Bridging the Academia-Secondary School Gap: Promoting STEM Education Through University-Community Engagement Initiatives in Tanzania

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Abstract

This study examined the University-Community Engagement (UCE) initiatives employed by the University of Dar es Salaam (UDSM) to promote STEM education in Tanzanian secondary schools. Using a qualitative case study design, data were collected through semi-structured interviews with 27 purposively selected participants, including district education officers, secondary school heads, science and mathematics teachers, school board members, and university lecturers. Documentary analysis of institutional policies, strategic plans, and outreach programme guidelines complemented the interview data. The findings revealed five key UCE initiatives: teacher capacity-building in improvisation and innovative pedagogy; student mentorship programmes; student-teacher co-teaching initiatives; research collaborations; and teaching and learning resource support. The findings demonstrate that while these initiatives enhance teaching quality, motivate students, and improve resource access, particularly in underserved areas, their long-term impact is constrained by limited funding, fragmented coordination, weak policy frameworks, and inconsistent stakeholder collaboration. The findings highlight the need for stronger institutional coordination and balanced collaboration among academia, government, industry, and communities to sustain university–community engagement in STEM.

Keywords: *university-community engagement, STEM education, teacher capacity building, quadruple helix model, secondary schools, Tanzania*

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1. Introduction

Education is a fundamental pillar of socioeconomic development, fostering knowledge acquisition and skills development that are essential for holistic

societal progress. Globally, universities play a crucial role in advancing education through teaching, research, and consultation, in addition to fostering active engagement with communities, a recent additional core function. The latter function, known as University-Community Engagement (UCE), represents a collaborative approach that allows higher education institutions to work with communities to address local challenges, including those in the education sector (Málovics et al., 2022). Indeed, UCE is increasingly serving as a means of bridging the gap between academia and society by ensuring that universities contribute directly to solving real-world problems through varied means, including promoting Science, Technology, Engineering, and Mathematics (STEM) at different levels of education.

Despite national policy commitments to strengthen STEM education in Tanzania, secondary schools continue to face critical challenges. These include shortages of qualified teachers, inadequate laboratory facilities, low student motivation in science subjects, and persistent gender disparities in STEM participation (Matete, 2021; Mgaya, 2024). These challenges at the secondary level directly affect higher education institutions, including the University of Dar es Salaam (UDSM), which depend on a steady flow of adequately prepared STEM students. The problem, therefore, is twofold: secondary schools struggle to deliver quality STEM education, and universities lack empirical evidence on how their community engagement initiatives can effectively address these foundational gaps.

In the global context, STEM education has become a key driver of technological and economic development. STEM refers to an integrated and interdisciplinary approach to education that focuses on science, technology, engineering, and mathematics—fields essential to solving complex problems in today's world (McDonald, 2016). Through UCE initiatives, universities in developed countries have established structured partnerships with schools, governments, and non-governmental organisations to enhance the quality and accessibility of education, including mentorship programmes, curriculum updates, and access to advanced scientific resources (Harkavy et al., 2015; Freeman, 2024). The African higher education landscape has increasingly embraced UCE as a mechanism to address educational challenges, particularly in STEM fields. Universities across the continent have initiated projects focusing on teacher training, curriculum development, and the promotion of science and technology (Wabike, 2023). However, UCE in Africa remains less structured than in developed contexts, often operating through informal partnerships with limited policy guidance (Harkavy et al., 2015). Challenges such as inadequate funding, weak institutional frameworks, and limited community participation hinder the full realisation of UCE's potential across the continent.

In Tanzania, the University of Dar es Salaam (UDSM), the University of Dodoma (UDOM), and Sokoine University of Agriculture (SUA)—all public institutions—have initiated UCE programmes to bolster the quality of education. These programmes include teacher capacity-building initiatives, school outreach programmes, and educational policy research (Nanyazi, 2023). At UDSM specifically, UCE has been increasingly embraced as a strategic approach to addressing educational challenges. UDSM has implemented various UCE initiatives to strengthen STEM education in secondary schools, including teacher professional development programmes, mentorship and student science camps, collaborative research with schools, and community-based STEM outreach activities (Mmbando, 2025). The university also partners with government agencies, schools, and non-governmental organisations to enhance science education through the provision of laboratory equipment, the development of localised STEM curricula, and training workshops that equip educators with modern pedagogical skills.

While previous studies have examined university-community partnerships in Tanzania (cf. Mtawa & Wangenge-Ouma, 2022; Nanyazi, 2023), they have tended to focus on broad conceptualisations of engagement or on private-good dimensions of university outreach. What remains underexplored is a systematic examination of the specific UCE initiatives universities employ to promote STEM education, their effectiveness in addressing key challenges, and the sustainability mechanisms that underpin them. For instance, Mtawa and Wangenge-Ouma (2022) question the private-good-driven nature of university-community engagement but do not specify the types of engagement initiatives or their impact on STEM education outcomes. Similarly, Kafyulilo (2013) highlights professional development through teacher collaboration, yet does not address how universities engage with the broader community to tackle STEM learning challenges. This gap is particularly significant given the urgent need to strengthen the STEM connection from secondary to higher education. This study, therefore, sought to answer two overarching research questions: *What UCE initiatives does UDSM employ to promote STEM education in Tanzanian secondary schools?* And, *in what ways are these UCE initiatives effective in addressing key challenges in STEM education, including teaching quality, student participation, and resource availability?* By addressing these questions, the study aims to generate empirical insights that can inform more effective collaboration among universities, schools, government, and other stakeholders in improving STEM education outcomes. The focus on UDSM is particularly appropriate given its strategic commitment to outreach and its long history of engagement with schools and communities.

