CL4STEM Scaling Up Initiative to Strengthening Secondary School Teacher Capacities for Higher Order Thinking with Inclusion and Equity

TANZANIA REPORT

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Abbreviations

CAST	Centre for Applied Special Technology
CBE	Competency-Based Education
CL4STEM	Connected Learning for STEM
CLIx	Connected Learning Initiative
CoP	Community of Practice
CPD	Continuous Professional Development
GB	Gigabyte
GPK	General Pedagogical Knowledge
HOTIE	Higher Order Thinking with Inclusion and Equity
IBBUL	Ibrahim Badamasi Babangida University, Lapai
ICT	Information and Communication Technology
IDRC	International Research Development Centre
KAP	Knowledge, Attitudes and Practice
OER	Open Educational Resources
OUT	Open University of Tanzania
PCK	Pedagogical Content Knowledge
SCE	Samtse College of Education
SMK	Subject Matter Knowledge
SNA	Social Network Analysis
STEM	Science, Technology, Engineering, & Mathematics
TE	Teacher Educator
TISS	Tata Institute of Social Sciences
TPACK	Technological, Pedagogical And Content Knowledge
TPD	Teacher Professional Development
TV	Television
UDL	Universal Design for Learning

1.0 Introduction

Tanzania's education sector has undergone significant transformations, including the introduction of fee-free education up to the secondary school level and the prioritization of STEM education particularly science and mathematics as key areas for driving innovation, inclusiveness, and socio-economic development. These efforts are supported by various policies, frameworks, and projects aimed at developing curricula, learning materials, infrastructure, and Continuous Professional Development (CPD) opportunities for teachers to ensure quality, inclusive, and equitable education. In alignment with this focus, the Open University of Tanzania (OUT) collaborated with a consortium comprising Ibrahim Badamasi Babangida University (IBBUL) in Nigeria, Samtse College of Education (SCE) in Bhutan, and the Tata Institute of Social Sciences (TISS) in India. This collaboration was part of the Connected Learning for Secondary School Teachers Capacity Building in STEM (CL4STEM) project, funded by the International Development Research Centre (IDRC), Canada, and the Global Partnership for Education (GPE) Knowledge and Innovation Exchange (KIX).

This CL4STEM project was built on the successes and lessons of its pilot phase, scaling its impact to enhance STEM education in Tanzania and partner countries. The project aimed to research an innovation designed to enhance the capacity of secondary school science and mathematics teachers to foster Higher-Order Thinking with Inclusion and Equity (HOTIE). This South-South collaboration intensified efforts to adapt and scale the Connected Learning Initiative (CLIx), originally developed in India, to diverse contexts in Tanzania, Bhutan, and Nigeria. The project's primary objectives included adapting and refining teaching modules for broader applicability, promoting systemic changes in teaching practices, integrating innovative digital tools, strengthening collaboration with policymakers, educators, and other stakeholders, and enhancing local and national capacities for STEM education delivery. This approach aligns with research by Panirsilvam (2017), Johnson *et al*. (2010), and Cooley and Linn (2014), emphasizing the importance of local adaptation, scalability, and synergy between organizational efforts and individual roles.

This phase involved knowledge transfer from OUT teacher educators (TEs) who had gained expertise during the pilot CL4STEM project (ref. CL4STEM report, 2023) to STEM teachers specifically in science (physics, chemistry and biology) and mathematics, from nine selected secondary schools in Iringa District Council (DC). The training focused on building capabilities to utilize and manage Open Educational Resources (OERs), Learning Management Systems (LMS) such as Moodle, online collaboration tools like Zoom, and mobile-based Communities of Practice (CoPs) such as WhatsApp groups. Key highlights of the project include capacity building through engagement with curated OER-based modules tailored to local contexts and accessible through various platforms. The professional development training sessions emphasized Technological Pedagogical Content Knowledge (TPACK), Universal Design for Learning (UDL), and collaborative learning including practical implementation where teachers developed and implemented lesson plans in their classrooms employing learned approaches.

The CPD intervention included a 13-module course designed to enhance teachers' Pedagogical Content Knowledge (PCK) using OERs and blended learning methods. This was achieved through orientation in a two-day onsite workshop in Iringa DC that introduced teachers to Moodle, Zoom, CoPs, pedagogical principles and subject-specific module engagement.

Subsequently, teachers participated in comprehensive reflective, practice-based assignments integrated into subject-specific modules. This involved the development and execution of lesson plans in the classrooms, followed by reflective reporting and evaluations (Figure 1). Seven Communities of Practice (CoPs) were established to enhance communication and collaboration. These included four subject-specific groups and three administrative groups, bringing together teachers, educators, heads of schools, administrators and policymakers focusing on scaling up educational initiatives.

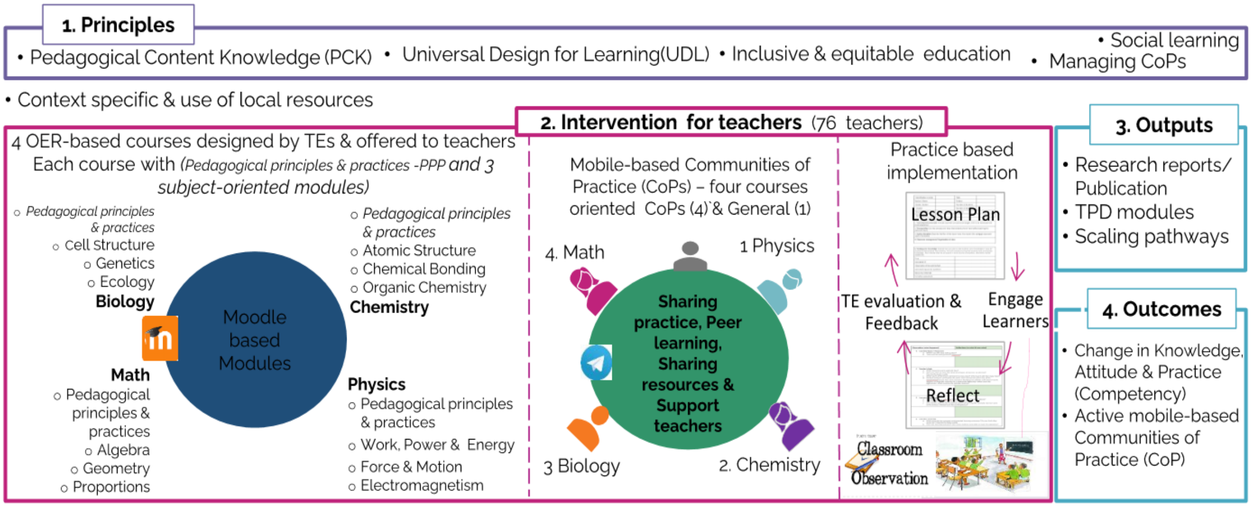


Figure 1 1: CL4STEM Project Overview

The project's outputs included practised TPD modules, endline research reports, and publications in journals and national outlets. The anticipated impact focuses on knowledge, attitude, and practice (KAP) transformation, where teachers' competencies were enhanced through engagement with CPD modules and reflective practices, and strengthened CoPs, where mobile-based CoPs promoted collaboration and peer learning.

The project was run from January to December 2024, during which 76 participating STEM teachers were empowered to integrate subject matter expertise, pedagogical skills, and inclusive practices into their classrooms. In parallel to the empowering process, teachers were also involved in baseline and endline surveys, interviews, classroom observations and peer reviews. The analysis of these data was done, and the resulting evidence provided the foundation for scaling the intervention, informing policy discussions, and ensuring sustainability in STEM education across Tanzania and beyond.

