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AN INVESTIGATION INTO THE COGNITIVE DIMENSIONS OF STEM EDUCATION COMPETENCIES AND THEIR IMPACT ON LIFELONG LEARNING

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Abstract
The global attention on strengthening scientific literacy for 21st century personnel development in developing countries, including Nigeria, demands in-depth studies on the cognitive and theoretical influence of STEM competencies and lifelong learning. Therefore, this study, based on social cognitive career theory, sought to explore the competencies developed in STEM pursuits and how STEM competencies support lifelong learning. The study is a descriptive survey was conducted with a sample of 400 senior secondary school students from both private and public secondary schools. The questionnaire items (instrument) used were duly validated, and the test of reliability yielded an index of 0.84. The data obtained were analyzed using descriptive statistics at a 3.00 benchmark, a t-test analytical tool at a 0.05 level of significance, and a 95% level of confidence. The descriptive, criterion-referenced, and inferential statistical approach adopted within this study provides a valid and transparent basis for the replicability of the research. Findings revealed that STEM education competencies significantly predict lifelong learning; lifelong learning in STEM can be encouraged through online resources, extracurricular programs, workshops and future-oriented discussions. Findings of this study underscore the need for educational stakeholders to embrace hands-on, real-world STEM pedagogical structures by providing adequate teaching materials and laboratory facilities with technological resources to foster STEM competencies for lifelong learning in schools, and implications of these findings for relevant educational practices, policies and stakeholders were discussed.
Keywords: STEM competences, lifelong learning, students, pedagogy, STEM, science instruction, learning

Introduction
Education in the 21st century has undergone rapid transformations due to increased globalization, technological advancements, and the growing demand for flexible and lifelong learning (Muhammadjonova, & Akhmedova, 2025) Education parameters are growing fast in pace with the scientific and technological advancement in the 21st century, which is characterized by witty inventions in every sector, with scientific breakthroughs in areas such as genetic sequencing, new

insight into cost-effective and more efficient solar and wind power energy organizations. Within this context, technological advancements have witnessed the development of scientific interfaces augmenting virtual realities, rapid interconnectedness, mobile technology transforming the manner and nature of communication, access to information, and bringing about globalization (Muhammadjonova, & Akhmedova, 2025). On account of the foregoing, Science Technology, Engineering and Mathematics (STEM) education is rapidly and massive evolving to build STEM competencies and cultivate higher order thinking skills that emphasizes metacognition, integrative problem-solving critical thinking and creativity to effectively empower individuals navigate or tackle the rapidly changing workspace and remain adaptive with the capacity for lifelong learning. The STEM competencies are so built because education is far more than the mere impartation or acquisition of knowledge; it develops critical thinking, imagination, and the ability to respond to new information and situations throughout an individual's lifetime, the crux of lifelong learning (Dumbuya, 2025). The concept of lifelong learning involves a continuous form of knowledge acquisition, knowledge renewal, and swift application of the skills and knowledge gained throughout a lifespan. This is solely determined by cognitive dispositions nurtured throughout early childhood education systems and sustained in style through the ranks in educational attainments and learning experiences. The demands of competence required in quality STEM education, such as critical thinking and understanding cognitive learning, are essential for enhancing the design of modern instruction and pushing the boundaries of global contexts in, nurturing learners' willingness and readiness to continuously engage in lifelong learning and continuous professional development. Despite the increasing awareness and promotion sponsored for enhancing STEM instructions, classroom settings devoted to STEM competencies and contributed to lifelong learning remain underexplored. Therefore, this study attempts to investigate cognitive dimensions of STEM education competencies as it influences lifelong learning.

Research Questions

What are the competencies developed in my STEM pursuit?
Do STEM competencies predict lifelong learning?

Theoretical Framework

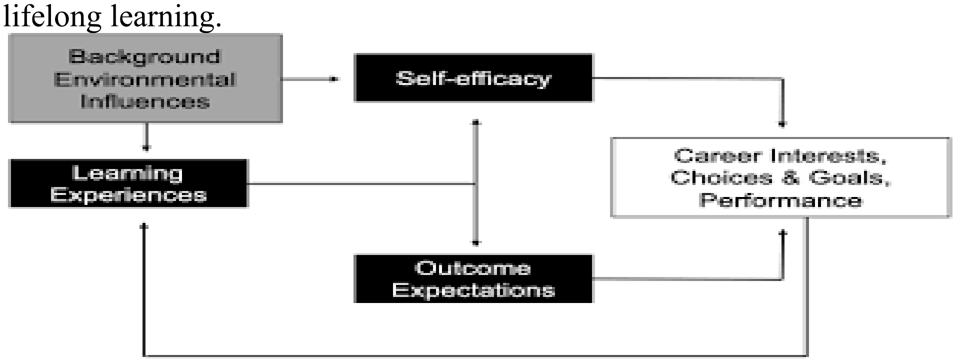
Social Cognitive Career Theory (SCCT)

