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Science Technology Engineering And Mathematics (STEM) Teacher Readiness: A Professional Development Perspective

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Abstract
The National Education Policy (NEP), 2020 recommends inculcating twenty-firstcentury skills among students through technology-driven innovative interdisciplinary teaching-learning strategies. A STEM-integrated approach may be adopted to fulfil these national educational goals, but a prior investigation into teachers' readiness is imperative. An explanatory mixed method approach was used to collect responses to closed-ended survey questions from 117 STEM teachers from schools in India's capital region to assess three STEM education dimensions: students' use of technology, innovative teachers' instruction in science, and their attitudes towards twenty-firstcentury learning among their students. To better understand the teachers' perspectives, focus group discussion revealed different comprehension of the survey responses and difficulties faced in enacting STEM classes. Thematic analysis of data provided input for further actions of teacher training and procuring digital infrastructural support to the educational institutes for a smoother implementation of the academic policy.
Keywords: *NEP-2020, integrated STEM approach, innovative science instructions, twenty first century learning, technology-use in STEM education.*

INTRODUCTION

India, like many other nations, is promoting scientific education within an integrated STEM framework (Insights Success, 2023; Iyer & Kalyandurgmath, 2022). Integrative teaching of STEM trains young generation to build real-world solutions through experiential learning that fosters critical thinking, teamwork and communication skills (Honey et al., 2014; Moore et al., 2014).
Bring a scientific temper to translate our strength of 'Jugaad culture' into 'Culture of innovation (VIF India, 2019, p136).
A 2019 Indian STEM task committee recommended reforming the educational system to transform the mindsets of all stakeholders, notably students and educators from the inclination to use 'Jugaad' or "hack," to rigorous training in divergent thinking to solve challenges creatively (VIF, 2019).
Science students in India are under parental and social pressure to gain admission to college courses leading to medical or engineering careers. To secure their place in colleges with limited seats, they opt for intensive coaching in the final two years of school, paying heavy fees at private tuition centers. The younger children strain their mental and physical health, managing time and energy between two institutes, miss out on the opportunities for self-constructed learning and gaining desirable skills, values, and attitudes (NEP, 2020). To reduce the students' stress to pursue their ambitions, the Ministry of Education (MoE, 2024) has set rigorous requirements to support the holistic development of school children. Broad educational reforms have been proposed to develop a professional STEM workforce with twenty-firstcentury skills (VIF, 2019), thus aligning educational goals with those of many developed and emerging countries. It reiterates the link between STEM integration and national policy aims of preparing global citizens.

STEM education in Indian schools and teachers' readiness

The new government-run Prime Minister Schools for Rising India [PM SHRI] (PM SHRI, 2024) use innovative classroom practices to develop strong interdisciplinary knowledge, human, democratic, and environmental values, progressive attitudes, and twenty-firstcentury learning skills while leveraging technology. A premier institute of higher learning, students and teachers in STEM education across Indian states are being trained to build STEM knowledge and experiences using low-cost materials to spark self-discovery (CCL IITGN, 2023). At the school level, Atal Innovation Mission supports Atal Tinkering Laboratories [ATLs] to expose young innovators to project-based learning, engineering solutions, and technology to boost innovation and entrepreneurship in India. It teaches them engineering design, computational thinking, and computing to foster curiosity, creativity, and imagination (AIM, 2024). In STEM fields, teachers help students comprehend abstract concepts, and contextualize them for real-life applications (Moore et al., 2014), therefore their perceptions towards students' learning are crucial (NEP, 2020). Their positive attitude toward twenty-firstcentury learning and technology-based teaching in the future may make the educational transformation possible. Therefore, to implement the recommendations of NEP-2020, the imperatives are to evaluate the STEM teachers' readiness for the same and identify the barriers that hold them back. Such assessments support addressing these issues through well-structured teachers' professional development programs [TPDs] and creating school support systems (NEP, 2020). In 2012, a similar evaluation tool, the T-STEM survey, was developed for STEM teachers in the USA (Enochs & Riggs, 1990; Friday Institute, 2012). Some of the constructs of this survey tool align with NEP-2020 visions (Table 1). This study adopted the questions from three sections of this survey. The questionnaire thus created assessed the STEM readiness of teachers by their innovative science instruction, use of Information and Communication Technology [ICT] by their students in STEM learning, and their attitudes toward twenty-firstcentury learning. Acknowledging that the survey questions were created for teaching professionals from different socio-cultural settings, ask for closed-end responses and STEM education is new for the Indian education system; the Indian STEM teachers may comprehend the questions as per their perspective. This study made the provision for assessing participants' diverse comprehension of the survey, gathering additional data concerning the challenges faced in STEM classrooms. Therefore, a qualitative part was included in the research design in the form of focus group discussion (FGD) with participant-teachers. (Insert Table 1 here)

Table 1 Connection between Indian educational policy vision and the three constructs of Teachers survey (as adapted from Friday Institute, 2012; NEP, 2020).