This report outlines the methodology, participant engagement, and results of the CL4STEM project, demonstrating its effectiveness in enhancing STEM-teacher KAP. By fostering social learning and systemic change, the project contributes to the broader goals of equitable and inclusive STEM education in Tanzania. The findings serve as a basis for further dissemination, policy integration, and scaling opportunities to ensure STEM education remains a driver of innovation, inclusion and equity.

2.0 Methodology

The chapter then outlines the data collection methods and strategies, including qualitative and quantitative methods, to gather relevant information for analysis. The chapter also describes the analyses performed to help understand the interventions' effectiveness and the impact on science and mathematics teachers' professional development. It emphasizes that the application of teacher professional knowledge is contextual and value-based**,** depending on the specific educational setting, educational policies, culture and the values held by the teachers.

This chapter outlines the methodology for implementing the CL4STEM scaling-up initiative in Tanzania, following the earlier pilot phase conducted in 18 schools across six regions (ref. Tanzania CL4STEM report, 2023). The pilot phase involved a limited number of STEM teachers from each school, providing a broader perspective on the intervention within a school setting. In contrast, the current CL4STEM scaling-up initiative focuses on one council, Iringa DC, encompassing nine secondary schools and involving all STEM teachers. This approach allowed for closer monitoring of the intervention's impact. Iringa DC was selected for the CL4STEM scaling-up initiative due to the strong cooperation demonstrated by regional and district educational officials during the pilot phase. This collaboration facilitated effective monitoring of progress, ensuring a smooth implementation of the project. The positive experiences from the pilot phase indicated that Iringa DC would provide an optimal environment for scaling up the initiative, allowing for more comprehensive engagement with all STEM teachers in the nine secondary schools involved.

The CL4STEM design leverages social connections and modern communication technologies to deliver educational resources to teachers in virtual environments. This innovative approach aims to revolutionize how teachers learn and connect, utilizing the power of social networks and contemporary communication tools to facilitate the sharing of ideas and teaching resources. Specifically tailored for Tanzanian educators, this strategy enhances traditional face-to-face interactions, ensuring that professional development programs are accessible and effective in a digital context. By embracing this new model, CL4STEM seeks to foster a collaborative learning atmosphere that empowers teachers to engage actively in their professional growth and improve their teaching practices.

Thus, the CL4STEM design utilised the following strategies;

i. **Online Modules**: High Order Thinking with Inclusion and Equity (HOTIE) in Mathematics, Physics, Chemistry and Biology had to be implemented by participating teachers in selected schools in Iringa DC. These modules are structured to provide teachers with professional knowledge, attitudes, and practices (KAP) in a flexible and accessible manner through the CL4STEM e-learning platform (Moodle).

ii. **Mobile-Based Communities of Practice (CoP)**: These platforms allow teachers to engage in social learning, share experiences, and collaborate on best practices, fostering a supportive and interactive professional development environment.

The chapter concludes by examining the demographic profiles of the participants, providing essential context for the collected data and grounding the findings in the authentic experiences of the participating teachers. By situating the findings within this demographic framework, the chapter emphasizes the relevance and applicability of the results to the broader educational landscape in Tanzania.

2.1 The Theory of Change and Conceptual Framework (Knowledge, Attitude and Practices)

The CL4STEM scaling-up initiative is anchored in the conceptual framework of Pedagogical Content Knowledge (PCK), emphasizing the importance of core subject content knowledge and pedagogy for effective teaching. This initiative aims to enhance teachers' knowledge, attitudes, and practices in classroom settings, incorporating elements of higher-order thinking while promoting inclusion and equity. Participating teachers have actively engaged with the designed CL4STEM online modules, implementing specific lesson plans, reflecting on their teaching activities, conducting peer assessments, and participating in classroom observations and online practice communities aimed at fostering new lines of professional development.

Additionally, the initiative integrates the Technological Pedagogical Content Knowledge (TPACK) framework, which underscores the significance of incorporating technology into education. This approach highlights the implications of developing PCK within the context of classroom teaching in developing countries. The foundational concepts of CL4STEM stress the importance of contextualization and evolution in education, recognizing the role of social learning within communities and the potential of mobile-based technologies to facilitate the adoption and scaling of innovations in teacher professionalism.

Figure 2.1 summarizes the key features and research activities of this theory of change;

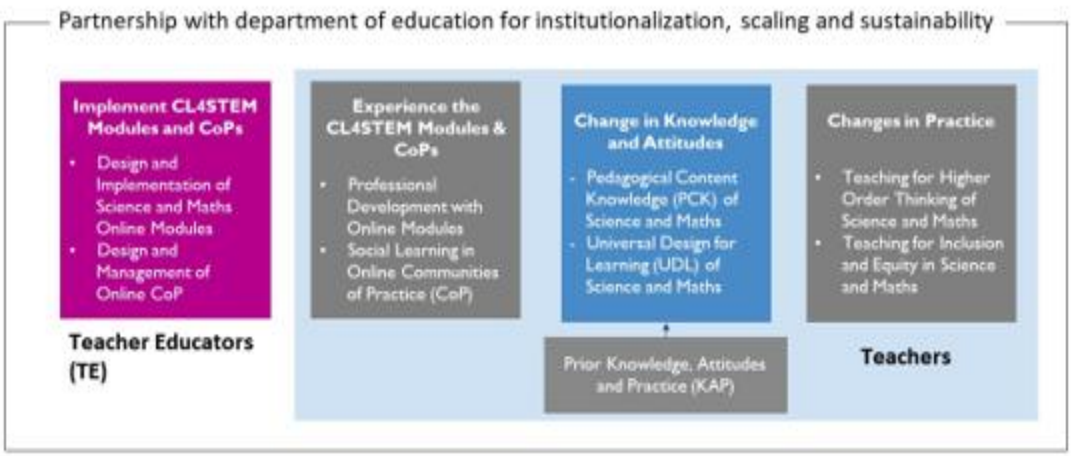


Figure 2. 1: CL4STEM Theory of Change

The CL4STEM framework, which emphasizes Higher Order Thinking with Inclusion and Equity (HOTIE), is designed to facilitate specific changes in teachers' knowledge, attitudes, and practices (KAP). This framework focuses on observing these changes by examining ten themes that guide the necessary transformations in teachers' KAP and assess their development in Pedagogical Content Knowledge (PCK) throughout the implementation period (Table 2.1). By comparing baseline and endline data, the initiative aims to evaluate the effectiveness of the changes made. The HOTIE framework serves as a structured approach to enhance teachers' professional development, ensuring that they not only acquire knowledge but also adopt inclusive practices that promote equity in the classroom. The systematic examination of these ten themes allows for a comprehensive understanding of how teachers evolve in their pedagogical approaches, thereby fostering an environment conducive to HOTIE among students.

Table 2.1 shows the themes to guide and observe changes in teachers' while pointing out the KAP to the principles of Pedagogical Content Knowledge (PCK) (Ball, Hill & Bass, 2005; Grossman, 1990; Kind, 2009; Ramchand, 2022; Shulman, 1986), Universal Design for Learning (UDL) (CAST, 2018), and Competency-Based Education (CBE) (Shawer, 2022).

