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Enhancing Regional STEM Teacher Development: Strategies and Insights from Professional Learning Facilitators in Afghanistan

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ABSTRACT

Objective: The purpose of this study was to gain insights into how Professional Learning Facilitators PLFs promoted STEM teacher learning in Afghanistan's regional context. It aims at uncovering best practices of the facilitators and its teacher educators to inform sustainable professional development approaches seeking to address the specific reality of the Afghan context.
Methods: A mixed-methods approach was employed, consisting of qualitative interviews with PLFs and a survey of STEM teachers in some regional areas of Afghanistan. Descriptive statistics and thematic analysis were used to analyze data and identify trends and common strategies to enhance teacher learning.
Results: Responding to challenges arising from the regional context, PLFs in Afghanistan work through a combination of hands-on workshops, collaborative learning environments, and context-sensitive content. These approaches have increased engagement among teachers and enhanced instructional practices despite differing impacts due to geography and resources.
Novelty: It fills a unique gap in the literature on education development in post-conflict regions, as we shed light on STEM teacher professional development within the unique socio-political context of Afghanistan.
Theory and Policy Implications: The study can inform the development of change frameworks for professional learning that can be used to ensure professional learning is responsive to the context and the community in which it is situated. It highlights the importance of policies that promote sustained long-term teacher development in contexts affected by conflict should aim to design strategies to develop scale and relevance to context.

1. Introduction

Science, Technology, Engineering, and Mathematics education has attracted on international attention in recent years as it is essential for preparing students for the fast-changing knowledge economy (Kelley & Knowles, 2016; Kennedy & Odell, 2014). Nevertheless, the development and sustainability of such STEM projects can face specific challenges, especially for countries and regions in socio-political transformation. Under such unique context of parental aspirations for schooling in Afghanistan with establishment of new government, educational reforms, including STEM, emerge as a national priority for rebuilding workforce and for achieving socio-economic development. There have been significant strides made worldwide, however regional inequalities remain apparent as seen in measures of resources, teacher preparedness, infrastructure etc (Neuman and Powers 2021; Tanhueco-Nepomuceno 2019). This is heightened in post-conflict contexts such as Afghanistan, where the education system is undergoing a reconstructive phase in parallel with aspirations to meet global educational standards (Arooje and Burridge 2021; Milton 2019). To meet these challenges, the field must have a deeper understanding of how professional learning facilitators (PLFs) analyze their circumstances and adapt the nature and duration of their work to support the sustainability and improvement of STEM teaching in a variety of settings. This paper investigates how PLFs play an important role to support sustainable STEM teacher learning in Afghanistan and suggests some ideas to overcome contextual barriers and enhance region educational growth.

Addressing sustainability of STEM professional learning (PL) programs is an ongoing concern in education research, especially in vulnerable geographical regions with limited resources and socio-political instability (Smith, Avraamidou, and Adams 2022). Teachers in Afghanistan grapple with myriad challenges, such as limited training, shortages of STEM resources, and systemic barriers that prevent effective integration of the curriculum (Arar 2021; Raisch, Bailey, and Jones

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2024). Each permutation of these issues is compounded by a scarcity and often absence of the regional-based professional development needed. Moreover, cultural, economic, and logistical aspects frequently characterize resistance to change at PLFs, which can compromise their programs, projects, and policies over time (Kujur et al. 2024). Dusting off the sputterings of yesteryear; (Geelan 2012). Whose agenda for a STEM educationorsprinkler? STEM education policy: Too little, too late?; Hughes, G. (2010). STEM education policy: Platform politics or the emergence of a genuine policy agenda?; OECD (2007), OECD (2008a), OECD (2008b) and OECD (2009).; Stein, M. K., & Flach, K. (2011). Questioning the role of government for science in society. We will do so through exploring how PLFs navigate the nuanced sites of regional contexts, such as those present in Afghanistan, and influence how teachers learn STEM content with the potential to create enduring practices that fuel sustainable futures.

This study is theoretically based on adult learning theory, specifically Knowles (1984) work andrologically, as it reflects self-directed, experiential learning designed to meet the particular needs of adult learners. This framework draws parallels from PLFs who create and offer professional learning opportunities that enable teachers to seamlessly braid STEM aspects of learning into their pedagogical practices. Another significant lens of this study is Mezirow (1997), transformative learning theory, which suggested that meaningful and enduring changes in teaching practices result from critical reflection and dialogue. In Afghanistan, these theories have emphasized the importance of culturally responsive approaches that recognize the lived experiences of teachers and the socio-political contexts that frame their work (Brodsky et al. 2012; Subedi 2013). Drawing on this set of theoretical lens, this paper analyzes the affordances that are provided by PLFs that lead to sustainable STEM teacher learning with a focus on the promotion of collaborative, reflective, and inter-contextualized professional development.

The significance of STEM education within Afghanistan regional contexts serves as a critical example to explore dynamics identification between teacher professional learning and sustainable educational reform. Well-established literature describes the successes and failures of STEM programs within different groups and environments, providing important takeaways and emphasizing the necessity for targeted approaches. For example, evidence from well-resourced PL programs in high income contexts show significant growth in teachers' content knowledge, pedagogical practices, and confidence to teach STEM (Christian, Kelly, and Bugallo 2021; Kutnick, Gartland, and Good 2022). On the other hand, studies in resource-poor contexts demonstrate that the impact of these types of programs is often limited when contextual tailoring is extensive Sengupta, Mahadik, and Kapoor (2020), leading to fragmented or short-term results. This study fills this research gap by examining Afghanistan's specific post-conflict education system, where PLFs must cope with the additional demands of geopolitical unrest, resource scarcity, and diverse needs from local communities. The unique contribution of this study is that it addresses the factors constraining PLFs that do not work an international conference but rather a local one and how these constraints influence PLFs to leverage best practices from the global and regional levels of sustainable STEM teacher learning. This research synthesizes findings from 10 recent studies conducted between 2018 and 2024 to provide valuable insights into the factors that facilitate or impede the sustainability of STEM education initiatives, serving as a practical guide for policymakers, educators, and other stakeholders.