NEP vision on school education	**Construct**	**Measurement Application**	**Number of questions [score]**	**Reliability Cronbach's Alpha [α]**
The Policy seeks to eliminate learning silos, develop conceptual understanding, skills like creativity and critical thinking to promote logical decision-making and innovation, and life skills like communication and teamwork through multidisciplinarity through extensive technology use in teaching and learning while embedding diversity and the local context into curriculum and pedagogy (NEP, 2020, pp 3-5).	Section III-Student Technology Use	How often students use technology in the respondent's classes	8[40]	.900
	Section IV-STEM Instruction	How often the respondent uses certain STEM instructional practices	14[70]	.934
	Section V-21st Century Learning Attitudes	Attitudes toward 21st century learning.	11[55]	.948

Research Questions

The questions answered by this study were:

1. To what extent do students in schools use technology in STEM learning?
2. To what extent do STEM school teachers use innovative pedagogies in their STEM classrooms?
3. What is the attitude of STEM school teachers towards twenty-firstcentury learning among their students?
4. What challenges do the school teachers face in using technology, employing innovative pedagogical strategies and facilitating twenty-firstcentury learning to their students during STEM activities?

The findings of this study indicated science teachers' needs for professional development, informing teacher trainers to design STEM TDPs around the specific areas where support may be more useful for them. This study also necessitates the development of an evaluation framework for teachers' STEM readiness in Indian socio-cultural settings.

Literature Review

Teachers' Perception and STEM instruction

Teachers' knowledge and attitude affect their pedagogical innovativeness which is an important pillar for STEM education performance and sustainability (Wahono et al., 2019). Zhang & Liu (2013) found that constructivist teachers preferred student participation and dynamic classrooms by providing an engaging learning environment that encourages discovery, cooperation, and innovative thinking (Cheng, Chan, Tang, & Cheng 2009). Despite a shift from drill and repetition, rote memory, and teacher authority practiced traditionally in favor of constructivist pedagogy in science education, several scholars (Donnelly et al., 2014) have found discrepancies between classroom activities and reform recommendations due to teaching orthodoxy. Teachers' views on skills and how to acquire them through pedagogies are shaped by their own educational experiences (Thibaut et al., 2018).

TPD programs to meet adaptive challenges to integrate STEM disciplines

Sulaeman et al. (2022) noted that innovative educational strategies and time management were major issues, while incorporating STEM learning by the instructors. The most common barriers to STEM education include transdisciplinary knowledge, adapting to new pedagogical methods and classroom duties, time constraints, and designing curriculum (Huang et al., 2022). Ramli et al. (2017) claimed that STEM teacher-efficacy was affected due to their limited knowledge, teaching resources, and lack of laboratory practices. TPD programs supported them to modernize laboratories and classrooms for active, hands-on learning, incorporating problem-solving skills. The focus of professional development (TPD) courses for pre-service and in-service teachers had been on subject-specific skills and not on interdisciplinary ones (Honey et al., 2014; Lo, 2021). STEM instructors must be supported in reorganizing their teaching activities, keeping in mind their attitudes and perspectives before the implementation of an innovation. While designing such teacher-led professional development programs, Margot and Kettler (2019) recommended comprehending STEM teachers' perceptions to address specific deficit areas.

Solving challenges of ICT in the STEM learning

Given current advances in technology and its importance in STEM, professional development in classroom technology integration is essential. Vanderlinde and van Braak (2010), while recognizing teachers' ICT competency as a key determinant in educational ICT use, noted that improving teachers' ICT skills and attitudes toward ICT integration is crucial. Koh et al. (2016) showed that TPD programs improve instructors' technology pedagogical content knowledge, especially for twenty-firstcentury learning. Alt (2018) found a high correlation between teachers' ideas of teaching and their interest in ICT based professional development to implement ICT in their classrooms.

