value of 4.774, with a 95% CI ranging from 0.169 to 0.404, confirming that faculty expertise also plays a crucial role in shaping the STEM curriculum design.

H7: Faculty Expertise and Training → STEM Resources and Facilities

Faculty expertise significantly impacts the availability and development of STEM resources and facilities, with the highest path coefficient (β) of 0.671, a *t*-value of 14.792, and a 95% CI between 0.579 and 0.758. This suggests that faculty expertise is a strong predictor of institutional support in terms of resources.

H8a: Faculty Expertise and Training → Pedagogical Approaches → Effective Hands-on STEM Education

This indirect effect of faculty expertise on hands-on STEM education through pedagogical approaches is statistically significant, with a path coefficient (β) of 0.064, a *t*-value of 2.605, and a 95% CI from 0.020 to 0.117. It indicates that pedagogical approaches partially mediate the relationship between faculty expertise and hands-on education.

H8b: Faculty Expertise and Training → Curriculum Design → Effective Hands-on STEM Education

The indirect effect of faculty expertise on effective hands-on STEM education via curriculum design is also significant, with a path coefficient (β) of 0.034, a *t*-value of 2.047, and a 95% CI ranging from 0.007 to 0.072. This suggests a small yet meaningful mediation effect of curriculum design on the relationship between faculty expertise and hands-on education.

H8c: Faculty Expertise and Training → Resources and Facilities → Effective Hands-on STEM Education

Lastly, faculty expertise significantly affects hands-on STEM education through its impact on resources and facilities. The path coefficient (β) is 0.246, with a *t*-value of 4.345, and a 95% CI from 0.131 to 0.355. This further emphasizes the importance of resources and facilities in the effective implementation of hands-on STEM education.

The findings are derived from the empirical observation that the numerical value of zero is not within the corresponding confidence intervals, which have been established at 95% in Table 6.

5 Discussion

This study investigates the key factors influencing implementation of effective hands-on STEM education in higher education institutions in Mogadishu, Somalia. It examines the role of faculty expertise, training, pedagogical approaches, curriculum design, and resources, using partial least squares structural equation modeling (PLS-SEM) to test 10 hypotheses. The findings offer significant insights into how these variables shape the effectiveness of STEM education.

Faculty Expertise and Training (H1) was found to have a notable impact on effective hands-on STEM education. With a path coefficient of 0.177, *t*-value of 2.301, and a 95% confidence interval (CI) between 0.026 and 0.330, the results confirm that faculty expertise positively influences the delivery of practical STEM education. This suggests that academic staff that possess strong subject knowledge and undergo continuous professional development can better facilitate effective hands-on learning. Their ability to incorporate evolving technologies and innovative teaching methods into STEM courses creates a more interactive and practical learning environment. And Continuous professional development for faculty, tailored to local challenges, is crucial for effective STEM learning. This aligns with findings from Hasim et al. (2022), who emphasize that professional development improves teacher efficacy and instructional practices in STEM. Furthermore, Alrasheed and Hamdan Alghamdi (2023) support the link between faculty training and successful implementation of project-based STEM learning approaches.

Pedagogical Approaches (H2) also significantly impact hands-on STEM education. The path coefficient of 0.165, combined with a *t*-value of 2.915 and a 95% CI ranging from 0.055 to 0.276, demonstrates the importance of adopting interactive and student-centered teaching strategies. Active learning approaches that emphasize problem-solving, teamwork, and critical thinking help students engage more deeply with STEM subjects. Practical exercises, simulations, and fieldwork provide real-world applications of theoretical knowledge, making the learning process more immersive and relevant to students' future careers (Geng et al., 2019). These findings are supported by Shernoff et al. (2017), who found that hands-on pedagogical models significantly enhance STEM engagement. Similarly, Hasim et al. (2022) reported that experiential learning in STEM fosters student motivation and curiosity, especially in resource-limited settings. Adopting interactive and student-centered strategies is essential for enhancing STEM education outcomes. Active learning methods, such as hands-on projects, simulations, and design challenges, bridge the gap between theoretical concepts and real-world applications.

Thus, pedagogical innovation plays a critical role in enhancing the quality of STEM education.

The findings related to STEM Curriculum Design (H3) reinforce the importance of a well-structured curriculum in hands-on STEM learning. A path coefficient of 0.121, *t*-value of 2.411, and 95% CI between 0.027 and 0.223 point to the significance of aligning the curriculum with industry trends and integrating real-world applications. Incorporating laboratory work, design challenges, and hands-on activities into the curriculum enables students to explore specific areas of interest and solidify their understanding of theoretical principles (Tscholl et al., 2023). Jacobs et al. (2016) similarly argued that 21st-century STEM curricula must be inquiry-driven and application-oriented to be relevant and effective. Jacobs et al. (2016) also observed that integrated hands-on STEM curricula promote collaboration and deepen student comprehension across multiple disciplines.