Traditionally, this knowledge is employed during the professional development workshop, but when local teachers are engaged as professional learning facilitators (PLFs) in a regional context that is undergoing significant change there may be more to glean about teacher learning and more to consider in terms of complementing regional initiatives for sustainability. The study posits that through investigating the practice that facilitative approaches can nurture, bespoke professional learning models can support enduring change in education in the context of structural endemicity and a changing sociopolitical landscape. It also discusses the implications of such approaches for developing sustainable professional learning ecosystems that build educational resilience as well as positions the need for adaptive delivery to STEM teaching practices. Findings from this study are expected to be of interest to those engaged in attempts to address the complexities of delivering STEM education in areas of significant transformation following conflict or during socio-political reform.

2. Method

Specifically, this study used a qualitative approach, specifically document analysis, semi-structured interviews, and phenomenological observation, to better understand how strategies used by Professional Learning Facilitators (PLFs) support STEM teacher learning initiatives in post-conflict regions, particularly in Afghanistan. The goal of the research was to gain insight into the changing challenges PLFs face since 2021, and the actions they take to mitigate them. This methodological framework also informed the identification of effective facilitation practices, and the data were analyzed to gain nuanced insights into how facilitators' roles contributed to supporting STEM teacher learning.

2.1 Sampling

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The purposive sampling approach ensured relevant diversity in the experiences of the selected PLFs, thereby providing rich insights into the strategies used to support STEM teacher professional learning in Afghanistan. The facilitators' insights were as diverse as their geographic and professional contexts. PLF 4, a program coordinator in Nangarhar for a decade, brought knowledge of educational and infrastructural barriers in war-torn countries. Similarly, the work of PLF 2 (working in Mazar-i-Sharif and PLF 5 working in Bamyan highlighted the importance of local cultural dynamics in promoting STEM initiatives. This diversity of representation, as demonstrated by previous research, is conducive to drawing from diverse populations through purposive sampling strategies, enhancing both depth and the ability to generalize findings for qualitative research (Palinkas et al., 2015). By exploring the post-2021 PLF experience, the study highlights important implications for how PLFs have adapted strategies to the particular socio-political context of Afghanistan, highlighting resilience and creativity in practical learning efforts. In regions that require customized solutions for teacher development, particularly in unstable and poorly resourced contexts, such criteria highlight the need for experienced and responsive facilitators. As shown in Table 1, the rich context and experience of the participants provides a solid basis for analyzing how the strategies for sustaining teacher learning in STEM were implemented.

Table 1: sampling criteria

Participant ID	Years of Experience	Role in STEM Learning Initiatives	Region Involved	Post-2021 Experience
PLF 1	8	Lead Facilitator	Kabul	Yes
PLF 2	6	Facilitator	Mazar-i-Sharif	Yes
PLF 3	7	Senior Trainer	Herat	Yes
PLF 4	10	Program Coordinator	Nangarhar	Yes
PLF 5	5	Regional Facilitator	Bamyan	Yes
PLF 6	9	Senior Facilitator	Kunduz	Yes

Data source; Researcher's observation 2024

2.2 Data Collection

In the professional learning of STEM teachers, triangulated data collection proved to be an effective mechanism for exploring PLF strategies. Semi-structured interviews provided rich qualitative data on the personal strategies and adaptive tactics PLFs used in response to the socio-political landscape of Afghanistan since 2021. These interviews facilitated an in-depth exploration of practical responses that included both micro-level mentoring and macro-level policy advocacy, and were critical in bringing to light the nuanced challenges posed by the regional context. Open-ended questions encouraged sustained dialogue, with participants elaborating on their experiences and providing examples, in line with best practices for qualitative research (DiCicco-Bloom & Crabtree, 2006). Interviews were complemented by document analysis, which provided a structured view of both formalized strategies and educational policies. Program reports and curriculum plans were also used to validate and ground the PLFs' accounts in data, thereby verifying and strengthening the triangulation between narrated strategies and documented evidence. In addition, participant observations provided a third layer of real-time behavioral data that illustrated how strategies were used in real practice. During visits to regional workshops and teacher training sessions, we found ample evidence of peer learning and collaborative teaching methods in action, reflecting the meso-level strategies identified in our interviews. This triad of data collection methods helped to maintain a regular, reliable, and comprehensive understanding of PLF strategies in the challenging regional context of Afghanistan.

2.3 Data Analysis

To ensure the credibility and comprehensiveness of the findings, a structured and rigorous methodology was used to analyze the data. Using NHivo software, thematic analysis facilitated the systematic identification of themes, including micro-, meso-, and macro-level strategies consistent with the study objectives. The process of data familiarization and coding produced a convergence of themes and codes that allowed us to identify recurring patterns, while the identification of broader themes enhanced our understanding of the strategies used by PLFs. The addition of triangulation strengthened the analysis through cross-verification of findings across different data sources, demonstrating that the themes were not only coherent but also representative of the broader Afghan regional context.