2. Literature Review and Theoretical Framework

2.1 Conceptualising University-Community Engagement

University-Community Engagement (UCE) has been conceptualised differently across global contexts, reflecting varied historical, social, and institutional circumstances. In Europe, UCE is broadly understood as a civic responsibility of higher education institutions, rooted in principles of knowledge democratisation and social accountability. European universities have embraced models such as engaged scholarship, service-learning, and science shops, which provide platforms for collaborative research between academics and communities (Compare, 2023). These approaches emphasise knowledge co-creation, mutual benefit, and long-term partnerships. The European University Association encourages universities to institutionalise engagement through policy frameworks and strategic plans, highlighting UCE's role in addressing societal challenges, including educational inequality and scientific literacy (Samaržija, 2023).

In South Africa, UCE is shaped by the country's historical and sociopolitical context, functioning both as a university function and as a constitutional imperative to redress past injustices and promote social transformation (Wabike, 2023). South African universities implement UCE through community-based research, participatory outreach, and integrated service-learning models to empower marginalised groups. For example, initiatives in rural STEM education link universities with under-resourced schools to improve learning outcomes through mobile laboratories and teacher training (Dube & Mojapelo, 2017). These engagements are conceptualised as transformative practices that reconnect universities with local realities while enhancing students' critical consciousness.

A critical comparison of these conceptualisations reveals important differences. European approaches tend to emphasise institutionalisation and policy frameworks, reflecting well-resourced higher education systems with established engagement infrastructure. South African approaches, by contrast, are more explicitly political and transformative, grounded in the redress of historical inequalities. Both contexts, however, share an emphasis on mutual benefit and knowledge co-creation, key principles that remain unevenly realised in many African contexts, where engagement often remains project-based and donor-dependent.

In Tanzania, UCE is formally recognised as one of the university's core functions, alongside teaching and research. At UDSM, it is institutionally referred to as "public service" or "outreach and consultancy services," coordinated through

various units, centres, and academic departments. This function reflects UDSM's strategic commitment to contributing to national development through knowledge exchange and community partnerships. UCE is operationalised through outreach programmes targeting schools and communities, including capacity-building workshops for teachers, mentorship programmes for students, provision of science kits, and curriculum support to enhance STEM education (UDSM, 2024). However, unlike European and South African contexts, where engagement is often embedded in formal curricula, UCE in Tanzania remains predominantly project-based and reliant on donor funding or institutional grants. This raises critical questions about institutionalisation, long-term impact, and sustainability, which the current study aims to address directly.

2.2 UCE and STEM Education in Africa

Across Africa, universities have increasingly embraced UCE as a means of addressing educational challenges, particularly in STEM fields. Research consistently demonstrates that UCE initiatives enhance academic outcomes, stimulate innovation, and promote socioeconomic empowerment. For instance, Dellelo (2024) highlights that outreach programmes involving mobile laboratories, science camps, and STEM fairs increase students' interest and competence in science subjects across Sub-Saharan Africa. Similarly, Mittal and Bansal (2024) argue that UCE promotes inclusive knowledge dissemination by encouraging collaborative problem-solving in real-world contexts. However, a critical synthesis of this literature reveals several patterns and gaps. First, while many studies document individual initiatives, few provide comparative analysis across different institutional contexts. Second, the literature tends to emphasise successes while underreporting challenges related to the institutionalisation and sustainability of UCE initiatives. Third, there is limited attention to how UCE initiatives address gender disparities in STEM, despite the persistent underrepresentation of girls and women in science disciplines across Africa (Wang & Degol, 2017; Matete, 2021).

In Tanzania, universities including UDSM, the University of Dodoma (UDOM), and Sokoine University of Agriculture (SUA) have implemented projects to equip secondary school teachers with pedagogical and practical skills in STEM disciplines. These initiatives strengthen the foundational pipeline for higher education and national development. However, as Nanyazi (2023) notes, the strengths of these initiatives in addressing STEM education challenges remain largely underexplored. This study addresses this gap by providing systematic empirical evidence on UDSM's UCE initiatives, their effectiveness, and the factors that enable or constrain their impact.

2.3 Linking UCE to School Outcomes

UCE directly influences educational outcomes in schools, particularly in under-resourced settings. By extending academic expertise, mentorship, and material support to schools, universities enhance students' performance, teacher competence, and curriculum relevance. Research indicates that schools involved in structured UCE initiatives demonstrate higher engagement in science-related subjects and improved examination results. Anderson et al. (2022) highlight how sustained university-school partnerships lead to increased teacher efficacy and improved instructional quality, particularly in STEM subjects.