The Social Cognitive Career Theory (SCCT), developed by Lent, Brown, and Hackett (2002), provides a robust lens for understanding the complex array of factors that shape students' career choices, particularly in the domain of STEM (Science, Technology, Engineering, and Mathematics) careers. Central to SCCT is the interaction between personal cognitive variables such as self-efficacy beliefs, outcome expectations, personal goals and social-environmental influences, including support or barriers originating from family, school, and societal expectations. This theoretical model has particular resonance in the African context, where both individual and contextual factors intertwine to inform students' career aspirations and choices.

In Nigerian educational settings, SCCT has been a guiding framework both explicitly and implicitly. For instance, Onyishi and Sefotho (2021) adopted SCCT constructs by measuring self-efficacy, perceptions, and social influences as predictors of STEM career interests among students with disabilities, revealing that higher self-efficacy levels corresponded to greater interest in STEM careers but were also moderated by negative perceptions and limited social expectations.

This finding demonstrates the applicability of SCCT in accounting for the career development of students uniquely positioned at the intersection of disability and marginalization.
In a broader sense, international studies have reinforced SCCT's relevance, suggesting the theory's capacity to explain cross-cultural variations in STEM career interest. Kaleva et al. (2023) used SCCT to highlight how sources of career information and mathematics self-efficacy significantly affect students' STEM interests. Such insights affirm the adaptability of SCCT to the Nigerian context, particularly where parental and teacher support assume prominent roles. Although much of the Nigerian literature does not always label the use of SCCT explicitly, the theory's components are evident in numerous discussions and analyses about the interplay of internal motivation, external supports, and outcome expectations in determining African secondary school students' STEM intentions (Iroaganachi et al., 2021; Opeke et al., 2020). The theory's value is underscored by its ability to integrate ecology and individual agency. In intense communal cultures, the role of social persuasion by parents, teachers, and role models may carry more influence over students' outcome expectations and personal goals than in individualistic societies. This is illustrated by repeated findings that teacher encouragement, exposure to female STEM professionals, and engagement with science clubs all correlate with higher intention to pursue STEM, critical components captured in the SCCT framework (Iloakasia, 2024; Iroaganachi et al., 2021; Opeke et al., 2020).

Applying SCCT thus not only enhances understanding of why students pursue or eschew STEM fields but also clarifies the roles that communities, institutions, and interventions play in mitigating barriers, ranging from gender stereotypes to socioeconomic hardship, within the decision-making process. The framework of SCCT highlights that learning occurs through an interplay of internal motivation from STEM learning experiences and external motivation. Fig 1illustrates how the BioRxiv model was used to explain perceptions on how, through the learner's background, internal motivation boosts STEM competence and can easily influence learners' career choices and goals, including lifelong learning.



Source: Musgrove , et.al 2021 (BioRxiv)

Literature Review

The development of education systems around the world is mirroring the change, with most countries shifting focus towards fostering a shift in mindset to growth and creating self-directed learning skills for lifelong learning and engagement in the knowledge economy (Ramamonjisoa, 2024). Perhaps the most apparent characteristic of this transformation in education is the prioritization of STEM education, an integrated system of Science, Technology, Engineering, and Mathematics. STEM education has been a global phenomenon as it has the ability to empower students with the potential to acquire the analytical, technological, and problem-solving capabilities required for innovation and economic development (Bybee, 2010; Marginson et al., 2013). STEM education is more than occupational and technical education; it is a strategic pillar of national development, economic competitiveness, personal empowerment, and lifelong learning in the 21st century (Kennedy & Odell, 2014). Lifelong learning is ongoing, self-directed learning for personal or career purposes. It encompasses formal learning, non-formal learning (e.g., workshops and community courses), and informal learning (e.g., on-the-job training, self-teaching, or distance education). The process of enhancing the knowledge, skills, and unique competencies of individuals in civic, social, and workplace settings is attributed to certain dimensions of STEM Competencies and learning, which continues throughout life from the cradle to the grave (Swain-Oropeza et al., 2023). However, components of STEM competencies, such as value-motivational, operational activities, and reflexive analytical and cognitive dimensions, are necessarily shaped through competencies and thoughtful approaches in the classroom (Yang et al, 2025). Moreover, the connectivity between these skills and approaches is potent in educational transformation in favour of lifelong learning (Nikulova & Bobrova, 2021) The twenty-first century competencies in STEM education can be promoted by focusing on career choices, STEM literacy, and components of design-based learning. However, interventions such as self-regulated learning and problem-based learning are effective in developing lifelong learning in students. (Halawa, Lin, & Hsu, 2024; Van Den Broeck *et al* 2024)