The strongest relationship in the study was found between STEM Resources and Facilities (H4) and hands-on STEM education, with a path coefficient of 0.367, *t*-value of 4.374, and a 95% CI ranging from 0.193 to 0.522. These results highlight the critical role that adequate resources and facilities play in supporting practical STEM learning. Access to well-equipped laboratories, workshops, and modern technology is essential for students to fully engage in experiential learning. Institutions must provide the necessary tools and infrastructure to allow students to apply their theoretical knowledge in practical settings. This supports prior findings by Connor et al. (2016), who found that access to mobile STEM centers significantly improved student engagement and performance. Ejiwale (2012) also emphasized that the absence of essential STEM facilities hinders the delivery of effective hands-on instruction, especially in under-resourced settings.

Additionally, the study highlights the indirect effects of faculty expertise on hands-on STEM education through pedagogical approaches (H8a) curriculum design (H8b) and STEM Resources and Facilities (H8C). These mediating relationships suggest that while faculty expertise is crucial, its impact is enhanced when combined with effective pedagogical strategies and well-designed curricula. For instance, the indirect effect of pedagogical approaches on hands-on STEM education, with a path coefficient of 0.064 and a t-value of 2.605, shows that teaching methods act as a bridge between faculty expertise and practical learning outcomes. Similarly, the indirect influence of curriculum design, with a path coefficient of 0.034 and a t-value of 2.047, indicates that faculty expertise shapes the curriculum, which in turn facilitates hands-on learning.

In conclusion, the findings of this study underscore the importance of enhancing faculty expertise, pedagogical approaches, curriculum design, and resources and facilities to improve hands-on STEM education. By investing in these areas, higher education institutions can create more engaging and effective learning environments that promote student success in STEM fields. These insights provide valuable guidance for educators and policymakers aiming to develop stronger, more practical STEM education programs. Future research should expand the scope of this study to other regions in Somalia to gain a more comprehensive understanding of the factors influencing hands-on STEM education.

6 Conclusion

The primary objective of this study was to examine the impact of Faculty Expertise and Training, Pedagogical Approaches, STEM Curriculum Design, and Resources and Facilities on the implementation of Hands-On STEM Education inside higher education institutions in Mogadishu, Somalia. The study's findings revealed that Faculty Expertise and Training, Pedagogical Approaches, STEM Curriculum Design, and Resources and Facilities are significant factors that predict the implementation of effective Hands-On STEM Education at higher education institutions in Mogadishu, Somalia. The findings align with previous studies, suggesting that these four factors hold significant predictive value for Hands-On STEM Education in higher education institutions in Mogadishu, Somalia. Therefore, the relational model produced and endorsed by PLS analysis is open to additional exploration using alternative constructs. The study was only done at Mogadishu Higher Education, which may restrict the generalizability of our findings.

Further investigation in various geographical areas is necessary to confirm the reliability of our findings, as different places may produce disparate outcomes. Furthermore, our research specifically examined a predetermined set of criteria, and it is essential to acknowledge that other variables or contextual factors may influence the implementation of effective Hands-On STEM Education in higher education institutions in Mogadishu, Somalia. Subsequent investigations ought to incorporate a more comprehensive array of variables and contexts. Future research should include broader variables, such as socio-political influences and resource allocation mechanisms, to provide more comprehensive insights.

Despite being geographically limited, the findings of this study have broader relevance for other post-conflict or resource-constrained countries that face similar challenges in delivering effective STEM education. The identified factors—such as faculty expertise, curriculum design, and access to resources—are common constraints in fragile or rebuilding education systems. Therefore, the strategies and insights provided in this study may be transferable to institutions operating in similar environments, offering a valuable framework for improving STEM education globally. Moreover, this research contributes to the comparative education literature by providing empirical evidence from an underrepresented region, enhancing our understanding of how hands-on STEM education can be scaled and adapted across diverse educational contexts.

Several recommendations have been made to improve the quality of effective Hands-On STEM Education within higher education institutions in Mogadishu, Somalia. These recommendations encompass various aspects such as faculty training and professional development, the promotion of student-centered and inquiry-based pedagogical approaches, the alignment of the STEM curriculum with industry demands, the allocation of resources and facilities, the cultivation of collaborations and partnerships, the implementation of rigorous assessment strategies, and the on-going evaluation and enhancement of hands-on initiatives based on feedback.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants or participants legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

AA: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing. MO: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing. AM: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing. AO: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing. CA: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing.

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Supplementary material

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