The ten themes within the HOTIE framework are categorised into three major sub-categories;

1. **Subject Matter Knowledge**: Knowledge specific to the subject (s) taught.
2. **Pedagogical Content Knowledge**: Understanding how to teach the subject effectively.
3. **General Pedagogical Knowledge**: Broader teaching skills and strategies.

Table 2.1: Conceptual Framework for HOTIE

Higher Order Teaching with Inclusion & Equity (HOTIE) ©CETE, 2022	
Subject Matter Knowledge	
1. Knowledge of Science/ Maths Subject Matter	● The knowledge possessed by the teacher in one or more disciplines of science or mathematics ○ 'Big' ideas, key concepts and theories in the discipline ○ Knowledge of interconnections between concepts/ topics within the discipline ● Ability to justify what counts as knowledge within the domain of science/maths
2. Nature of Science /Mathematics	● Teachers' knowledge of the nature of science, such as its empiricism, situated in a particular historical, social, and economic context; that it requires creativity and imagination; the understanding of modern science as a collaborative enterprise located in institutionalised spaces. ● Teachers' knowledge of the nature of mathematics; beliefs about mathematics; processes of mathematics: problem-solving,

	reasoning, proving and communicating; mathematisation of thinking or ability to represent something mathematically ● Ability to communicate the nature and structure of science/maths to students
Pedagogical Content Knowledge	
3. Instructional Strategies	● Knowledge of different instructional strategies and resources ○ To develop scientific thinking, skills in experimentation, observation, inferring, categorising through data gathering, plotting graphs, problem-solving ○ To develop mathematical thinking, mathematisation, reasoning, and argumentation ● Knowledge of topic-specific pedagogical strategies and resources ● Ability to use different instructional strategies and resources to address diverse needs of learners, including addressing students' misconceptions and learning difficulties
4. Students' Misconceptions & Conceptual Difficulties	● Knowledge of students' prior conceptions, errors, misconceptions/alternative conceptions, ways in which students think, and concepts students find difficult to learn ● Knowledge of areas that students find challenging ● Ability to use students' errors to understand their ways of thinking and to design learning experiences to support students' STEM learning
5. Representation of the Content	● Knowledge of multiple forms of representation of content - e.g. analogies, equations, gestures, graphs, diagrams and illustrations, models, tables, texts, videos, simulations, photographs ● Knowledge of the limitations of models and illustrations in representing content ● Ability to use multiple representations of content to meet the diverse needs of students

6. Context for Learning	● Knowledge of the larger school/regional infrastructure and discursive context which shapes their pedagogical choices ● Knowledge of the environmental/ lab/ material resources available in the context utilised to promote science/ maths learning ● Ability to adapt resources/use locally available materials to meet the needs of learners ● Ability to connect different topics in science/maths to everyday experiences/ daily life practices of the students
7. Curriculum Knowledge	● Knowledge of the goals and purposes of teaching science/mathematics ● Knowledge of the hierarchical sequence of foundational concepts for teaching and its interconnection with other concepts/topics in the curriculum across grades ● Knowledge of linkages between science and maths and with other school subjects ● Ability to use knowledge of curriculum to design integrated learning experiences for students
General Pedagogical Knowledge	
8. Equity and Inclusion	● Knowledge of Universal Design for Learning ● Ability to provide equal opportunities to all students to participate in classroom interaction ● Ability to use UDL principles to design and implement lesson plans, resources and assessments to meet the diverse needs of learners
9. Classroom Management	● Knowledge of multiple modes of classroom interaction, e.g. organising inquiry learning/project-based learning/problem-solving to promote students' agency, employing a variety of grouping practices to support collaborative learning, using activities to offer multiple ways for students to engage and express ● Knowledge of positive disciplining techniques

	● Ability to organise and manage multiple modes of interactions, including group activities ● Ability to manage time, space and teaching-learning resources effectively ● Ability to manage students' behaviour
10. Assessment	● Knowledge of multiple methods and tools of assessment for students to express in multiple ways ● Ability to use assessment for and of learning ● Ability to design and use a variety of methods and tools of assessment, including task-based assessment

The online Communities of Practice (CoP) played a crucial role in designing and implementing the CL4STEM initiative by facilitating social learning among participating teachers and their educators, thereby enhancing professional development. CoPs have long been recognized for fostering social interactions that can translate into professional learning through ongoing engagement among community members (Wenger, 1998). Grounded in situated learning theory (Lave and Wenger, 1991), these communities emphasize that professional learning is inherently linked to social processes within specific socio-cultural contexts.

In this project, CoPs provided a platform for social learning, enabling participating teachers to collaborate as a unified team within their areas of expertise. They facilitated the sharing and discussion of experiences related to the school curriculum and the newly implemented CL4STEM modules. To initiate this process, a Pedagogical Principles and Practice - WhatsApp group was established, allowing STEM teachers to interact with one another and their educators. This group served as a space for teachers to enhance their pedagogical skills, navigate the CL4STEM Moodle e-learning platform, and complete required activities before the implementation of subject-specific online modules.

Subsequently, individual WhatsApp groups were created for mathematics, biology, chemistry, and physics. Each teacher educator took on the role of course instructor for their respective subject modules as well as for the pedagogical principles module, ensuring active participation from all teachers involved. The CoPs played several crucial roles:

- **Facilitating Knowledge Exchange**: participating teachers and teacher educators engaged in discussions about their experiences with the CL4STEM modules and practices, fostering productive dialogues that allowed them to share best practices and collaboratively address challenges within their specific domains.
- **Building Networks**: The subject-specific WhatsApp groups served as central hubs for communication and knowledge sharing, enabling deeper and more focused discussions in each subject area.
- **Ensuring Active Participation**: Teacher educators provided guided instructions and facilitated discussions on their respective subject modules and pedagogical principles. This structure ensured that all teachers remained actively engaged in the CL4STEM learning and design process.

2.2 Data Collection

Data collection for the study employed a mixed-methods approach, integrating both quantitative and qualitative methodologies. Baseline and endline surveys were administered to assess the changes in teachers' KAP from baseline to endline data collection periods. Baseline data collection was done in January 2024 before the actual modules implementation, and the endline data collection was done in October 2024 after the implementation of all CL4STEM modules across all four subjects.

Quantitative data was collected via surveys, where two sets of survey questions, i.e. mathematics survey questions and science (physics, chemistry and biology), were separately administered to mathematics and science teachers in the baseline and endline data collection periods. Teachers accessed and did all the surveys via the CL4STEM Moodle e-learning platform, where results were stored for analysis. On the other hand, qualitative data were collected via semi-structured interviews and classroom observations for baseline and endline data sets.

The complete set of CL4STEM data includes mixed data collected via surveys, lesson plans, lesson reflections, modules pre- and post-tests, interviews and classroom observation. Researchers implemented a data collection strategy for the CL4STEM initiative, utilizing baseline-online activities through the CL4STEM Moodle e-learning platform, face-to-face interviews, and classroom observations. Ethical protocols were followed; each participating teacher signed a consent form and was assigned a unique CL4STEM code number to ensure anonymity and confidentiality during data collection. This approach allowed for a thorough examination of the impact of the initiative on teachers' knowledge, attitudes, and practices (KAPs) over time. Table 2.2 below shows the sequence of data collection and their respective techniques during the project implementation:

Table 2.2: A step-by-step flow of research tools in CL4STEM

Baseline Data

Table 2.3 presents data on a total of 81 science and mathematics teachers from nine secondary schools in Iringa DC who participated in the CL4STEM project. By January 2024, all available STEM teachers from these schools contributed to the baseline data collection. The distribution of teachers by subject reveals that mathematics teachers comprised the largest portion at 32%, followed by physics at 25%, biology at 22%, and chemistry, which had the fewest participants at 21%.