Through collaborative teaching programmes, student mentorship, and research-informed interventions, UCE strengthens the academic ecosystem that supports student learning outcomes. Moreover, UCE fosters a culture of collaboration and shared responsibility for educational development. In Tanzania, where schools frequently experience shortages of teaching aids, laboratories, and experienced teachers, university-led outreach programmes help fill these gaps by providing laboratory equipment, facilitating interactions with university lecturers, and organising science camps. These efforts enhance learning, increase student motivation, and improve academic results (Mittal & Bansal, 2024).

Gender equity represents a critical dimension of UCE's potential contribution to STEM education. Gender disparities in STEM persist globally, with girls significantly underrepresented in science, technology, engineering, and mathematics disciplines (Wang & Degol, 2017). In Tanzania, cultural norms and systemic inequalities intensify these barriers (Matete, 2021). UCE can challenge these imbalances through targeted outreach programmes, mentorship schemes, and science camps that inspire and support girls to engage with STEM subjects. Lee (2021) highlights how gender-responsive pedagogy and community sensitisation efforts have contributed to increased female participation in STEM education in East Africa. This study examines how such gender-focused initiatives are considered.

2.4 The Quadruple Helix Model: Rationale and Adaptation

This study is guided by the Quadruple Helix Model (Carayannis & Campbell, 2009), which conceptualises innovation and knowledge production as emerging from interactions among four key actors: academia, industry, government, and civil society. The model builds on the traditional Triple Helix by adding civil society as a fourth player, recognising that sustainable development requires broader participation to address complex social problems (Leydesdorff & Etzkowitz, 2021; Carayannis & Grigoroudis, 2022).

The Quadruple Helix Model is particularly suitable for analysing UCE in Tanzanian STEM education for three reasons. First, it explicitly recognises civil society—including schools, communities, NGOs, and individuals—as active participants in knowledge production and innovation, rather than passive recipients of university outreach. This aligns with UCE's collaborative ethos and the study's focus on multi-stakeholder engagement. Second, the model draws attention to interactions among all four helices, enabling analysis of how government policies, industry partnerships, and community participation enable or constrain UCE effectiveness. Third, the model's emphasis on sustainability and innovation provides a framework for assessing not only the existence of UCE initiatives but also their long-term viability and impact.

In adapting the model to the Tanzanian context, this study recognises that helix development is often uneven. UDSM may be relatively strong, while government support, industry engagement, and civil society participation may be weaker or inconsistent. The model thus provides a diagnostic tool for identifying gaps and opportunities—examining which helices are active, how they interact, and what this means for UCE sustainability. As the findings will demonstrate, applying the Quadruple Helix Model reveals that while UDSM has developed multiple engagement initiatives, their long-term impact is constrained by weak government policy frameworks, limited industry involvement, and fragmented civil society collaboration.

3. Methods

3.1 Research Design and Approach

This study employed a qualitative research approach to explore participants' experiences, meanings, and practices in their real-life contexts, recognising the complex and socially embedded nature of UCE. A case study design was selected as most appropriate because it enables in-depth examination of a contemporary phenomenon within its real-world context (cf. Yin, 2018). The case of UDSM's UCE initiatives for promoting STEM education was bounded by the institution (UDSM), focused on STEM education, and considered the level of secondary schools (units). While a phenomenological research design could be appropriate for exploring participants' lived experiences, the case study design was deemed more appropriate because the research questions sought to examine not only participants' experiences but also institutional practices, programme implementation, and contextual factors, which are key elements that the case study design is specifically designed to address.

3.2 Sampling and Participant Selection

Participants were selected using purposive sampling, followed by snowball sampling for specific categories. Purposive sampling was initially employed to ensure inclusion of key informants with direct knowledge of UCE initiatives and STEM education in Tanzania. The sample comprised 27 participants: three district education officers (responsible for overseeing secondary education), three secondary school heads (Engaged with UDSM outreach), 12 science and mathematics teachers (direct beneficiaries of UCE initiatives), three school board members (representing community perspectives), and six university lecturers (directly involved in designing and implementing UCE initiatives).

Snowball sampling was subsequently used to identify university lecturers, as they were not easily identifiable. The initial two lecturers, identified by their heads of department as being involved in prior UCE initiatives in schools, were reached out to and later asked to recommend colleagues actively involved in UCE initiatives targeting STEM education. This approach was justified because UCE involvement cuts across departments and faculties, making comprehensive identification through purposive sampling alone impractical. Snowball sampling continued until data saturation was reached, the point at which additional recommendations yielded no new information and interviews no longer generated novel insights (cf. Guest et al., 2020). Thus, saturation was achieved after interviewing six lecturers, with the final three interviews confirming rather than extending emerging themes.

3.3 Data Collection Methods

Data were collected for three months through two primary methods: semi-structured interviews and documentary review. Semi-structured interviews, lasting 45-60 minutes each, were conducted with all 27 participants. The interview protocol was designed explicitly to address the study's two research questions, with more specific questions exploring: types of UCE initiatives participants were involved in or aware of; perceived effectiveness of those initiatives in addressing STEM challenges; factors enabling or constraining initiative success; and suggestions for strengthening UCE. Interviews were conducted in Kiswahili or English, depending on the participant's preference, audio-recorded with consent, and transcribed verbatim. Those conducted in Kiswahili were translated into English during transcription, with back-translation checks to ensure accuracy.