Research design

Research design used to analyze STEM teachers' survey quantitative data followed an explanatory sequential mixed method approach using SPSS version 23 for descriptive statistics (Creswell & Creswell, 2018, p.52). Next, focus group discussions (FGDs) provided more explanations to supplement the survey data.

Tools

Out of the two investigative instruments, the first one, a questionnaire, featured three components from the STEM Teacher's survey (Friday Institute for Educational Innovation, 2012). The online Google form tested teachers' STEM education readiness by asking closed-ended questions about technology use in STEM classrooms, innovative instructional practices, and attitudes toward twenty-first century learning on a five-point Likert scale. Student Technology Use in STEM classrooms and teachers' STEM Instruction ranged from one (never) to five (always). Twenty-First-Century Learning Attitudes varied from scoring one (strongly disagree) to scoring five (strongly agree). All construct reliability factors were retested through a pilot study before employing them for a larger sample and found to have α values of 0.9 (Friday Institute, 2012). The questionnaire's initial findings on all instrument questions' validity and reliability have been included in Table 1.

Researcher consensus was reached to write focus group questions to distil teacher perceptions on the three parameters. To design and finalize appropriate questions that address any ambiguity in participants' comprehension of the questionnaire tool and identify challenges for science instructors in their STEM classes, two experts were consulted to validate them. The open-ended, FGD questions asked participant teachers why and how often they utilize technology in STEM class, what digital devices they use, and what the school provides in terms of infrastructure, technology, and administration. They were asked to present instances of STEM class activities where they noticed their students working together, critically analyzed and trying to solve problems scientifically. The discussions on the manner of their sensory experiences, laboratory work and communication. At the end of each FGD session, the researchers summarized teachers' descriptions of STEM instruction, use of technology and their perspectives for twenty-first century learning and how their diverse student population engaged in STEM activities to reach a consensus on reporting.

Sampling, Data collection and analysis

A note regarding the research's goal and ethics accompanied the online survey.
Social media platforms, WhatsApp, Facebook, and Telegram, were used to distribute the questionnaire to 989 STEM teachers across India, considering their use to share teaching-learning ideas and materials. The educational policy may be implemented differently in each Indian state's school board and curricula; therefore, for the sake of uniformity, participant-teachers were selected only from the national capital region, Delhi. All 117 STEM teachers were purposively sampled to include those holding at least one science graduate degree and teaching license, currently employed at secondary schools in Delhi, India. The mix-gender sample included teachers of 25–60 years of age, from government and private schools, with 5–15 years of experience, and teaching 8th–12th graders. These teachers were invited to continue to next step of research. Out of all 117 participants invited for FGDs after school hours, 43 agreed to physical sessions while 13 attended FGDs facilitated through virtual Google meets. All nine sessions were held with five or fewer participants. The data gathered was categorized for teachers' comprehension of survey questions and challenges in STEM classrooms.

Online Google form data transformed into Excel sheets was cleaned and filtered. Teachers' data from three questionnaire sections was analyzed using descriptive statistical indicators (Table 2) and visualized as frequency-distribution curves showing the standardized values of scores for each variable against the number of teachers.

The numbers of participants in the survey and FGDs were not equal.
Responses for the FGD questions were recorded using the software Sound Notification and Transcribe. At the end of each session, Software NVivo was used for coding FGD transcripts, their comprehension of survey questions presented in Table 3 and their challenges in Table 4. Focusing on instructors' comprehension of survey questions during focus groups, the three main codes were the three survey section constructs. Furthermore, emergent codes were added as child codes. Table 3 shows coded frequencies of respondent-responses calculated as percentages of total responses. The responses of the second category 'challenges' were used to extract subthemes (child codes) for under four major themes. Table 4 also depicts theme-specific percentage frequencies. Because one respondent's replies may be included under multiple themes and the number of respondents in both tools was different, the quantitative comparison was abandoned. Descriptive statistics analysis of survey scores and insights from FGD have been presented in the result section to answer the research questions.