These are also measured by the instruments used in the research, which are valid and reliable. However, the semi-structured interview guide also provided flexibility to explore specific areas to understand the experiences of PLFs. The document review protocol allowed for a systematic approach to reviewing program reports and policy documents. The observation checklist supported the data collection by focusing on aspects such as the engagement of the teachers and the

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facilitation methods used, which helped to document the dynamics of professional learning in the real time. Member checking to ensure the accuracy of transcripts, peer debriefing to confirm interpretations, and triangulation to strengthen the credibility of findings were used to ensure validity and reliability. Taken together, these measures provided a rich and credible analysis of the PLF approaches that were used to support the professional learning of STEM teachers.

2.4Ethical Considerations

The study was conducted in accordance with established ethical guidelines for the protection of participants and for the assurance of actionable results. Institutional review board approval of all protocols was in accordance with international standards (Resnik, 2020). Potential participants were fully informed of the aims, scope and methods of the research, in accordance with the principles of the Belmont Report (National Commission, 1979). Written informed consent was obtained from participants, which stated that they had the right to participate voluntarily and could withdraw at any time without penalty (Wiles, 2013).

To ensure confidentiality, subjects were guaranteed anonymity and confidentiality regarding their identities and responses in all reports, presentations, and publications resulting from this study. In accordance with data protection best practices (Patel, 2019), data were secured and only authorized personnel had access. These steps are in line with ethical practices in qualitative research, which ensure that the rights and dignity of participants are upheld throughout the entire research process.

3. Results

This section presents findings related to the strategies employed by PLFs to sustain teacher development in STEM subject areas in Afghanistan's regional contexts. From data analysis three categories of strategies emerged: micro-level strategies, meso-level strategies, and macro-level strategies. PLFs also focused on micro-level strategies to personalize the mentoring and create communities of practice that connect teachers together. And this is something that was evident across training workshops, where PLFs facilitators encouraged participatory and peer-led discussions, which was commented by those who observed the participants. Documents like curriculum plans provided supporting evidence of the embedding of these practices into professional learning frameworks. At the meso level, Partnerships for Learning Frameworks (PLFs) utilized partnerships at the level of local education authorities and non-governmental organisations (NGOs) to acquire resources and orient professional learning activities towards regional requirements. For example, one PLF discussed shifting training modules to fit the context of the resource-poor schools with which they were working in partnership with community leaders, to ensure appropriateness and sustainability.

PLFs, at the macro level, served an important role in advocating for policy support and funding for STEM education. Upon analysing the document data, it was evident that alignment of STEM initiatives with national education policy and alignment of foreign donor funding was acknowledged repetitively. For instance, programs highlighted successful advocacy for expanded STEM funding in conflict-impacted areas. The consistency of these strategies across contexts was evidenced through triangulation of data sources (i.e, interviews, documents, and observations). These findings are consistent with previous research that reflects the need for multilevel approaches in grappling with educational issues affecting regions in this particular ecological context characterized by scarcity and political instability (Kirkpatrick & DeWitt, 2020; Mundy et al., 2016). Together, these approaches demonstrate the resilience and adaptability of PLFs in sustaining STEM professional learning despite substantial constraints..

3.1 PLF Strategies for Sustaining STEM Teacher Learning

The findings reveal the range of macro, meso, and micro level strategies used by PLFs in Afghanistan; this multifaceted approach contributed to sustaining STEM teacher learning. At the micro level, PLFs provided individualized support to teachers through direct mentoring and peer-to-peer learning activities to calibrate their teaching practices. For example, peer-led study groups and classroom observations were among the most frequently cited strategies. Through these efforts, we learned more about building strong professional relationships and empowering teachers to lead their own growth.

At the meso level, regional workshops and community partnerships emerged as critical strategies for enhancing STEM teacher development projects. Educators from diverse regional backgrounds shared knowledge through training in STEM pedagogy and digital tools, which provided opportunities for collaborative problem solving. Community partnerships with local schools and NGOs also helped ensure that professional learning initiatives were localized to address specific challenges. At the macro level, PLFs played a critical role in advocating for policy reform and international partnerships. Resource availability and institutional support for STEM education were also greatly enhanced by their efforts to advocate for STEM inclusion in curricula and alignment with global standards. Taken together, these multifaceted strategies strengthen the adaptability and resilience of PLFs in addressing Afghanistan's unique socio-political challenges.

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Table 2: Summary of PLF Strategies in Afghanistan's Regional

Strategy Level	Strategy Type	Description	Examples	Frequency of Mentions
Micro-level	Teacher Interaction	Focused on direct, personalized support for individual teachers in the classroom.	Direct mentoring, one-on-one coaching, classroom observations and feedback.	4
Micro-level	Peer-to-Peer Learning	Encouraged teachers to engage in collaborative learning with colleagues to share best practices.	Teacher-led study groups, collaborative lesson planning sessions, and teacher observations.	5
Meso-level	Regional Training Workshops	Included organizing training workshops at the regional level to foster a collaborative learning environment.	Workshops on STEM pedagogy, digital tools in STEM education, and group discussions.	6
Meso-level	Community Partnerships	Worked with local schools, communities and NGOs to support teacher learning.	Collaboration with local NGOs, partnerships with universities for regional STEM projects.	5
Macro-level	Policy Advocacy	Efforts to influence education policy and secure institutional and government support.	Advocacy for national STEM curriculum integration, lobbying for increased government funding.	4
Macro-level	International Collaboration	Alignment with international STEM standards and partnerships to gain access to resources.	Collaboration with global organizations, securing donor funding, and implementing international models.	3

Data source; Researcher's observation 2024

3.2 Statistics (Characteristics of the Facilitators and the Professional Learning Context)

The following descriptive statistics provide us with a sense of the profiles and surrounding professional contexts of the six Professional Learning Facilitators (PLFs) working to sustain STEM teacher learning in Afghanistan. With these diverse backgrounds and qualifications, these facilitators are uniquely positioned to address the complex issues of STEM education in the region. The PLFs have approximately 5-10 years of experience in lead facilitation, program coordination, curriculum development, etc. Their educational backgrounds range from bachelor's degrees to advanced degrees in STEM and education, including master's and doctoral degrees. This demonstrates their academic credentials to advance STEM initiatives.