Countries such as the United States of America, Finland, South Korea, and Singapore have made significant investments in STEM education through the inclusion of inquiry-based learning, technology integration, and real-world applications in their curricula (OECD, 2019). Countries have shown that STEM attainment is closely linked with national productivity, employment, and innovation. In Africa, particularly in Nigeria, the need to embrace a STEM-based model of education is increasingly recognized. Nigeria, being a youth-intensive nation with an emerging economy, is at a point where STEM education can be a driver of development, innovation, and poverty alleviation (Penprase, 2020). However, the reality of STEM education in Nigeria is plagued by several obstacles. These are resource-poor schools, pedagogic materials shortages, poorly trained teachers, antiquated curricula, and wide inequalities in accessing quality education, particularly across the rural and urban areas (Okeke, 2017; Onwu & Otuka, 2014). Through this study, we hope to close a knowledge gap in literature and provide more insight into STEM competencies as they impact lifelong learning by investigating the competencies developed in STEM pursuits and the impact of STEM competencies as they predict lifelong learning.

Methodology

The study adopted a descriptive survey, which was deemed appropriate for examining perceptions of participants without manipulating variables. This design is most preferred in diagnostic STEM education research to profile competencies and orientations. The population for the research included students of science in private and public secondary school in Osun state. This study adopted a simple random sampling technique, four (4) public and sixteen (16) private secondary schools were randomly selected among the secondary school in Osun state as respondents for this study. A total of 20 students were randomly selected from the 16 private secondary schools, while 20 students were randomly selected from the 4 public secondary school. Therefore, 400 students were altogether selected, which constituted the sample size of the study.

The research data were gathered using a researcher-designed questionnaire comprising items measuring key dimensions of STEM competencies, including lifelong learning orientation, communication skills, problem-solving ability, innovations, and contextual support for STEM engagement. Questionnaire items to elicit responses were constructed and rated on a four-point likert scale ranging from strongly agree to strongly disagreement. The questionnaire was sub-divided into four sections. Section A was designed to elicit demographic information, section B items measured key dimensions of STEM competencies. Section C measured lifelong learning orientation, communication skills, problem-solving ability, and section D items measured innovations, and contextual support for STEM engagement.

The data gathered was aggregated in nature and was therefore analysed using item mean scores, rank-order and t-test inferential analysis. A criterion-referenced evaluation approach was employed to determine the level of STEM competence as reflected by each of the items. Thus, a criterion mean of 3.00 was adopted as the benchmark for interpretation, and mean scores equal to or above this threshold were interpreted as indicating high levels of STEM competency, while mean scores below the benchmark were considered moderate. The relative prominence of each competency indicator was also identified with the aid of the rank-order analysis. This analytical approach is consistent with established practice in educational needs assessment and competency profiling studies, particularly where the objective is to identify strengths and areas for improvement rather than to establish causal relationships.

Results

Table 1: Demographic representations of the data

Variable	Category	Frequency (n)	Percentage (%)
Age (years)	16	98	24.5
	17	122	30.5
	18	180	45.0
	Total	**400**	**100.0**
Gender	Male	167	41.8
	Female	233	58.2
	Total	**400**	**100.0**
Ethnic Group	Igbo	58	14.5
	Yoruba	326	81.5
	Hausa	16	4.0
	Total	**400**	**100.0**
School Ownership Type*	Public	4	20.0
	Private	16	80.0
	Total	**20**	**100.0**

The demographic characteristics of the respondents are presented in Table 1. The age distribution reflects that majority of the participants were 18 years (45%), followed by the (30.5%) and 16 years (24.5%) age groups. This means that the sample drawn was mainly from senior secondary school students. The gender spread of the gathered data constituted a larger percentage of female students (58.2%); while male students were (41.8%).