Table 2.3: Overview of the baseline data for CL4STEM participants

Subject	**Number of participating teachers**	**Techniques for baseline data collection**	
		Survey	**Interview**
Physics	20	20	9
Chemistry	17	17	9
Biology	18	18	9
Mathematics	26	26	9
Total	81	81	36

Qualitative data was collected through in-depth key informant interviews and classroom observations. Before every classroom observation session, observers did a general school environmental analysis of the school resources regarding the availability of science labs, biological gardens, and physical infrastructures like classrooms, libraries, or learning materials. Interviews were conducted physically, at the interviewees’ respective schools. Interview schedules followed the following steps:

i) Heads of schools were contacted to check teachers' availability to take an interview.
ii) Interviewees were contacted, and arrangements for the time and date to take the interviewee were agreed upon with the interviewer.
iii) The interview commenced as per the schedule and audio recorded.
iv) Ice-breaker questions were asked.

v) All interview questions were asked, guided by the prompt responses and follow-up questions.

After interviews, the following steps were taken:

i) All recorded audio files were uploaded to the CL4STEM Google Drive folder to ensure data security and ethical compliance. For participant anonymity, interviewee names were redacted, and only their assigned CL4STEM identification numbers were used during storage and analysis.

ii) To facilitate future analysis, all audio recordings were transcribed using the automated transcription service otter.ai, generating Word document transcripts.

iii) The produced Word documents from audio transcriptions were cleaned to remove typing errors during transcription.

iv) Verbatim transcripts were generated and uploaded to the same CL4STEM Google Drive folder.

v) All transcriptions were coded to produce the specific changes in teacher KAP according to the ten themes in the HOTIE framework.

On top of the interviews, classroom observations were also conducted to capture additional qualitative aspects of the implementation. A total of 36 teachers from all 9 participant schools, at least one per subject per school, made classroom observations.

During classroom observations, observers wrote detailed descriptions of their observed lessons. They also conducted pre-observation and post-observation interviews with the teacher to understand the context of the lesson. Along with classroom observations, qualitative interviews were conducted, which focused on teachers' attitudes and practices towards SMK, PCK, GPK, participation in WhatsApp CoPs, and their perceptions of CL4STEM.

Finally, the Endline tools consisted of the following:

1. The subject survey, essentially a repetition of the Baseline subject impact survey, measured teachers' knowledge and attitude towards high order thinking with inclusion and equity by

assessing their subject matter knowledge, pedagogical content knowledge, and general pedagogical knowledge.

2. Interviews were carried out with the same set of teachers at baseline. These interviews focused on innovation diffusion by capturing teachers' perceptions about the innovation after its implementation. The interviews also focused on documenting the teachers' knowledge, attitudes, and practices around higher-order thinking with inclusion and equity to supplement the survey data.

Endline data collection was carried out between October and December 2024. An overview of the Endline data collected is shown in the Table 2.4:

Table 2.4: Overview of the endline data for CL4STEM participants

Subject	**Number of participating teachers**	**Techniques for baseline data collection**	
		Survey	**Interview**
Physics	20	19	9
Chemistry	17	15	9
Biology	18	17	9
Mathematics	26	25	9
Total	81	76	36

From Table 2.4, it is noted that only 76 teachers completed the professional development program by the endline survey in October 2024, a decrease from the 81 who initially participated in January 2024. This represents a drop of five teachers, accounting for 6% of the participants. The reasons for this decline included retirement from public service, transfers to schools and regions where CL4STEM was not operational, and challenges in keeping up with activity completions on the CL4STEM Moodle e-learning platform. Despite this attrition, a significant 94% of teachers successfully finished the professional development program.

2.3 Data Analysis

Quantitative data from administrative surveys were categorized and coded within the HOTIE framework, which facilitated the identification of patterns and discrepancies between numerical survey results and qualitative data derived from interviews and observations. This stratification provided an understanding of the study's implications for teacher professionalism in STEM education.

All interview data was meticulously transcribed and coded using the HOTIE framework, allowing researchers to categorise systematically and analyse teachers' responses focusing on changes in knowledge, skills, attitudes, beliefs and experiences in CL4STEM.

The qualitative data collected from interviews were meticulously transcribed and coded using the same HOTIE framework. This systematic categorization allowed researchers to analyze teachers' responses regarding their knowledge, skills, attitudes, beliefs, and experiences in CL4STEM.

Classroom observations were conducted to provide a direct window into teachers' teaching practices in the actual classroom environments. All observations were coded using the CL4STEM HOTIE framework to understand and study actual changes in teachers' KAP impacted by the project. Before the actual classroom teaching observations, observers conducted pre-observation interviews with teachers to delve deeper into their thinking and understanding of the relevant themes in the HOTIE. During classroom observations, observers took important notes about teaching and learning activities with emphasis on the attainment of objectives in their lesson plans, lesson development, managing time, and use of resources and assessments. Post-observation interviews were executed soon after the classroom observations, fostering reflection, providing actionable feedback, and promoting continuous improvement in teaching practices.

Data from pre- and post-observation interviews, as well as classroom observations, were systematically coded using the CL4STEM HOTIE framework to assess how teachers' perceptions of their practices evolved throughout the project. This approach allowed researchers to analyze qualitative data alongside contextual factors influencing teaching practices, aiming to uncover the broader dynamics that shaped teachers' actions and outcomes.

The qualitative data from the CL4STEM project was meticulously summarized and distilled into significant findings that identified patterns, themes, and trends across various data sources. This multi-layered approach aimed to create a clear and concise picture of the program's impact on teacher practices.

Social network analysis (SNA), combined with qualitative thematic analysis, was also used to examine data from the mobile-based Communities of Practice (CoPs). SNA explores relationships within socio-cultural contexts, revealing the informal networks that influence change. As Daly (2010) suggests, these informal relationships often determine the speed, stability, diffusion, and sustainability of change efforts. The social network analysis graphs were created using specialized software to visualize participation trends. This combined analytical approach provided a dynamic perspective of teacher engagement with CL4STEM, yielding valuable insights into the factors driving successful implementation and long-term sustainability of innovative teaching practices.

2.3.1 Demographic Details of Participating Schools and Teachers

In the current phase of the CL4STEM project implementation in Iringa District Council (DC), Tanzania, nine schools participated with characteristics as follows:

- Types of schools - boarding schools (3), day schools (6) where one school was boys-only and the rest (8), co-Education.
- School ownership – special government schools (1), community government schools (5) and private schools (3) (Table 2.5).

Table 2.5: Ownership, Characteristics and Names of the Schools Involved in the Project

Ownership	Characteristics	Name of the School
Special Government Schools	Larger schools with a significant number of students, teachers, and support staff. Fully funded by the government, and well-furnished with	1. Ifunda Secondary School

	adequate learning equipment and facilities	
Community Government Schools	Ward schools are owned and funded by the government through local community initiatives. Often smaller in terms of physical infrastructure but accommodates a large number of students in a limited space.	1. Mgama Secondary School 2. Tanangozi Secondary School 3. Lipuli Secondary School 4. Lyandembela Secondary School 5. Lumuli Secondary School
Private Schools	Schools are owned and operated by private entities or individuals. They are subject to oversight by government officials from the district council to ensure educational standards are met.	1. Bread of Life Secondary School 2. St. Mary's Ulete Secondary School

2.4 Gender of Teachers in CL4STEM Project

Tanzania has historically and culturally fewer female science and math teachers than male teachers. For this phase of the CL4STEM project implementation, all available science and math teachers at participating schools took part. Of the 81 teachers who began the implementation, 76 (94%) completed it. Impressively, all 17 female teachers (100%) finished the project, showing complete dedication. However, five male teachers withdrew from the program. Table 2.6 presents the gender distribution of the participating teachers.