RESULTS

Results from sequential analysis (Creswell and Creswell, 2018) on the questionnaire and FGD responses on each construct are grouped objective-wise, while results for the fourth question on teacher challenges are divided into four subsections. Table 2 shows the summary of descriptive statistics analysis of survey scores. (Insert Table 2 here)

Table 2: Descriptive statistical analysis from the questionnaire

Statistical parameters	Use of ICT by the students	Science instructions	twenty-first century learning attitudes
Mean	26.18	49.59	45.15
Median	27.00	51.00	44.00
Mode	32	42	44
Std. Deviation	7.809	10.259	6.772
Minimum	7	24	19
Maximum	40	67	55
Percentiles 25	20.00	42.00	43.00

50	27.00	51.00	44.00
75	32.00	57.00	49.00

The first research question examined the extent of technology use in participant teachers' STEM classrooms. (Insert Figure 1 here)

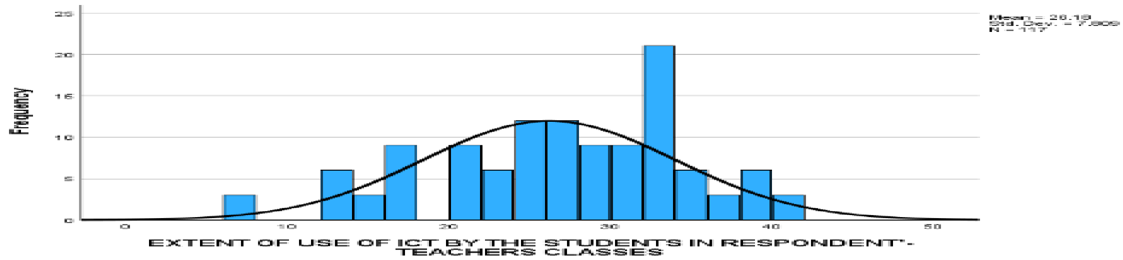

Figure 1: Frequency distribution curve for respondent-teacher students' use of technology. In the survey, teachers reported the type and frequency of technology used by their pupils to solve problems, collaborate, and communicate creatively. Student ICT use in respondent-teachers' classes may be described on the basis of Table 2 and Figure 1. A median value of 27 and a mode of 32 indicates the good usage of ICT by more than half of the students though some are using it less efficiently. During focus group discussions, 33% confirmed ICT use for STEM learning. Teachers explained that students' usage of digital gadgets for socializing with others and amusement could not be segregated from usage while learning. A few students getting the opportunity to use school resources while participating in project work or competitions suggests inequitable accessibility. Only 22% confirmed equity in technology access. A larger digital divide was reported in schools where pupils can bring their own devices. This perspective of 'partial use of ICT' could not be reported through closed responses in the questionnaire. Some teachers confirmed using smart boards, PowerPoint presentations, movies, spreadsheets, and digital microscopes in STEM classes, however, high-end digital devices mentioned in the survey question were not available in any of their schools (refer Table 3 and Table 4). This pointed to the need to adopt design and language for the survey tools according to the participants' backgrounds.

The second research question assessed STEM teachers' use of innovative pedagogies. (Insert Figure 2 here)

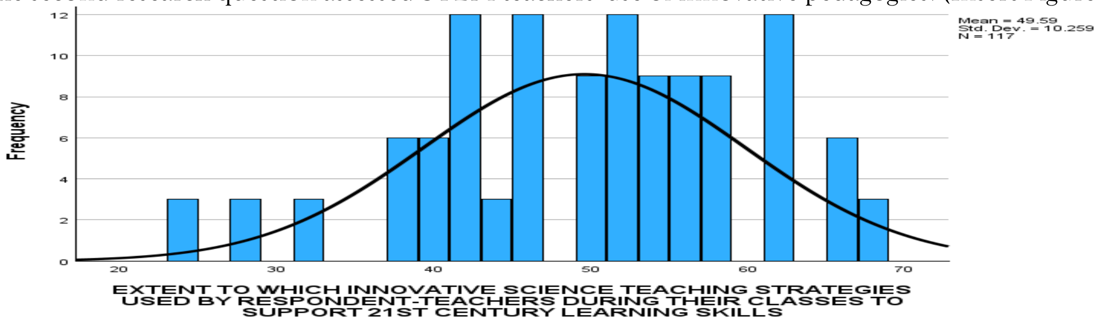

Figure 2: Distribution curve for innovative science instructional practices used by respondent-teachers