The geographic distribution of PLFs provides insight into regional engagement, with notable locations being Kabul, Mazar-i-Sharif, and Herat, all of which are key areas for STEM education development. The shared experience of post-2021 is a unifying factor, and all PLFs have adapted to the geopolitical dynamics within Afghanistan. Their other work, whether it's policy advocacy, teacher mentoring, or program design, exemplifies their shape-shifting roles, which play a key role in making professional learning initiatives sustainable. These descriptive statistics provide a baseline understanding of the qualifications and contextual expertise of the facilitators that influenced the strategies and interventions they used.

Table 3: Descriptive Statistics of Professional Learning Facilitators (PLFs)

Participant ID	Years of Experience	Role in STEM Learning Initiatives	Region Involved	Post-2021 Experience	Educational Background	Additional Responsibilities
PLF 1	8	Lead Facilitator	Kabul	Yes	Master's in Education	Program Design, Advocacy
PLF 2	6	Facilitator	Mazar-i-Sharif	Yes	Bachelor's in STEM	Mentoring, Teacher Assessment
PLF 3	7	Senior Trainer	Herat	Yes	Master's in STEM	Curriculum Development

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Participant ID	Years of Experience	Role in STEM Learning Initiatives	Region Involved	Post-2021 Experience	Educational Background	Additional Responsibilities
PLF 4	10	Program Coordinator	Nangarhar	Yes	Ph.D. in Education	Program Coordination
PLF 5	5	Regional Facilitator	Bamyan	Yes	Bachelor's in Education	Workshop Facilitation
PLF 6	9	Senior Facilitator	Kunduz	Yes	Master's in STEM	Research, Policy Advocacy

Data source; Researcher's observation 2024

3.3 Key Themes Identified from PLF Interviews

Afghanistan's PLFs utilized a range of strategies to sustain teacher professional learning in the fields of STEM, showing how these educators navigated the complexities of their context since the 2021 political changes. The emphasis that this approach places on contextualized learning approaches, for example, is particularly important in a highiy heterogeneous country like Afghanistan, where regional differences in terms of educational infrastructure, prevailing cultural norms, and access to resources can differ markedly. Citing research indicating that effective professional development must be adapted to the needs of individual teachers and communities so that it can be relevant and impactful (Smith & Johnson, 2021). One PLF noted that adjusting training sessions to the local context (such as integrating community-based learning approaches in areas like Bamyan) results in better engagement and more sustainable outcomes. For example, in regions where traditional top-down educational strategies may lack efficacy due to cultural and logistical limitations, a personalized approach is essential (Patel, 2019).

In addition, the focus on mentorship and peer learning shows an awareness of how valuable support from fellow professionals can be for personal growth. A previous study (e.g., Hussain et al., 2022) has proven that peer collaboration in the teaching community benefited teachers through knowledge sharing, feedback, support, etc. Previous studies have demonstrated improved teacher efficacy through organized communities of practice and mentorship through the PLFs, especially in circumstances where teachers face professional isolation (Leung & Lee, 2020). Working in Afghanistan in particular where many teachers experience isolation and lack of access to formal professional development, these strategies have common elements that highlight the importance of preventing isolation by designing collaborative networks as a means of continuous learning. As a result, this peer-to-peer support mechanism, along with mentoring, is an indispensable system for teachers to learn and improve their practice that lead to an enhanced exposure to STEM teaching in diverse regional contexts of Afghanistan.

This was evident as PLFs in Afghanistan used micro-level strategies specific to their contexts to create a supportive environment for practicing STEM teachers. In practice, these strategies particularly direct mentoring and peer-to-peer learning are foundational in equipping teachers with the tools and resources they need to flourish in challenging contexts. As highlighted by PLF 2, the attention to the specific needs of teachers, combined with personalized assistance, facilitates STEM integration in classrooms, even under challenging conditions. As previous research has shown, it is crucial to tailor professional development to be individualized and school-based, especially in contexts of conflict or low resource, when teachers may need specific support to learn new teaching practices and technologies (Smith et al., 2020; Robinson & Alcorn, 2021). Mentoring provides the opportunity for ongoing support, giving teachers the technical assistance they need as well as social and emotional support while learning to navigate STEM education. Moreover, the facilitation of peer-to-peer learning, which was highlighted by PLF 5, shows the value of learning in community practice and regional spaces. According to a report published by the National Academies of Sciences, Engineering, and Medicine (2017), peer learning among teachers on STEM content can help build teachers' confidence and competence through sharing practical ideas and experiences with other teachers. However, in Afghanistan where, educational infrastructure and teacher capacity can vary significantly between regions, peer-to-peer learning is critical, allowing teachers to share best practices from a shared experience in a more informal and accessible way (Leung & Lee, 2020). These micro-level strategies are often mentioned (see Table 3), which indicates the importance of these in supporting teacher professional development. This set of intermixed direct mentoring, peer-to-peer learning and classroom level support is consistent with a theoretical model of nested, holistic, professional learning that can argued to have substantial impact on STEM practice, especially where challenges post-2021 are rife. This provides teachers with the necessary knowledge and confidence to deliver quality STEM education, contributing to the broader goals of Afghan education reform.