Table 2.6: Gender-wise Distribution of Participating Teachers

Subject	**Baseline Survey**		**Endline Survey**	
	Males	**Females**	**Males**	**Females**
Physics	19	1	18	1
Chemistry	15	2	13	2
Biology	11	7	10	7
Mathematics	19	7	18	7
Total	64 (79%)	17 (21%)	59 (78%)	17 (100%)

2.4.1 Professional Qualifications of Teachers in CL4STEM Project

All participating teachers in the CL4STEM project had completed a professional course in education and held either a diploma or a degree (B.Ed. or M.Ed.) in education. This aligns with Tanzanian teacher recruitment policies. Among the teachers involved, the majority (47, or 58%) held a B.Ed., followed by 30 (37%) with a diploma. Smaller proportions held a postgraduate diploma in education (3, or 4%) and a master's degree in education (M.Ed.) (1, or 1%). Table 2.7 provides an overview of the qualifications of teachers involved in the CL4STEM project.

Table 2.7: Professional Qualifications of participating teachers

Professional Qualification	**Number of Teachers per Subject**				**Total**
	Physics	**Chemistry**	**Biology**	**Mathematics**	
Ordinary Diploma	7	7	5	11	**30** (37%)
Bachelor's degree	12	8	12	15	**47** (58%)
Post-Graduate Diploma	1	1	1	0	**3** (3.7%)
Master of Education	0	1	0	0	**1** (1.2%)
Total	20	17	18	26	81

2.4.2 Total Number of Years of Professional Teaching Experience

CL4STEM participants were categorized into three groups based on teaching experience: less than 5 years, 5-10 years, and more than 10 years. The majority of participants (37%) had over 10 years of experience, followed by 33% with 5-10 years, and 30% with less than 5 years (Table 2.8). This distribution indicates that participants possessed substantial classroom experience, providing them with the necessary expertise to contribute effectively to the project.

Table 2.8: Years of Experience of participating teachers

Experience (Years)	**Subjects**				
	Physics	**Chemistry**	**Biology**	**Mathematics**	**Total**
Less than 5	7	4	4	9	24
Between 5-10	3	6	8	10	27
Above 10	10	7	6	7	30

2.4.3 ICT Devices and Usage

The CL4STEM project utilized online delivery for its modules and design, requiring participating teachers and teacher educators to access the modules and complete activities through digital platforms. This approach necessitated the use of various devices and gadgets to facilitate online access. Researchers were particularly interested in identifying the range of devices owned by teachers to support their engagement with the online modules across all subjects.

2.4.4 ICT Devices Owned by Teachers

Teacher ownership of ICT devices provided researchers with insights into their frequency of use for online learning and communication. Some teachers owned multiple devices, which were observed in use during both module implementation and Community of Practice (CoP) activities within CL4STEM. Collectively, the participating teachers owned 168 ICT devices. Smartphones were the most common (43%), followed by government-provided tablets (30%) and laptops (16%). Personal tablets (7%) and desktops (4%) were the least frequently owned (Table 2.9).

Table 2.9: ICT Devices Owned by Teachers

Device	Device by Subject				
	Physics	**Chemistry**	**Biology**	**Mathematics**	**Total**
Desktop	2	2	-	2	6
Laptop	6	6	5	9	26
Personal Tablet	2	4	4	2	12
Official Tablet provided by Government	15	11	10	15	51
Smartphone	18	14	16	25	73

2.4.5 ICT Proficiency Among CL4STEM Teachers

Most participating teachers in the CL4STEM project owned their own ICT device(s), but their levels of mastery and proficiency in using these devices varied. Table 2.10 illustrates the self-reported proficiency levels in online communications, as categorized in the CL4STEM design: beginner, intermediate, and proficient. The results revealed that 54% of participating teachers rated their ICT proficiency as intermediate, 30% as beginners and 16% as proficient. This distribution indicates that the majority of teachers fell within the intermediate and proficient categories of ICT proficiency. This suggests that they had the necessary skills to effectively engage with online resources and collaborate on digital platforms, a key factor in the successful online implementation of CL4STEM.

Table 2.10: ICT Proficiency Levels of Participating Teachers

ICT Proficient Level	Number of Teachers by Subject				
	Physics	**Chemistry**	**Biology**	**Mathematics**	**Total**
Beginner	5	2	9	8	24 (29%)
Intermediate	12	10	6	16	44 (54%)
Proficient	3	5	3	2	13 (16%)

2.4.6 Frequency of ICT Usage in Teaching

Researchers investigated which ICT devices are frequently used by participating teachers in the CL4STEM project for online learning, module implementation, and engagement in Communities of Practice (CoPs). Understanding the specific devices and usage patterns provided valuable insights into how readily teachers could complete online assignments, share information, and ask questions, thereby maximizing the project's impact. Teachers primarily used four ICT devices during the CL4STEM project: smartphones (39%), government-provided tablets (31%), laptops (11%), and projectors (8.5%). The least commonly used devices included: personal tablets (5%), desktops (3%), smart TVs (2%), and smart boards (0.5%). This data reflects usage across all subjects and participating schools. Table 2.11 summarizes the ICT devices most commonly used by participating teachers.

Table 2.11: Frequently Used ICT Devices by Participating Teachers

Device	**Usage by Subject**				
	Physics	**Chemistry**	**Biology**	**Mathematics**	**Total**
Desktop	1	-	1	3	5
Laptop	4	7	5	5	21
Personal Tablet	2	2	3	2	9
Official Tablet provided by Government	14	11	10	20	55
Smartphone	17	13	17	22	69
Smart Board	-	-	-	1	1
Smart TV	1	-	-	2	3
Projector	5	3	-	7	15

2.4.7 Frequently Used Communication Media

To maximize project impact, researchers sought to understand teachers' preferred communication channels. Participating teachers selected their preferred media from a provided list, with the option to choose multiple channels based on their experience and comfort level. WhatsApp (36%)

emerged as the most frequently used communication medium among participating teachers across all subjects. WhatsApp served as the primary platform for communication within CL4STEM Communities of Practice (CoPs). This platform facilitated communication across subjects, supported teachers with online modules, enabled resource sharing, and fostered networking and social networking among participating teachers. Other utilized media, in descending order of frequency, included email (20%), Facebook (11%), Instagram (10%), YouTube (9%), Facebook Messenger (9%), and Telegram (5%) (Table 2.12).