Survey questions asked how STEM classroom instruction supports twenty-first century skills like innovative thinking to solve problems, collaboration in scientific problem-solving, contextualizing scientific principles to their lives, and clear communication of findings. The scores ranged from 24 to 67. Half of the participants scored 51 or above out of 70, suggesting that their instructional strategies achieved the desirable objectives (refer Table 2 and Figure 2). Optimizing learning approaches that were research-based, project-based, and inquiry-based, 21% of STEM teachers were optimistic about twenty-first century learning in their classrooms. Innovative scientific learning included 'good use' of laboratories to undertake structured experiments with rigorous uniformity of presenting identical results and 'project work' where students used web-based resources to gather material for investigatory projects. Here ambiguity in teachers' comprehension was significantly noted for what they understood as the inquiry-based approach was copying information without much analysis. The structured experiments were again equivalent to following step-by-step instructions from a lab manual to note observations and calculate to reach a predictable result (refer Table 3 and Table 4).

The third research question examined teachers' views on twenty-first century student learning.

Respondent-teacher's perspectives on twenty-first century student learning have been statistically reported in Figure 3 and Table 2. (Insert Figure 3 here)

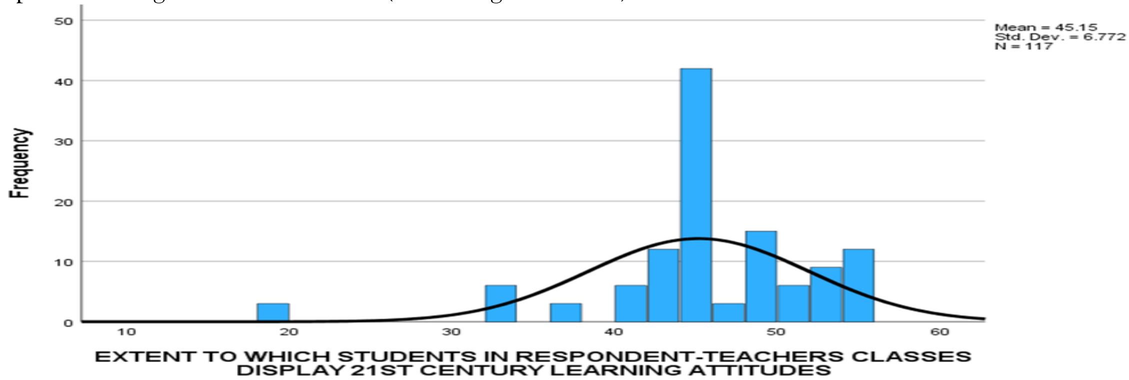

Figure 3: Distribution curve for twenty-firstcentury learning attitudes displayed by the students of respondent teachers

The survey asked science teachers about their observations on leadership, flexibility, tolerance, and global citizenship displayed by their pupils'. Half of the teachers scored 44 or above out of 55. Scores were near normal, with close values of the mode, the median the mean. The mean twenty-firstcentury learning attitude is 45.15, with a standard deviation of 6.772, suggesting that many pupils have these skills. In a focus group, 58% of teachers' responses indicated students showing leadership and global citizenship, including tolerance for diverse cultures, adaptability to social values, and gender stereotyping. About 60% of responses indicated pessimistic views on pupils' mindset, expressing an inability to change the current social system (refer Table 3 and 4). (Insert Table 3 here)

Table 3: Teachers' comprehension of the survey questions

Level 1 themes	Level 2 themes
Use of technology was not for promoting STEM learning [78%]	Approval from stakeholders and other non-academic reasons
Use of technology promoted STEM learning [22%]	Student engagement and differentiation
	Rigorous learning
	Collaboration and communication
Equity in accessibility to ICT resources [33%]	Common resources accessible to all
No equity in sharing ICT resources [68%]	Resources with limited access Use of personal resources Limited use of common resources
Learning by rote and in silos with limited comprehension [79%]	Science instruction not supportive of 21st century learning
Science or STEM instruction to develop 21st Century learning [21%]	Science instruction supportive of 21st century learning
Positive 21st century attitude [58%]	Students show tolerance, inclusivity, leadership and gender sensitivity.
Negative 21st century attitude [60%]	Students show biases with respect to caste, socio-economic status, and gender.

The last research question was to identify the science teachers' STEM classroom challenges concerning technology use, new pedagogical practices, and twenty-firstcentury attitudes. Table 4 presents some instances and summarizes the teachers' challenges. (Insert Table 4 here).