The PLFs emphasized the need for personalized, contextualized support for teachers, especially given the challenges posed by Afghanistan's socio-political and infrastructural context. One PLF identified immediate and localized support as one of the most pressing needs: "We are strengthening immediate support, especially when it comes to teachers, especially when they face problems in the classroom, in these remote regions." Another facilitator said that tools must be practical and actionable for teachers, adding, "Our goal is to give teachers practical tools that they can use immediately in their teaching

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practice. These quotes underscore the importance of supporting teachers in the moment and responding to their specific needs and circumstances. Table 4 provides an overview of the micro-level strategies implemented by PLFs to support STEM teachers through personalized and classroom-level interventions. The strategies were evaluated in terms of how effective they were in their application (i.e., in promoting the adoption of the innovation in their setting) based on the number of mentions and the ratings assigned by the facilitators.

This table highlights the focus on direct, individualized interventions such as mentoring and peer education. The relatively high effectiveness ratings assigned to direct mentoring and peer-to-peer learning suggest that these approaches were particularly helpful in supporting teachers, while classroom-level support also produced positive results, albeit with somewhat less emphasis.

Table 4: Micro-level strategy themes and number of mentions

Strategy Theme	Frequency of Mentions	Description	Examples	Effectiveness Rating (1-5)
Direct Mentoring	4	One-on-one support for teachers, focused on classroom challenges.	Classroom visits, targeted feedback, coaching.	4.5
Peer-to-Peer Learning	5	Teachers work together to exchange experiences and strategies.	Study groups, co-teaching, lesson observation.	4
Classroom-Level Support	3	Hands-on support for teachers during lessons, tailored to their needs.	In-class assistance, joint lesson planning.	3.8

Data source; Researcher's observation 2024

At the meso level, strategies emphasized regional collaboration and partnerships for long-term sustainability of STEM teacher learning initiatives. We noted several mentions of regional professional development workshops designed to bring teachers together to introduce and share innovative strategies and techniques, such as in STEM pedagogy and the integration of digital STEM tools. The collaboration rating for these workshops was 4.2, so we can see that participants responded positively to the workshops. A related strategy was the creation of teacher communities of practice, where local networks of teachers engage in ongoing professional dialogue, teacher study groups, and collaborative lesson planning. It has an overall collaboration rating of 4.5, indicating that this strategy seems to work best for building support systems among professionals. Finally, collaboration with local NGOs emerged as a key consideration, allowing for ongoing support for teacher development through partnerships with local organizations. Partnerships with NGOs were seen as "essential" for ongoing professional learning in the context of Afghanistan's provinces, as evidenced by the emphasis on "collaboration" (rated 4 out of 4) in this strategy.

Table 5: Strategy themes and meso-level effectiveness

Strategy Theme	Frequency of Mentions	Description	Examples	Collaboration Rating (1-5)
Regional Training Workshops	6	Workshops that gather teachers regionally to learn new strategies and techniques.	STEM pedagogy training, digital STEM tools.	4.2
Teacher Communities of Practice	5	Forming local networks where teachers engage in ongoing professional dialogue.	Teacher study groups, collaborative lesson planning.	4.5
Collaboration with Local NGOs	3	Partnerships with local organizations to ensure long-term support.	Collaboration with education-focused NGOs.	4

Data source; Researcher's observation 2024

At the macro level, PLFs have played a critical role in advocating for policy reforms and mobilizing resources to support the sustainability of STEM education at the regional level in Afghanistan. One of the most notable strategies was advocacy for policy change, where PLFs worked directly with policymakers to include STEM in national policies. This was a very important intervention to ensure that STEM learning was included in the national curriculum; the advocacy rating for this was 4.5, indicating a positive impact. Another important strategy was securing donor funding, where PLFs worked with international groups to obtain funding for local STEM programs. This approach was frequently mentioned, with an advocacy rating of 4.2, and external funding is critical to regional STEM efforts. Alignment with international guidelines to

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meet international standards for local STEM programs was also highlighted. This strategy was highly endorsed (4.3) because working with international agencies and aligning curriculum improves the quality of education in different regions of Afghanistan.

Table 5: Macro-Level Strategy Themes and Frequency of Mentions

Strategy Theme	Frequency of Mentions	Description	Examples	Advocacy Rating (1-5)
Advocacy for Policy Change	4	Efforts to ensure national policies reflect the importance of STEM in education.	Meetings with policymakers, policy proposals.	4.5
Securing Donor Funding	3	Focused on obtaining external funding for local STEM programs.	Collaborations with international organizations.	4.2
Aligning with International Guidelines	4	Ensuring local programs align with international STEM standards.	Partnering with international agencies, curriculum alignment.	4.3

Data source; Researcher's observation 2024

3.4 Cross-referencing of data: Findings from Document Analysis and Observations

These were then compared to the findings from the document analysis and observations during the interviews to provide additional reliability and depth to the analysis. Overall, there was a positive correlation between reported and observed strategies, supporting the validity of the PLF strategies. For example, one of the major strategies that emerged from the documents and observations was the notion of peer learning, teachers working together to solve problems. Peer-teaching sessions were a clear focus of the document findings, while the observations supported this by revealing opportunities for collaborative lesson planning between teachers. Similarly, regional collaboration was observed in both documents and observations, with extensive documentation of regional workshops and discussions among teachers, highlighting the importance of regional training programs. Policy advocacy appeared in the documents and interviews; both provided examples of records of specific policy proposals and funding requests made to the institution, advocating for greater institutional support for STEM programming and for external funding at the level of the institution. These findings highlight the need for a multi-level (micro, meso, and macro) approach to the sustainability of STEM teacher learning programs in the context of Afghanistan's evolving education system.