Table 2.12: Most Frequently Used Communication Media

Media	**Media access by subject**				
	Physics	**Chemistry**	**Biology**	**Mathematics**	**Total**
Email	14	8	11	15	48
Facebook	8	9	5	4	26
Youtube	7	5	3	6	21
Whatsapp	20	18	17	33	88
Messenger (Facebook Messenger)	8	5	3	5	21
Instagram	10	7	2	6	25
Telegram	5	2	2	3	12

2.4.8 Online Teaching and Professional Development

The CL4STEM design seeks to revolutionize teacher professional development through online platforms. This approach aims to support the government in reducing the costs associated with traditional face-to-face professional development, which are often expensive and can leave science and mathematics teachers lagging in updated teaching methodologies. To this end, researchers sought to understand the types of online teaching and professional development (OTPD) courses attended by participating teachers. All participating teachers reported experience with online platforms, either teaching or participating. 45% had actively engaged in online forums within online courses, 32% had completed online courses, and 23% had taught online (Table 2.13). These findings suggest that CL4STEM is a valuable professional development program for Tanzanian science and mathematics teachers, building upon their existing familiarity with online teaching practices.

Table 2.13: Online Teaching and Professional Development

Type of Online Engagement	OTPD by Subject				
	Physics	**Chemistry**	**Biology**	**Mathematics**	**Total**
Taught online	4	7	5	7	23
Taken an online course	7	5	7	13	32
Actively participated in online forums in online courses	12	11	7	15	45

2.4.9 Internet Access During the CL4STEM Implementation

Internet access was crucial for the implementation of the CL4STEM project, as it operated entirely online. Teachers were responsible for internet costs associated with accessing online materials and participating in Communities of Practice (CoPs). The project provided each teacher with a monthly stipend of Tsh 70,000/- to help cover data expenses. Researchers investigated teachers' typical monthly data bundle usage for general communication and their additional data needs for CL4STEM.

Table 2.14 reveals that all participating teachers used at least 1GB of data, suggesting established online communication and learning habits. Most teachers (45%) used between 6 and 15 GB, while 22% used 16-30 GB and another 22% used 2-5 GB. A notable 16% of teachers had unlimited data plans, likely indicating a strong commitment to online learning and a positive outlook for CL4STEM's success.

Table 2.14: Monthly Internet Data Usage

Amount of Data	**Data Usage by Subject**				
	Physics	**Chemistry**	**Biology**	**Mathematics**	**Total**
Less than 1GB	-	-	-	-	-
Between 2-5 GB	1	5	5	3	14
Between 6-15 GB	12	5	7	12	36
Between 16-30 GB	4	5	3	6	18
Unlimited	3	2	3	5	13

3.0 Teacher Knowledge, Attitudes and Practice

This section focuses on the impact of the CL4STEM project on teachers' Knowledge, Attitude and Practices (KAP) using a detailed analysis of multiple data sources, including the Baseline-Endline surveys, interviews, classroom observations, lesson plans and pre-tests as well as post-tests. The KAP framework introduced in Section 2 forms the analytical basis for all discussions and evaluations in this section. The analysis is structured around three core domains: subject matter knowledge which covers Knowledge of Science & Mathematics and the Nature of science & mathematics; pedagogical content knowledge and general pedagogical knowledge. These categories allow for an in-depth exploration of how the CL4STEM project has influenced teachers' professional improvement across different aspects of their teaching practices, providing insights into the transformation of their knowledge base, attitudes towards teaching and classroom practices. The findings from this section highlight the diverse ways in which the CL4STEM project has contributed to enhancing teachers' capabilities, equipping them with the tools and mindset necessary for more effective teaching of science and mathematics in secondary schools in the Iringa region, Tanzania.

3.1 Subject Matter Knowledge

Subject Matter Knowledge (SMK) refers to the depth of understanding that a teacher possesses regarding the content of a particular subject area. It involves a comprehensive understanding of the concepts, principles, theories and methodologies that are fundamental to the subject. This knowledge is essential for effectively teaching STEM subjects as it enables teachers to present accurate information, answer students' questions, connect various ideas within and outside the subject as well as reflect on the real-life applications of the concepts. A strong foundation in subject matter knowledge allows teachers to adapt their instruction to meet the diverse needs of students, thus fostering a deeper understanding of the content being taught. In this CL4STEM project, subject matter knowledge is divided into two key themes: Knowledge of science and mathematics as well as the Nature of science and mathematics.

3.1.1 Knowledge of Science and Mathematics

The box below provides a concise summary of the concept of subject matter knowledge as outlined in the conceptual framework for this report in Section 2.

- The knowledge possessed by the teacher in one or more science or mathematics disciplines:
- The 'big' ideas, key concepts and theories in the discipline
- Knowledge of interconnections between concepts/ topics within the discipline
- Ability to justify what counts as knowledge within the domain of science/mathematics

To investigate the effect of the CL4STEM project on enhancing science or mathematics participants' subject matter knowledge, a range of quantitative and qualitative data were systematically analyzed. This included conducting in-depth interviews with participants, observing their teaching practices in the classroom, reviewing their prepared lesson plans, examining their reflective thoughts on the professional development process and analyzing survey responses as well as pre-tests and post-tests. This triangulation approach provided a more thorough evaluation of how the CL4STEM project contributed to enhancing teachers' understanding of their subject areas. The detailed results of this analysis are presented and discussed in the subsequent subsection.

In STEM, the term 'Big Ideas' refers to key concepts that provide a framework for understanding and organising knowledge within the disciplines. These big ideas serve as fundamental themes that help students make meaningful connections between various topics and promote a deeper understanding of the subject. Qualitative results from the interviews show a positive change in how participants perceived and understood the 'big ideas' in science and mathematics. After engaging with CL4STEM project modules, participants reported a deeper awareness of the key concepts and principles that underpin various topics in science subjects and mathematics, indicating a shift from their previous understanding which was more fragmented. Before engaging with the CL4STEM project, many participants struggled to identify key concepts but during the endline, they were able to recognize a wider array of central concepts across different topics and offered relevant real-world examples to illustrate how these big ideas apply in practical situations. These are evidenced in the subsequent quotations:

Biology

"… Science needs observation and experimentation. When teaching my students about theoretical concepts, I know that they also need the practical part." Teacher 6706, Baseline.	"….in the topic of cell structure, key concepts are cell types, cell membranes and organelles. When teaching this topic, I prepared and showed students a 3D model of a cell structure. This approach assisted students to better understand the function and structure of organelles such as the nucleus, mitochondria and ribosomes. In addition, this approach allowed students to visualize the relationship between the cell's components and their specific roles making abstract concepts easier to comprehend." Teacher 6706, Endline.

Physics

"…physics is effectively understood by theory and experiment." Teacher 6319, Baseline	"….in the topic of work, energy and power, the big ideas are work done, kinetic energy, potential energy and power consumed. When teaching this topic, I used diagrams and physical demonstrations to show how work-done when a force is applied to move an object. In this case, diagrams helped students to visualize how forces act on objects and how these forces result in movement. For example, a diagram showing a box being pushed across a floor clearly illustrated the force vector and the displacement vector, helping students to understand the relationship between the two terminologies. On the other hand, demonstrating the big idea (work done) with physical examples made the abstract

	concept more concrete. For instance, pushing a book across a desk or lifting an object vertically helped students physically experience the process of doing work. When students saw the force applied and the object moved in real-time, this reinforced the idea that work requires both a force and a displacement in the direction of the force." Teacher 6319, Endline.