Table 4: Challenges faced by science teachers during STEM education enactment in their respective schools

Broad Challenge-area	Specific-areas
Technology use	● igital divide. ● imited access to technology, insufficient digital gadgets and Internet connectivity from school.

	● imited teacher training, lack of real-time support. ● he unmonitored use of mobile phones causing distraction among the students ● isk of cyber-safety to students.
Innovative STEM pedagogies (Science instructions)	● he curriculum and assessments support rote learning. ● PDs on subject pedagogy, not on STEM classroom strategies. ● eachers burdened with non-academic work ● ocietal pressure, marks and certain STEM careers. ● nsufficient time on high-order learning skills ● rivate tutoring prioritized over STEM learning in classrooms. ● nsufficient school infrastructure or unsupportive administrators
Experiential learning and lab work	● nsufficient laboratory materials and training-training. ● ab time and space not optimized
Developing 21st century attitudes	● nability to break barriers of gender, caste, race, socio-economic status and physical features. ● ack of support from school administrators to counter students' attitude of non-inclusivity. ● arental and community interference. ● ack of mental conditioning and training to work as team from early school years.

DISCUSSION

Teachers claimed to believe in the potential of innovative teaching methods to transform their students' STEM learning. However, a disparity was noted between the recommendations and the implementation of these approaches, which may be attributed to societal pressure on STEM students to obtain high grades in examinations and follow specific careers (NEP, 2020). The problem of the digital divide, extensive curriculum, time constraints (Huang et al., 2022) a lack of proficiency in integrating technology (Vanderlinde and van Braak, 2010), constraints in school resources, minimal use of STEM laboratories and teachers' lack of expertise (Ramli et al., 2017) were noted.

This study found that professional development programmes taught participants new pedagogies in their subject area but did not help them to overcome their fear of making mistakes and confusion about organizing and conducting STEM activities, Merley getting certified for professional development programs on novel multidisciplinary pedagogies, could not help them to manage time, resources, and workload (Donnelly et al., 2014). Future TPD programmes must build on their previous training, and perceptions and focus on deficit areas (Margot & Kettler, 2019; Huang et al., 2022). The government's efforts to moderate syllabi and improve school infrastructure need reinforcement by designing suitable TPDs around the discipline they studied and taught in the classrooms (MoE, 2024).

CONCLUSION AND SUGGESTIONS

This study aimed to build a framework to assess Indian teachers' readiness to teach integrated STEM and identify areas for support needed. This study examined Delhi NCR schools' STEM practices, technology utilization, and teachers' views on educational innovations for twenty-firstcentury learning for pupils. The necessity to prioritize educators' unique needs and challenges was also stressed in designing future TPDs. Instructors have to monitor students' technology use and follow equitable access standards. TPDs can be designed for improved STEM instruction, by leveraging ICT, enhancing classroom collaboration and diversity, and identifying alternative technologies to substitute digital technology. The teachers may be trained to create or identify inexpensive curriculum aids available locally. They may also learn to identify public-private partnerships with universities and industry to enhance schools' technological infrastructure, procuring user-friendly digital resources, enabling resource exchange and outreach campaigns. In the context of K -12 educational environments, a thorough analysis of the current scholarly work can provide valuable insights and recommendations for successful practices that have demonstrated effectiveness in comparable educational settings. They may offer significant insights to school administrators concerning the requisite assistance needed to boost the efficacy of science instructors in STEM courses. This is the basis and final assurance of change-ready instructors. Conducting more research to develop a tool for assessing students' preparedness will help instructors gain a deeper knowledge of their students and better prepare them for effective STEM education.

Teacher preparation should be didactic and knowledge-based to translate content material into pedagogically effective forms that are adaptable. They need to receive professional training within their work environment, with real-time practice to meet the challenges specific to their setting. To deal with stereotypes based on gender and socio-economic status, counselling of other stakeholders and involving NGOs for inclusivity may also be considered. Each issue needs to be addressed chronically with regular follow-ups, and if needed individual real-time support may be provided to the teachers. The local challenges such as the role of community and social hierarchy revealed during the discussion need further research. Similar studies with larger sample sizes spread across other socio-geographical locations and extensive quantitative analysis would add credibility to the findings.

It is crucial to ensure that sufficient measures are implemented to deliver high-quality STEM education to all individuals. Therefore, teachers' readiness to implement this approach may also be evaluated through other tools like unannounced observation but without threatening their dignity or employment. What they need is care, empathy and support.

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