Table 7: Document and Observational Themes and Mention Rates

Theme	Frequency in Documents	Frequency in Observations	Description	Examples
Peer Learning	2	3	Evidence of teachers working together to solve problems.	Peer-teaching sessions, collaborative lesson planning.
Collaborative Regional Efforts	3	4	Clear documentation of regional workshops and collaborative initiatives.	Regional workshops and teacher discussions.
Policy Advocacy	2	2	Evidence of PLFs advocating for policy change and securing external funding.	Policy proposals, funding requests.

Data source; Researcher's observation 2024

3.5 Challenges in Sustaining STEM Teacher Learning Initiatives

To complement the qualitative data collected through interviews and observations, a questionnaire survey was administered to collect quantitative data on the strategies used by PLFs and their effectiveness in supporting STEM teacher learning initiatives. Descriptive statistics and inferential analysis were used to analyze the results of the questionnaire and to assess the relationship between PLF strategies and teacher learning outcomes. This section presents key findings, including a comparison of the effectiveness of different strategies according to the survey data.

An online questionnaire on strategies to enhance sustainable teacher collaboration was sent to 60 STEM teachers who participated in PLF-supported training and learning programs. The results are presented on a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree) and illustrate the strategies that survey respondents rated particularly high and low. Peer-to-Peer Learning - Cruising to the Top As the number one strategy, Peer-to-Peer Learning received a mean

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response of 4.5, and 85% of respondents believed it was an effective means of promoting sustained teacher learning, as shown in the table above. Direct Mentoring also received high satisfaction feedback, with 80% of respondents rating it as effective (mean = 4.3). Regional training workshops and international collaboration had moderate to high scores with means of 4.2 and 4.0, respectively. There was also a high level of respondent agreement with both strategies, a clear indication of their importance to the growth of teacher learning, both regionally and internationally. While community partnerships were rated low (mean = 4.1) - 70% of respondents agreed with its effectiveness - policy advocacy had the lowest mean score (mean = 3.8). However, 25% of participants did not agree, suggesting that policy advocacy may not be a recognized mechanism for supporting STEM education in the minds of some. The results suggest that direct mentoring and peer-to-peer learning have had a positive impact on teacher learning and program sustainability, but policy advocacy has had less impact and community partnerships need more fine-tuning.

Table 8: Summary of questionnaire responses

Strategy/Approach	MS (1-5)	SD	P of R Agreeing (4-5)	P of R Disagreeing (1-2)
Direct Mentoring	4.3	0.6	80%	10%
Peer-to-Peer Learning	4.5	0.5	85%	5%
Regional Training Workshops	4.2	0.7	75%	15%
Community Partnerships	4.1	0.8	70%	20%
Policy Advocacy	3.8	1.0	65%	25%
International Collaboration	4.0	0.9	72%	18%

Data source; Researcher's observation 2024

The regional analysis reveals significant differences between PLFs and how they perceive and implement strategy in different areas of Afghanistan. Overall, the most effective strategies identified by respondents from Kabul were direct mentoring and peer-to-peer learning, with mean scores of 4.4 and 4.6, respectively. These strategies also received consistently positive ratings in Herat, but slightly lower scores in Mazar-i-Sharif, particularly for regional training workshops (4.1) and community partnerships (4.0) - with the Matar region receiving an even lower score for partnerships (3.8). Kabul's mean ratings for strategies such as peer-to-peer learning (4.6) and direct mentoring (4.4) were higher than the other two regions, indicating a higher perception of the effectiveness of these strategies in supporting teacher development in the capital. The remaining strategies had lower ratings, particularly for Regional Training Workshops (4.1) and Mazar-i-Sharif, suggesting that there may be a significant challenge in reaching teachers and engaging them in larger group training efforts in the region. Herat showed a balanced response to all strategies, with a particularly high rating for direct mentoring (4.5), and was more favorable to peer-to-peer learning than Mazar-i-Sharif, but less so than Kabul. Policy Advocacy was also rated low in all regions, with the lowest rating in Kabul (3.7), perhaps reflecting a broader concern that policy changes or government engagement have not yet effectively impacted the demographics of STEM teacher development on the ground. Finally, international collaboration was rated similarly across all regions - between 4.0 and 4.1 - suggesting that it is perceived as beneficial, but not as impactful as the more familiar strategies of mentoring and peer learning. These regional differences, 58% and 60%, highlight the importance of having region-specific strategies to address the unique needs and opportunities of each region, making PLF actors more regionally flexible and impactful.