This positive change concerning the big ideas was also observed during the classroom observations. For example, Biology teacher 6713 demonstrated a strong understanding of 'big' ideas in Biology as she demonstrated the ability to identify and explain key concepts, including genetic material and its various subtopics. In her explanation, Teacher 6713 effectively broke down complex concepts into smaller, more manageable parts, ensuring that students grasped the foundational principles behind topics such as DNA structure, inheritance, and genetic mutations. This approach of breaking down and connecting these big ideas to real-world examples helped students to understand not just the theoretical aspects of genetics but also its practical applications. Furthermore, during a lesson on the topic of 'Work, Energy and Power,' physics Teacher 6318 effectively identified and clearly explained several key concepts including the fundamental idea of *work done*. This presentation not only highlighted the essential principles but also ensured that students gained a solid understanding of the topic by breaking down key concepts into digestible parts. For example, the teacher explained to students that, in physics, work is done when a force is applied to an object and the object moves in the direction of the force. He further elaborated on this concept by providing real-life examples such as lifting an object off the ground (Image 3.1.1). In contrast, the teacher highlighted situations where no work is done, such as when a person pushes against a wall that does not move (Image 3.1.2) or when an object is held stationary in place. In these cases, despite the application of force, no work is done because there is no displacement.

Image 3.1.1: Demonstration - Work is done since an object is lifted off the ground

Image 3.1.2: Demonstration - Work done is zero since the wall is not moving

The interconnections between various concepts or topics within STEM subjects are crucial for cultivating a comprehensive understanding of the integrated nature of these concepts/topics. The findings from the interviews highlight the significant impact of the CL4STEM project on enhancing the knowledge of the participants. The positive change of the participants is reflected in the responses provided across baseline and endline which offered concrete examples of their evolving understanding and ability to apply their knowledge across diverse areas of study.

For instance, in the baseline interview, teacher 6319 expressed a limited understanding of how different concepts and topics within physics are interconnected. However, during the endline interview, the same teacher demonstrated a significant improvement in understanding these interconnections showing a much clearer and more integrated understanding. This improvement is evident in the following quote: "*…when teaching the topic of 'work, energy and power', I used a video that depicted how energy from the sun is transformed into chemical energy in plants. This helped students to understand the interconnections between energy in physics and agriculture."* In addition, classroom observations further validated the insights gathered from the interviews. For instance, teacher 6521 exhibited a strong understanding of the interconnectedness between various subtopics in Chemistry. The teacher effectively demonstrated how each concept builds upon the previous one showing a clear understanding of the knowledge of interconnections between concepts/ topics within the subject. For example, teacher 6521 emphasized in a class how mastering basic chemical bonding is crucial for comprehending more advanced topics such as molecular structure and reaction mechanisms. This approach not only showcased the teacher's profound understanding of how different concepts within the subject are interrelated but also emphasized the ability of the teacher to guide students in linking fundamental principles to more advanced ideas.

The ability of the teacher to justify what counts as knowledge within the domain of science/mathematics refers to the capacity of the teacher to explain why certain ideas, concepts or facts are considered valid and important in science/mathematics. This involves the teacher's understanding of the nature of knowledge in STEM subjects including the ability to differentiate between established foundational and concepts that may change over time. Qualitative findings from interviews revealed that the CL4STEM project significantly enhanced teachers' understanding of how to justify what counts as knowledge within the fields of science and mathematics. Teachers demonstrated substantial growth in their ability to explain the relevance and rationale behind key concepts. Before the project, many teachers expressed uncertainty about the importance of certain concepts. However, after engaging in the CL4STEM project, teachers developed a deeper understanding and became more proficient in justifying the importance and relevance of the topics they taught. The project empowered them to not only explain what they were teaching but also articulate why these concepts were significant and how they connected to real-world applications. This improvement in teachers' ability to justify knowledge is reflected in the following quotations from participating teachers, which demonstrated their enhanced confidence and clarity in explaining the rationale behind key scientific/mathematical principles:

Physics

"…I teach the laws of motion in physics, but I struggle to explain how these laws	"…. Newton's laws of motion are not just rules to follow; they are grounded in centuries of experimental evidence. Newton's laws of motion are

were validated through experiments and evidence." Teacher 6318, Baseline.	not just abstract scientific principles; they are deeply embedded in real-life processes, from the safety of car rides to the performance of athletes, the design of machines and even the exploration of space." Teacher 6318, Endline.

Mathematics

"…I teach students about proportions and percentages, but I do not explain why they matter in real life." Teacher 6107, Baseline.	"…. proportions and percentages are everywhere; from calculating discounts to understanding statistics in news reports. These concepts are crucial in daily decision-making." Teacher 6107, Endline.

In addition to the interview results, classroom observations also highlighted the positive impact of the CL4STEM project on teachers' ability to explain and justify key scientific concepts. For example, a physics teacher was able to effectively explain how Newton's laws of motion were derived through experiments and observations. The teacher demonstrated the first law by showing how an object continues moving unless acted upon by an external force, using the example of an object on a frictionless surface. The teacher also connected this principle to real-world applications such as vehicle safety, explaining how Newton's first law explains why we continue moving in car crashes and the essential role of seatbelts. In the case of mathematics, the teacher demonstrated how percentages represent a part of a whole and showed students how to convert between fractions, decimals and percentages. The teacher was able to effectively explain how percentages are used in various real-life situations, such as calculating discounts, interest rates, or test scores.

Research findings have revealed that the CL4STEM intervention had a positive impact on teachers' understanding of how to justify what counts as knowledge within the fields of science and mathematics. Teachers demonstrated substantial improvement in explaining why certain ideas, concepts or facts are considered valid and important in science/mathematics.

3.1.2 Nature of Science and Mathematics

The nature of science and mathematics knowledge possessed by teachers plays a significant role in shaping and influencing their classroom practices. Teachers' understanding of the core principles, methods and connections within these disciplines directly impacts how they design and deliver lessons, engage with students and facilitate learning. The box below provides an overview of the foundational understanding of the nature of science and mathematics as it has been conceptualized in this study. This conceptualization encompasses the key principles, methods and characteristics that define these fields of knowledge. The findings related to the nature of science and mathematics are presented in the following subsection.

- Teachers' knowledge of the nature of science, such as its empiricism; that it is situated in a particular historical-, social, and economic context; that it requires creativity and imagination; and that modern science is a collaborative enterprise located in institutionalized spaces.
- Teachers' knowledge of the nature of mathematics; beliefs about mathematics; processes of mathematics: problem-solving, reasoning, proving and communicating; mathematisation of thinking or ability to represent something mathematically.
- Teachers' ability to communicate the nature and structure of science/mathematics to students

The nature of science was explored by examining its empirical foundation, the influence of historical, social and economic factors as well as the role of creativity and imagination in scientific inquiry. The results derived from both qualitative and quantitative data are detailed in the subsequent subsections.

Qualitative findings from interviews indicate that there was a noticeable enhancement in the participants' understanding of the empirical nature of science after being engaged with the CL4STEM project modules. Before the project, many teachers had limited awareness of how scientific knowledge is built on empirical evidence with a focus on theoretical concepts. However, after the project, teachers demonstrated a stronger understanding of how experimentation and observation form the basis of scientific inquiry. For example, in physics, teachers successfully led students through a series of hands-on experiments covering a range of topics that were highly practical and relevant to real-world applications. These experiments allowed students to directly engage with key concepts by observing and measuring the effects. For instance, when asked about the nature of science, teacher 6304 offered the following responses that demonstrate an understanding of the fundamental principles that define science:

"…physics is effectively understood by theory and experiment." Teacher 6304, Baseline.	"…learning physics is normally done through experiments and observations. As a teacher, I often emphasize the importance of experiments and observations in learning physics as they provide students with firsthand experience of how theoretical concepts are applied in the real world. For example, when teaching the concept of work done, I guided students through an experiment where they measured the force applied to an object and the distance it moves, allowing students to be able to calculate the work done. Experiments are essential in science because they are the foundation of empirical knowledge. The data allows us to test hypotheses, validate theories and refine our understanding of the laws that govern the physical world." Teacher 6304, Endline.