The documentary review complemented the interview data by providing contextual information and triangulating the findings. Documents were purposively selected based on their relevance to UCE and STEM education at

UDSM and nationally. Selection criteria included: official status (institutional or government documents); relevance to UCE or STEM education; coverage of the study period (2015-2024); and accessibility. Analysed documents included: *UDSM's Five-Year Rolling Strategic Action Plan 2020/2021–2024/2025 (Directorate of Research and Publication, 2020), UDSM Guidelines for Outreach Programmes (2024), UDSM Research Policy and Operational Procedures (2015), outreach programme brochures, STEM workshop lecturers' diaries, and relevant government policy documents including the Handbook for Standards and Guidelines for University Education in Tanzania (TCU, 2019), Tanzania Education and Training Policy (Ministry of Education and Vocational Training, 2014), and National Higher Education Policy (Ministry of Education, Science and Technology, 2016)*. Document analysis enhanced triangulation by corroborating interview data, providing historical context, and exposing gaps between policy rhetoric and implementation.

3.4 Data Analysis

Data were analysed using Braun and Clarke's (2006) six-phase inductive thematic analysis. Analysis began with familiarisation through repeated reading of transcripts and documents. Initial codes were generated inductively, capturing features of the data relevant to the research questions. Codes were then grouped into potential themes, which were reviewed and refined through an iterative process of moving between data, codes, and themes. This process was both inductive (themes emerging from the data) and theoretically informed (with attention to Quadruple Helix concepts during later analysis). The final phase involved defining and naming themes, six of which were used to structure the findings section. Rigour was enhanced as the themes were reviewed by the two researchers, one of whom was a senior qualitative research expert, and later shared with an outsider who assessed their coherence and grounding in the data.

3.5 Ethical Considerations

This study adhered to established ethical principles for research. All approvals and research permits were obtained from the University of Dar es Salaam (Reference: UDSM/REC/2024/017). In addition, all participants received detailed information about the study's purpose, procedures, and their rights, including the right to withdraw at any time without consequence. Written informed consent was obtained from all participants prior to data collection. To ensure anonymity, all identifying information was removed from transcripts, and pseudonyms are used in reporting findings. Participants are identified only by their professional roles (e.g., Science Teacher 3, Lecturer 2) to prevent identification while providing contextual information essential for interpretation.

4. Findings

This section presents findings organised around six major themes that emerged from thematic analysis. Each theme corresponds to a specific UCE initiative through which UDSM engages with secondary schools to promote STEM education. Consistent with the study's research questions, findings focus on both the nature of these initiatives and their perceived effectiveness in addressing STEM challenges. Quotations are presented as clearly identifiable, authenticated statements, followed by their respective interpretation.

4.1 Teacher Capacity-Building Through Improvisation Training

Analysis of interview data revealed that a significant barrier to effective STEM education in Tanzanian public secondary schools is the lack of functional science laboratories, which hinders practical instruction. In response, UDSM, through its outreach initiatives, conducts training programmes for science teachers focused on the improvisation and use of locally available materials for science experiments. Teachers who participated in these trainings expressed enthusiasm and noted marked improvements in classroom dynamics. One secondary school science teacher from school B explained:

> Before the training, practicals were a dream in my school. We just explained theories. However, now, I can confidently demonstrate combustion using a charcoal stove and simple materials in one of my Chemistry topics. The students are finally seeing what we have been talking about (Science teacher 2—Chemistry, Secondary school B).

Another teacher reported:

> I never imagined a plastic bottle could replace a test tube in a meaningful way. My chemistry students are more curious nowadays and ask deeper questions since we started using these locally available materials. They even bring materials from home, suggesting experiments we could try and work out (Science teacher 2—Chemistry, Secondary school A).

A third participant noted:

> What impressed me most was that science no longer feels distant, expensive or difficult. The training offered by UDSM science experts helped me realise that with creativity, I can bring science to life, even without a lab. This has transformed how I teach and how my students learn physics (Science teacher 1—Physics, Secondary school A).

Documentary analysis of training manuals and post-training reports confirmed that teachers were trained to use local materials, including plastic bottles, charcoal stoves, glass bottles as test tube substitutes, clay pots for heating, vinegar and baking soda for chemical reactions, and banana stems to demonstrate water absorption and osmosis. These materials are cost-effective and widely accessible in local communities.

The effectiveness of this initiative (teacher capacity-building through improvisation training) lies in its contextual responsiveness. Rather than assuming that only Western-style laboratories are essential for quality science education, the training builds on local resources and teachers' creativity. Students benefit from seeing abstract scientific principles demonstrated with familiar materials, enhancing comprehension and retention. However, as one lecturer noted, the initiative's reach remains limited:

> We train perhaps 50 teachers in secondary schools near the university, whom we reach out to each year, but there are thousands of schools. Without government support to scale this up, we are making a small difference in a very big problem (Lecturer 4, UDSM, outreach coordinator).