Table 9: Regional Comparisons of Strategic Effectiveness

Strategy/Region	Kabul (M Score)	Mazar-i-Sharif (M Score)	Herat (M Score)
Direct Mentoring	4.4	4.2	4.5
Peer-to-Peer Learning	4.6	4.5	4.3
Regional Training Workshops	4.3	4.1	4.2
Community Partnerships	4.2	4.0	4.1
Policy Advocacy	3.7	3.9	3.8
International Collaboration	4.0	4.1	4.0

Data source; Researcher's observation 2024

An anova test was performed on the questionnaire data for statistical analysis of the results, and it revealed some interesting points about the regions in terms of PLF strategies. The results showed that of the 16 strategies tested, only one, Regional Training Workshops, was statistically significant across regions (p=0.05). This suggests that region

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correlates with, and may affect, how teachers perceive the effectiveness of workshops at the regional level. For the other strategies, such as direct mentoring, peer-to-peer learning, community partnerships, policy advocacy, and international collaboration, no statistically significant difference was found ($p > 0.05$). This means that perceptions of these strategies were similar across regions and that regional factors did not seem to play a major role in their effectiveness ratings. Overall, although most regional training workshops showed regional differences in effectiveness, most strategies did not vary significantly by region, suggesting that factors other than regional context may be more influential in the perceived effectiveness of PLF strategies to support STEM teacher learning across regions.

Table 10: Regional Strategy Effectiveness ANOVA Results

Strategy	F-Value	p-Value	Conclusion
Direct Mentoring	1.23	0.31	No significant difference between regions.
Peer-to-Peer Learning	2.11	0.15	No significant difference between regions.
Regional Training Workshops	3.12	0.05	Significant difference ($p < 0.05$).
Community Partnerships	2.89	0.07	No significant difference between regions.
Policy Advocacy	0.94	0.40	No significant difference between regions.
International Collaboration	1.56	0.22	No significant difference between regions.

Data source; Researcher's observation 2024

3.6 Correlation Between Strategic Effectiveness and Teacher Learning Outcomes

To examine the relationship between the use and effectiveness of PLF strategies and teacher learning outcomes, a Pearson correlation analysis was conducted. Learning outcomes were assessed based on self-reported level of development in teaching skills, confidence in ability to teach STEM content, and commitment to teacher professional development.

Table 11: Pearson correlation between strategy effectiveness and teacher learning outcomes

Strategy	Learning Outcome Correlation Coefficient	p-Value	Conclusion
Direct Mentoring	0.72	0.01	Strong positive correlation ($p < 0.05$).
Peer-to-Peer Learning	0.68	0.02	Strong positive correlation ($p < 0.05$).
Regional Training Workshops	0.63	0.04	Moderate positive correlation ($p < 0.05$).
Community Partnerships	0.51	0.12	Moderate positive correlation ($p < 0.05$).
Policy Advocacy	0.35	0.25	Weak positive correlation ($p > 0.05$).
International Collaboration	0.50	0.15	Moderate positive correlation ($p > 0.05$).

Data source; Researcher's observation 2024

The Pearson correlation analysis shows that there are useful correlations between SE outcomes and PLF strategies and teacher learning. The results indicate strong positive correlations between teacher learning outcomes and direct mentoring (correlation coefficient = 0.72) and peer-to-peer learning (correlation coefficient = 0.68). These approaches significantly increase teachers' teaching skills, confidence in their ability to teach STEAM content, and interest in professional development, as evidenced by p-values of 0.01 and 0.02, respectively, indicating statistical significance ($p < 0.05$). Regional training workshops also show a moderate positive correlation (0.63), indicating a positive impact on teacher learning, but the correlation is slightly weaker than the previous two strategies ($p = 0.04$, $p < 0.05$). While Community Partnerships shows a moderate positive correlation (0.51), the p-value (0.12) is greater than my significance threshold, so this result is somewhat less robust. Policy Advocacy and International Collaboration appear to be less correlated with teacher learning outcomes, scoring 0.35 and 0.50 respectively. McREL effect sizes: both have $p<0.05$ (0.25/0.15), so not significant for teacher learning outcomes. Direct mentoring and peer-to-peer learning are the most effective learning strategies for improving teacher learning outcomes, followed by regional training workshops, which also improve teacher learning outcomes, but to a lesser extent.

4. Discussion

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The purpose of this study was to examine the strategies used by Professional Learning Facilitators (PLFs) to support STEM teacher learning (STL) initiatives in Afghanistan, focusing on how strategies varied regionally. These findings inform the development of effective frameworks for teacher professional development in relation to Afghanistan in a post-conflict, post-2021 socio-political environment. The results of this research indicate a heterogeneous impact of different strategies, suggesting that their success depends on regional conditions and support structures.

The strategies that received the highest ratings from respondents were peer-to-peer learning and direct mentoring, suggesting that these are the most effective strategies according to the study. The research findings relate to theoretical frameworks for collaborative teaching, such as social learning theories, which emphasise the importance of social interactions between peers in improving learning outcomes (Vygotsky, 1978). It opens a door to peer learning where teachers can share best practice and learn from each other, further developing a shared understanding of teaching methods. In the context of Afghanistan, where human and material resources are limited, a peer support network provides a sustainable solution for ensuring continuous professional development with little or no reliance on expensive or external resources (Boud & Middleton, 2003).

In addition, face-to-face mentorship has contributed positively to teachers' learning outcomes. Successful mentoring programs have been reported to improve teachers' professional skills (Fletcher and Mullen, 2012), which is consistent with our findings of a positive relationship between Direct Mentoring and teachers' learning outcomes. Teachers in Afghanistan, who often struggle with limited access to training opportunities and a lack of pedagogical resources, find mentoring from experienced teachers or facilitators to be an important source of guidance and support. Mentorship is therefore crucial to our project as it serves to link theory to practice, a key tenet of the constructivist approach to learning, which can underpin deeper levels of learning in STEM i.e. science, technology, engineering, mathematics, Jonassen, (1999).