Stem Education Competencies

Table 2: Rank-Order Competency Indicators

Rank	Competency Indicator	Mean	Interpretation
1	Continuous learning in STEM	3.32	High
2	Communicating complex STEM ideas	3.31	High
3	STEM supports self-development	3.22	High
4	STEM problem-solving	3.20	High
5	STEM as lifelong journey	3.18	High
6	Parental expectation of application	3.15	High
7	Innovation & creativity	3.14	High
8	Staying updated in STEM	3.12	High
9	Parental encouragement	3.00	Threshold
10	Workshop participation	2.90	Moderate

Table 2 shows the ranked mean scores of the respondents' perception of STEM competencies. Rank-Order STEM competency indicators. Majorly, the assessed competencies were recorded mean values of 3.00 or above, which serves as the benchmark. Though the perceived competencies were generally serious and popular among the sampled population. The highest ranked item was ability of learners to see learning in STEM as a career pathway (M=3.32), ranked next was the ability to navigate scientific communication and communicate complex scientific ideas (M=3.31) the rank of these items as very high indicate that the participants demonstrate a strong orientation of learners to foster sustained engagement in stem fields and a coherent perception towards STEM as an ongoing and lucrative career pathway. Similarly, items relating to the development of the notion in learners, that adequate knowledge of STEM improves problem-solving capacity, (M=3.20). and staying updated with STEM developments, the acquisition of skills for novel initiatives to generate scientific innovation, and favour lifelong learning in science, also exceeded the benchmark and the items ranked moderately high, suggesting that co-textual reinforcement of STEM knowledge may be less internalized. However, findings also reveal that experiential exposure to scientific knowledge through participation in workshops and parental support (M=2.90) ranked very low, by providing comparatively lower mean values, which may point to comparatively weaker experiential and external mechanisms for STEM engagements.

Stem Education Competencies and Lifelong Learning

Table 3: One sample t-test Analysis on STEM competencies as it Predicts Lifelong Learning

Test Value = 2.5	T	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference
STEM_Total	17.11	399	0.000	0.65	0.58 – 0.72

In a bid to determine the relationship between STEM competencies and lifelong learning, one sample T-test was conducted to determine if students significantly agreed that STEM competencies nurtures lifelong learning and the overall mean score (M = 3.15, SD = 0.76) was significantly higher than the test value of 2.50, $t(399) = 17.11$, $p < .05$. the results revealed that STEM competencies generally is important to determining lifelong learning competencies such as problem-solving skill acquisition, ability to communicate scientific ideas, innovations and continuous self-development. However, individual items were considered and their contribution as to predicting lifelong learning are presented on the ensuing tables.

Discussion

The findings of this study reveal that STEM competencies generally encourage lifelong learning through specific learning orientations that involve hands-on experiments and real-world scenarios within learning structures. Policymakers across the three tiers of learning institutions are encouraged to integrate real-world applications and translational research that foster industry partnerships and research impact. Effort should also be geared towards incorporating competency-based, community-based STEM initiatives, such as the inclusion of content in favour of during curriculum development to institute and sustain STEM competency development. Furthermore, findings from this study underscore the need for STEM education stakeholders to complement strong lifelong learning with practical classes, and the criterion-referenced approach provided a valid and transparent competence profile. Also, it was well demonstrated that lifelong learning in STEM is driven primarily by competencies hidden in inherent qualities such as continuous learning, problem-solving, and effective communication. This discovery aligns with educational frameworks that emphasize reflective practice (Ng *et al,* 2022; Thwe & Kálmán, 2023), knowledge transfer, and adaptability, all core elements of lifelong learning. Some STEM competencies are moderately associated, such as parental support and participation in workshops, conferences, and in-service training, exposing the existing gap between intrinsic motivation for lifelong learning and access to experiential opportunities, which may be connected to the need for intervention programmes to encourage mentorship and informal learning opportunities, suggesting that this can invigorate a holistic development to bring about lifelong competencies.

Conclusion

Summarily, these results give a pointer to cognitive, attitudinal, and STEM competencies that are innovation-oriented and can form the basis for lifelong learning engagement, while contextual and experiential supports complement these core abilities. These findings have curricula implications for curriculum developers, educational policy makers, and scheduling program development aimed at sustaining STEM students' engagement and building a STEM workforce in support of nation-building. Further studies may build on this work by incorporating multivariate analyses to investigate how STEM competencies affect lifelong learning.

Recommendations

Therefore, it was recommended based on findings from this study that STEM curricula should be developed to lay emphasis on continuous learning, career progression and also give a list of opportunities in STEM fields so that learners can appreciate the long-term career nature of STEM. Similarly, hands-on learning experiences such as laboratory practicals, innovation projects, field work and inquiry-based learning that foster STEM competencies should be integrated into TSEM instruction.

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