4.2 Training on Innovative Pedagogical Approaches

Beyond improvisation, UDSM has contributed to enhancing the quality of STEM education through workshops focused on innovative, learner-centred teaching methods. Teachers reported being introduced to inquiry-based learning, in which students engage with scientific concepts through guided experiments, investigations, and collaborative problem-solving rather than rote memorisation. One science teacher reflected:

> Before the training on innovative pedagogical approaches, my teaching was mostly textbook-based. Now, I use inquiry-based methods to guide my students in asking questions and exploring their ideas. I have seen them become more confident and curious. They don't just memorise formulas. They always want to understand why things work, hence, probing (Science teacher 3—Biology, secondary school C).

Another teacher explained:

> I used to think experiments were only for advanced schools with big labs. However, after learning inquiry-based methods, I realised I can create meaningful science experiences using simple materials and thoughtful questions. My students now design their own simple experiments (Science teacher 2—Chemistry, Secondary school C).

In addition to learning inquiry-based methods, the integration of Information and Communication Technology (ICT) emerged as a central theme in the training. Participants noted an emphasis on utilising digital tools, such as simulations, virtual labs, and online learning platforms, to enhance classroom delivery and address the limitations of conventional resources. One teacher shared:

> The virtual labs blew my mind. My students, too, were surprised and attracted. Even without real chemicals, my students could see reactions and interact with experiments on-screen during UDSM science events. It keeps students engaged, especially those who struggle with theory. Despite limited ICT resources in my school, nowadays I use my smartphone to facilitate some lessons (Science teacher 1—Physics, Secondary school B).

Another added:

> In overcrowded classrooms, ICT has helped me personalise instruction. Students can revisit lessons online or experiment digitally through YouTube on their smartphones. This is particularly helpful for slow learners who need more time. The only problem is when students are not allowed to possess phones (Mathematics teacher, Secondary school A).

A documentary analysis of workshop materials confirmed that the training sessions covered inquiry-based and problem-based learning, as well as the integration of open educational resources. Lecturers' diaries from outreach events noted that teachers consistently rated these sessions as highly valuable, with one diary entry observing: *"Teachers are hungry for these methods. They tell us their students become more engaged when they use what they've learned"*.

The effectiveness of this initiative lies in addressing the gap between traditional teacher-centred approaches and the demands of modern, skills-based STEM education. By equipping teachers with twenty-first-century teaching skills, UDSM contributes to modernising classroom practice. However, as with improvisation training, scale and sustainability remain challenges. Training reaches a fraction of teachers, and without follow-up support, newly acquired skills may not be sustained.

4.3 Mentorship Programmes for Secondary School Students

Mentorship emerged as a crucial UCE component, with UDSM facilitating connections among students, teachers, and experienced professionals to enhance learning, skill development, and career guidance. The mentorship programme involved UDSM lecturers, UDSM students, and alumni providing academic

and professional support to secondary students pursuing STEM careers. One physics teacher described:

> It was the first time I had someone from the university walk into my classroom, not to supervise but to teach with me and reflect on the lesson. The mentorship gave me new ways to explain complex ideas, such as energy transfer, using real-life examples (Science teacher 1—Physics, Secondary school A).

Another teacher highlighted the aspirational value:

> One of the UDSM alumni mentored my Form Five students. They were so inspired hearing from someone who came from a similar background and is now in engineering. It made university feel achievable for them (Mathematics teacher, Secondary school C).

A school head observed the broader impact of the mentorship programmes**:**

> Now I feel part of a bigger professional community. It's not just about teaching what is in the syllabus, but preparing learners for the future with confidence and guidance. The mentorship has changed how our teachers see themselves professionally (School Head 3).

Documentary analysis of outreach programme brochures confirmed that mentorship activities included career talks, subject-specific tutoring, laboratory demonstrations, and university visit days. These activities aimed to demystify university education and STEM careers, particularly for students from disadvantaged backgrounds. Despite these benefits, analysis indicates that mentorship programmes are not yet systematically integrated into UDSM's broader STEM education strategy. One lecturer acknowledged:

> We do mentorship when we have time, funding, or someone volunteers. It's not institutionalised. Some departments do a lot, others do nothing. The students who benefit are those whose teachers happen to know someone at UDSM (Lecturer 2, UDSM).

This lack of systematic integration leads to inconsistent access, uneven implementation across departments, and limited long-term impact, contrasting with structured mentorship frameworks in countries like South Africa and Ghana, where university-industry collaborations have demonstrated higher STEM retention and success rates (Albertyn, 2023; Skrzypek et al., 2022).

4.4 University Student-teacher Co-teaching Programme

The university student-teacher co-teaching programme enabled UDSM student-teachers to volunteer in nearby secondary schools facing critical shortages of qualified science teachers. Unlike structured field attachment programmes, this voluntary initiative allowed university students to offer their time and knowledge to support struggling schools. Organised by their university departments, student-teachers assisted in delivering lessons, providing subject-specific tutoring, and supporting extracurricular activities. Teachers in beneficiary secondary schools expressed deep appreciation for the programme. One mathematics teacher explained:

> When the UDSM students came, it felt like a burden had been lifted. We were only two staff members in the science department. Their help in teaching and running practical sessions changed everything. We could finally give students individual attention (Mathematics teacher, Secondary school A).