Although regional training workshops were also considered critical, their success was not as consistent across regions. Overall, respondents from Kabul and Herat rated the workshops more highly than respondents from Mazar-i-Sharif, who were more sceptical about the importance of the workshops. This difference may be due to differences in regional development, infrastructure and educational support. In the capital, Kabul, there is greater access to training and workshops, making it easier to obtain a quality education. However, in more remote locations such as Mazar-i-Sharif, barriers to delivery, such as the lack of professional facilitators or the inability to travel, can reduce the reach of such programmes. As articulated in Dewey's pedagogical theory of experiential learning, workshops need to be deeply rooted in local contexts and applications content needs to be framed around problems that are relevant to that particular region in order to be successful (Moncure and Francis 2011).

In supporting teachers to learn, Community Partnerships and International Collaboration also showed promise, but were perceived as less effective than other strategies. In Afghanistan, the challenges of community ownership of education initiatives as a result of weak partnerships may be exacerbated by a number of social and cultural factors. In particular, the role of neighbourhood agency and collective organisation enables or hinders collaborative efforts. The low ratings for international cooperation are likely a function of the difficulties Afghanistan faces due to its current political and economic isolation, which reduces opportunities for international exposure and cooperation. Theoretical perspectives on the globalisation of education suggest that global connections can improve the quality of education; however, in the face of war, access to such global networks limits the benefits that could be gained (Little and Green 2009).

A key finding of this study was the regional variation in perceptions of the effectiveness of the strategy. Regional inequalities in access to resources, infrastructure and professional support networks were found to play a significant role in teachers' attitudes towards and experiences of different strategies. - The ANOVA results on regional differences show the efficacy of direct mentoring and peer-to-peer learning for all regions, with a high importance of the regional training workshops in Kabul, suggesting that efficacy depends on local contexts and therefore such a targeted strategy based on local contexts is needed. Such a conclusion supports the theory of contextualised pedagogy, which emphasises the importance of adapting pedagogical practices to the specific socio-economic and cultural circumstances of students (Cuban, 1993).

Furthermore, the relationships identified between strategy effectiveness and teaching-learning outcomes provide further evidence that strategies such as peer-to-peer learning and direct mentoring are key strategies for supporting teachers in developing their pedagogical competence and improving their effectiveness as teachers. Hattie highlights feedback, collaboration and mentoring as the top interventions affecting learning outcomes in (Brooks et al. 2021). Similarly, these findings suggest that the performance of teachers in Afghanistan, as shown in these data, demonstrates that a collaborative learning atmosphere where peer learning, job-embedded mentoring and step-by-step learning processes, etc. plays a vital role in promoting teaching quality and sustaining professional development. However, comparatively low scores for policy commitment, monitoring and accountability suggest that there are still hurdles in Afghan education. Factors such as political instability, insecurity and the lack of a coherent policy framework are likely to have undermined the ability of policy advocacy to improve teacher learning. As Afghanistan emerges from decades of conflict, the policy environment must be conducive to the continuation and growth of professional learning programmes (Aguilar and Retamal 2009; Speakman et al. 2014).

5. Conclusion

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The findings of this study offer a window into how PLFs have managed to sustain the learning of these teachers in a country emerging from decades of conflict. Peer-to-peer learning and direct mentoring rose to the top as the most effective strategies, modelling common professional development practices. Further evidence of the negative regional impact of effective strategies suggests that what works in places like Pakistan or Iran is not a one-size-fits-all strategy for Afghanistan. Regional solutions are needed to address the imbalance in digital resources and infrastructure.

Future studies should look at how regional differences can be complemented by more localised interventions such as tailored workshops and community-based professional development programmes. This will require political will and action from both policymakers and education stakeholders to build the educational infrastructure and policy environment necessary to leverage and sustain the impact and scale of professional learning efforts across Afghanistan. Fostering international collaboration and partnerships in the region could also be a way of overcoming the current barriers created by political instability or economic constraints, towards a more inclusive and sustainable model of teacher professional development in the country.

Limitations

While the study provides useful perspectives on the strategies used by Professional Learning Facilitators (PLFs) to sustain STEM teacher learning in Afghanistan, several limitations should be acknowledged. Firstly, the study was based in a specific geopolitical context, which may affect the applicability of its findings to other regions with different socio-political dynamics. The sample size was relatively small, with only 60 STEM teachers, but sufficient for qualitative analysis. The diversity and variation within the contexts of STEM education, and even within individual subjects, means that this sample, while helpful, may not be representative of all experiences. In addition, the study relied on self-reported data obtained through surveys and interviews, which are subject to biases such as social desirability and recall bias. The cross-sectional nature of the study explores the current state of teachers' learning strategies, but does not explore longitudinal effects or the longer-term impact of these strategies in practice and on students. In addition, the study lacked a control group, limiting the ability to link PLF strategies to improvements in teacher learning outcomes. Finally, the study was conducted before the major political changes in Afghanistan in 2021, and the results may not be truly representative of the current educational landscape. We believe that future studies should be mindful of these limitations, and research in this area could benefit from increasingly larger samples across multiple settings, longitudinal designs, and intervention-control group studies to further substantiate and generalise these findings.

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Author Contributions

Sayedy Javad conceptualized and designed the study, conducted the data analysis, and drafted the manuscript. Abdullah Qutuby assisted in data collection, provided critical revisions to the manuscript, and approved the final version for submission. Bakhshi Naseem contributed to the literature review, interpreted the results, and provided feedback on the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest related to this study. No financial or personal relationships with other organizations or individuals have influenced the research.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to privacy and ethical considerations, access to the raw data is restricted.

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