Another teacher added:

> The UDSM student-volunteers were well-prepared. They connected easily with our students and employed creative methods to explain complex topics such as algebra. You could see the students gaining confidence week after week. This has made our work easy (Mathematics teacher, Secondary school B).

One head of school elaborated on the broader impact of the university student-teacher co-teaching programme:

> They did not just come to teach. They organised science clubs, prepared extra classes before national exams, and even mentored some of our students about university life. Our students started staying after school to study together, though the programme did not last long (School Head 2).

A documentary analysis of outreach reports confirmed that the participating student-teachers were drawn from the College of Natural and Applied Sciences (CONAS). They received orientation before they went to the identified schools, but without formal compensation, though some schools provided transport and meals when it was within their financial capability. Through their voluntary efforts, university students helped improve the delivery of education while gaining valuable teaching experience, leadership skills, and a deeper understanding of the challenges facing secondary school education. One teacher summarised:

> It is a win-win situation. Our students learn, and the university students grow into passionate, experienced educators. Some of them have told me this experience confirmed their calling to teach (Science teacher 3—Biology, Secondary school A).

However, some challenges still threaten the programme's sustainability. One university lecturer involved in coordination noted:

> We rely entirely on student-teachers' goodwill. There is no budget, no formal recognition, no transport support. Many students cannot afford to volunteer regularly because they need to earn money. Some schools are too far for them to reach. We need institutional support to sustain this (Lecturer 1, UDSM).

Documentary analysis revealed that no formal policy framework governs the programme; it operates informally through individual lecturer-student networks. This lack of institutionalisation, combined with reliance on volunteer labour and absence of transport or stipend support, limits scalability and long-term viability.

4.5 Research Collaboration

Research collaboration between UDSM and schools emerged as another UCE dimension fostering knowledge co-creation to address educational challenges. UDSM lecturers collaborate with schools and teachers to conduct research identifying problems in quality education and proposing evidence-based solutions. Though few teachers were involved, on a few occasions, those collaborations contributed to improved curriculum implementation, teaching methodology, students' academic performance, and educational policy recommendations. Teachers expressed the value of being involved in such research activities. A school head shared:

> When UDSM experts involved us in data collection and discussions on how to implement the curriculum, it felt like our voices finally mattered. We helped shape the research by sharing our practical on-the-ground experience, and we also learned from it. Now, other teachers and I use those findings to adjust how we approach science lessons (School Head 1, also a Science teacher, School A).

Another teacher reflected:

> It was the first time I had been part of a research project. The university researchers did not just study us; they worked with us. That partnership gave us confidence and better knowledge for teaching. They shared the findings

> with us in simple language, and the improvement in our teaching is quite significant (Science teacher 3—Biology, Secondary school C).

One science teacher highlighted the practical orientation:

> Through collaboration with a researcher from UDMS, we were able to present real classroom issues, such as overcrowding and a lack of labs, and the researcher listened. It was a change from a top-down approach to understanding our realities, though no changes were seen (Science teacher 1—Physics, Secondary school B).

Documentary analysis of research policy documents confirmed that UDSM's strategic plan emphasises community-engaged research. However, lecturers noted that promotion and reward systems still prioritise traditional academic publications over engaged scholarship, while research funds for collaborative research were limited.

4.6 *Teaching and Learning* Resource Support to Schools

Teaching and learning resource support represents a related UCE initiative. Interviews revealed that UDSM provided textbooks, laboratory equipment, and science kits to secondary schools, particularly in underserved schools. A Biology teacher explained:

> Before the university stepped in to support us by providing lab kits, our students had never seen a proper lab kit. Now they perform Biology experiments themselves, not just read about them. The difference in their understanding is dramatic (Science teacher 3—Biology, Secondary school A).

Another teacher noted:

> The textbooks we received have made a huge difference. I used to teach Form Three chemistry, using photocopied notes and outdated ones. Now we have books that align with the syllabus (Science teacher 1—Physics, Secondary school A).

However, interview data from heads of schools and university lecturers revealed significant inequities in the distribution of teaching and learning resources. Urban schools, those with existing university connections, and those near the UDSM campus received substantially more support than peripheral schools.

A lecturer acknowledged this challenge:

> We try to reach schools, but the facilities are limited, and, of course, we mainly offer the resources we no longer need in our departments. So often,

> we work with schools where we already have contacts because it's easier. But this means the most disadvantaged may not benefit (Lecturer 6, UDSM).

This uneven distribution raises critical questions about equity and the university's mission to serve all communities, not only those already advantaged. It also highlights the need for stronger collaboration with government and civil society to ensure equitable resource distribution.

5. Discussion

This study examined UCE initiatives implemented by UDSM to promote STEM education in Tanzanian secondary schools. It assessed their effectiveness in addressing key challenges that could affect the quality of secondary education. Applying the Quadruple Helix Model as an analytical lens, this section interprets findings in relation to existing literature and draws out theoretical and practical implications:

5.1 Interpreting Findings Through the Quadruple Helix Model

The Quadruple Helix Model posits that sustainable innovation and knowledge production emerge from interactions among academia, industry, government, and civil society (Carayannis & Campbell, 2009). Applying this model to UDSM's UCE initiatives reveals important patterns about helix development and interaction. The academia (UDSM) emerged as the most active helix in engaging secondary schools within the larger community. The university initiated multiple engagement programmes, including teacher training, mentorship, co-teaching, research collaboration, and the provision of teaching and learning resources. All these demonstrate institutional commitment to community engagement as a core function. This aligns with UDSM's strategic documents, which formally recognise outreach as a university responsibility (UDSM, 2024). The university's role as a knowledge creator and disseminator is evident across all six themes, from training teachers in improvisation to conducting collaborative research with schools.

However, the other three helices are notably weaker and less engaged. Government involvement appears limited and inconsistent. While national policies articulate commitment to STEM education (Ministry of Education and Vocational Training, 2014; Ministry of Education, Science and Technology, 2016), they provide little specific guidance or funding for university-school partnerships. Teachers and lecturers repeatedly mentioned the lack of government support for scaling up successful initiatives, integrating them into national programmes, or providing sustainable funding. This policy-implementation gap constrained the reach and sustainability of the UCE initiatives.

Industry engagement is even more limited. No initiative described in the findings involved a substantive industry partnership. A teaching and learning resource support and scholarship programme for qualified STEM students could require corporate sponsorship, in collaboration with the university and donors. Mentorship programmes also did not systematically involve industry professionals. This absence is significant, as the industry could provide funding, equipment, expertise, and authentic career pathways for students. Thus, the Quadruple Helix Model's emphasis on industry-academia collaboration for innovation remains largely unrealised in this context.

Civil society, on the other hand, including schools, communities, and individuals, participated in UCE initiatives but primarily as beneficiaries rather than co-creators. Schools received training, resources, and mentorship, and individual teachers attend workshops. However, they were not systematically involved in the design, implementation, or evaluation of the initiatives. In this case, community knowledge/experiences and priorities do not consistently and adequately shape university programmes. This represents a missed opportunity, as research emphasises that sustainable engagement requires genuine partnership and mutual knowledge exchange (Mittal & Bansal, 2024; Wabike, 2023).

The model thus reveals uneven helix development: strong academia, weak government and industry, and passive civil society participation. This misalignment has important implications. First, it explains the sustainability challenges evident across all themes—initiatives dependent on a single helix (academia) are vulnerable to funding cuts, staff changes, and shifting institutional priorities. Second, it limits sustainability, as government policy support and industry resources are needed to expand successful programmes. Third, it constrains innovation, as diverse perspectives and resources across multiple helices typically yield more creative, contextually appropriate solutions.

5.2 UCE Effectiveness in Addressing STEM Challenges

Despite the revealed structural limitations, the findings demonstrate that UCE initiatives were quite effective in addressing key STEM challenges in several ways. First, UCE initiatives directly addressed the resource gap that constrained practical science teaching. Improvisation training enabled teachers to conduct experiments without fully equipped laboratories, while resource provision supplied textbooks, kits, and digital materials. These interventions address the material realities of Tanzanian schools, where traditional laboratory infrastructure is often absent or under-equipped. The effectiveness of improvisation training, in particular, lies in its contextual responsiveness, building on local resources rather than lamenting their absence. This finding extends research

on contextualised science education in resource-limited settings (cf. Dube & Mojapelo, 2017; Dellelo, 2024).

Second, UDSM UCE initiatives address the teaching quality gap by building capacity and introducing innovative pedagogies. Inquiry-based learning, ICT integration, and learner-centred approaches equipped teachers with twenty-first-century teaching skills that enhance student engagement and comprehension. The finding that teachers report increased student curiosity and confidence after applying these methods aligns with research demonstrating that pedagogical innovations tend to improve STEM outcomes (Anderson et al., 2022; Singh et al., 2024).

Third, UDSM UCE initiatives addressed the motivation and aspiration gap through mentorship and scholarships. Secondary school students exposed to university mentors and successful alumni developed a clearer understanding of STEM career pathways and increased motivation to pursue them. These findings align with other research findings on the aspirational effects of university-school partnerships (Sithole et al., 2017; Mwangi et al., 2024).

Overall, however, the effectiveness of the UCE initiatives in addressing key challenges in STEM education, including teaching quality, student outcomes, and resource availability, is uneven and conditional. Schools with existing university connections benefit disproportionately. Urban and nearby schools receive more resources, while students whose teachers happened to know UDSM staff accessed mentorship. This unevenness reflects the absence of systematic, policy-driven approaches to UCE right from the university level, and it raises equity concerns that the university's mission to serve all communities must address.

5.3 Reflection and Critical Analysis of the Emerged Contradictions

Several contradictions emerged from the findings, warranting researchers' reflection and critical analysis. First, there is a contradiction between institutional commitment and the reality of implementation. UDSM's strategic documents formally recognise outreach as a core function (UDSM, 2024), yet on the ground, initiatives operate informally, depend on individual lecturers, and lack sustainable funding. This gap between policy rhetoric and practice reflects broader patterns in African higher education, where engagement is often acknowledged but under-resourced (Mtawa & Wangenge-Ouma, 2022; Nanyazi, 2023).

Second, there is a contradiction between strong teacher feedback and weak

sustainability mechanisms. Teachers consistently report that UCE initiatives transform their practice and benefit their students. However, these same teachers describe initiatives as one-off events without follow-up, scaling, or institutionalisation. This suggests that while UCE generates genuine value, that value is not systematically built upon or sustained.

Third, there is a contradiction between equity rhetoric and uneven impact. UCE initiatives aim to serve underserved communities, yet resource distribution favours already-advantaged schools. This reflects what Mtawa and Wangenge-Ouma (2022) identify as *private good-driven* engagement, where outreach benefits those already connected to the university rather than those most in need.

All the aforementioned contradictions point to deeper structural issues. Dependence on university support, the absence of government policy frameworks for UCE or a clear implementation modality, limited industry engagement, and weak civil society partnerships all constrain effectiveness. Without addressing these structural constraints, even well-designed UCE initiatives will remain limited in reach and sustainability.

5.4 Theoretical Contributions

This study makes two theoretical contributions to the literature on UCE and STEM education.

First, it extends the *Quadruple Helix Model* by demonstrating its utility as a diagnostic framework for analysing UCE in resource-constrained contexts. The model is typically used to describe ideal-type innovation systems. This study shows that applying it critically to identify which helices are active, how they interact, and where gaps exist, reveals structural constraints that might otherwise remain invisible. The finding that uneven helix development (strong academia, weak government and industry, passive civil society) undermines sustainability and scalability provides a framework for understanding why UCE initiatives often fail to achieve long-term impact.

Second, the study contributes to the empirical literature on UCE in Africa by providing detailed, context-specific evidence of how one university operationalises community engagement for STEM education. While previous research had examined the UCE conceptually (Wabike, 2023) or critiqued its private-good dimensions (Mtawa & Wangenge-Ouma, 2022), few studies have documented specific initiatives, their perceived effectiveness, and the factors enabling or constraining them. This study addresses that gap, offering evidence that can inform both theory and practice.

6. Conclusion and Recommendations

This study examined UCE initiatives employed by UDSM to promote STEM education in Tanzanian secondary schools and assessed their effectiveness in addressing key challenges. The findings revealed that UDSM has developed multiple engagement initiatives, including teacher capacity-building, mentorship, co-teaching, research collaboration, and resource provision that demonstrably enhance teaching quality, motivate students, and improve resource access. These initiatives reflect the university's commitment to its third mission and generate genuine value for participating schools and teachers. However, applying the Quadruple Helix Model as an analytical lens revealed significant structural constraints. While academia (UDSM) was active, government engagement was limited and inconsistent, industry involvement was virtually absent, and civil society participation remained passive and beneficiary-oriented. This uneven helix development explains the sustainability challenges evident across all initiatives, including the absence of policy frameworks, limited scalability, and inequitable distribution of benefits. The study's empirical contribution is thus to provide detailed, context-specific evidence of UCE operationalisation in a Tanzanian university, evidence that can inform both institutional strategy and national policy.

Based on the findings, the following policy recommendations are addressed to specific stakeholders: For the UDSM leadership, a formal, institutionalised UCE policy framework that moves beyond ad hoc, project-based initiatives toward systematic, sustainable programmes with dedicated budgets, staffing, and monitoring mechanisms could be put in place. Furthermore, an equity-focused resource distribution plan that prioritises underserved schools and addresses the current pattern of urban and connected-school advantage could be developed. For the government, particularly the Ministry of Education, Science and Technology, a national policy framework for university-community engagement could be introduced that provides guidance, standards, and funding mechanisms specifically for UCE initiatives targeting STEM education at the secondary level. At the same time, establish matching grant programmes that incentivise universities to partner with industry and civil society in expanding successful UCE initiatives.

7. Limitations and Future Research

This study encountered several limitations that suggest directions for future research. First, as a single-case study of UDSM, findings may not be transferable to other Tanzanian or African universities with different institutional histories, resources, and engagement approaches. Comparative studies across multiple

universities would illuminate how institutional factors shape UCE effectiveness. Second, the study relied primarily on participant perceptions of effectiveness rather than direct measurement of student learning outcomes, examination performance, or STEM career progression. Future research employing longitudinal designs and outcome measures would strengthen evidence on UCE impact. Fourth, while the study identified gender as a relevant dimension, it did not systematically examine how UCE initiatives address gender disparities in STEM. Future research specifically focused on gender and UCE would address this gap. Despite these limitations, this study provides robust evidence that UCE initiatives can meaningfully contribute to STEM education in Tanzanian secondary schools, and that realising their full potential requires addressing structural constraints through systematic, multi-stakeholder collaboration of the kind the Quadruple Helix Model envisions.

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