In addition, classroom observations provided further evidence that supported the findings from the interviews that the implementation of the CL4STEM project improved the knowledge of the teachers concerning the nature of science. Teachers understood the importance of experimentation and observation in science and effectively integrated these practices into their teaching methods. For instance, teacher 6508, while teaching organic chemistry, deliberately used hands-on experimentation (Images 3.1.3 & 3.1.4) as essential components of the lesson to convey core concepts and solidify fundamental scientific principles. This approach not only highlighted the empirical nature of scientific inquiry but also helped students to recognize the iterative nature of scientific exploration where hypotheses are tested, results are observed, and conclusions are drawn based on empirical evidence.

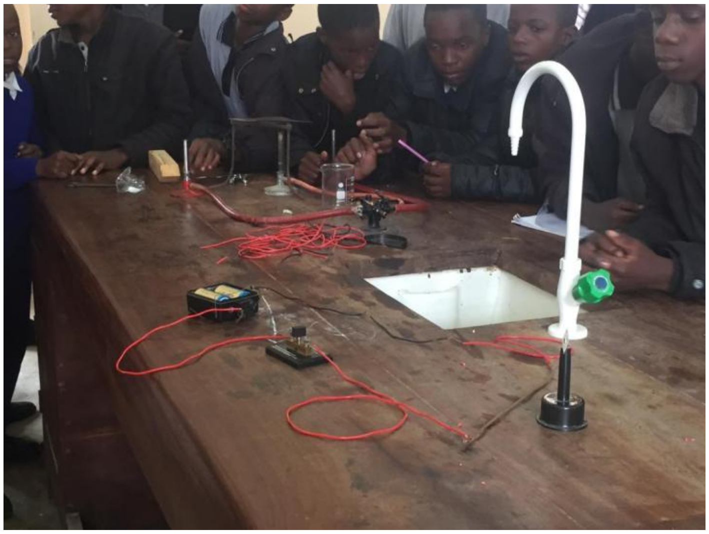


Image 3.1.3: Demonstration of the hands-on experience in the lab

Image 3.1.4: Demonstration of the characteristics of organic compounds

Figure 3.1.1: Teachers' knowledge of the nature of science

Besides the qualitative findings, the teachers' knowledge of the nature of science was also assessed quantitatively. To explore this aspect, science teachers were presented with a series of questions designed to evaluate their knowledge of the nature of science particularly concerning empiricism. Figure 3.1.1 provides a comparison of the teachers' responses during baseline and endline surveys. Results indicate that while many practices related to inquiry-based learning and empirical science were already being utilized by teachers, endline results indicate that the CL4STEM project helped to reinforce and enhance these behaviours, particularly in the areas of hypothesis formulation and experimentation that specifically pattern to the empirical nature of science. As an example, there was a notable increase in physics teachers' awareness of the empirical nature of the subject with improvements of about 14% in hypothesis formulation and 5% in experimentation. (Figure 3.1.2)

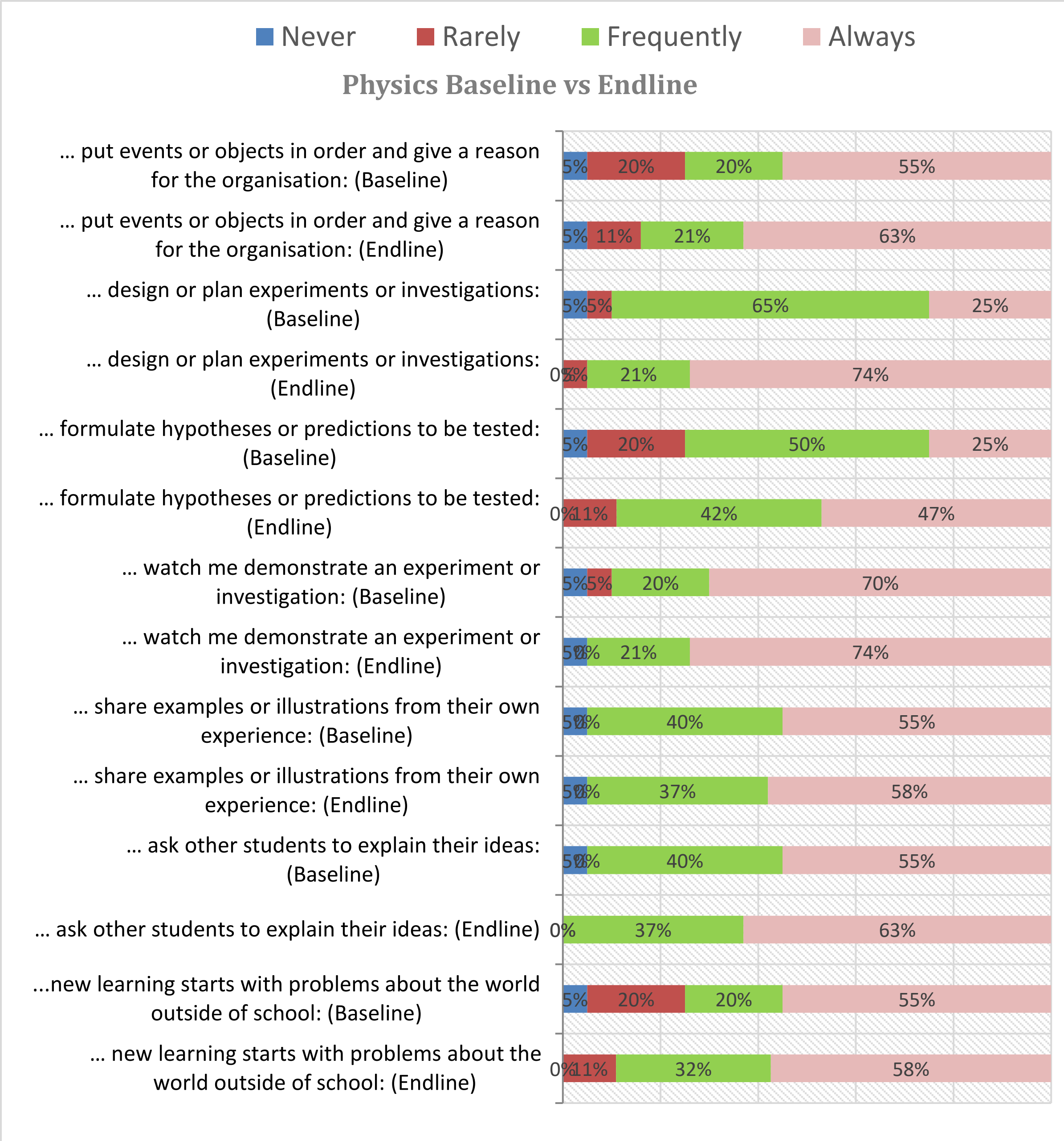


Figure 3.1.2: Physics Teachers' responses to various questions that were assessing their understanding of the empirical nature of science

Teachers' knowledge of the role of creativity and imagination are essential components of scientific work. It highlights the idea that science is not just about memorizing facts but it also involves thinking creatively to generate new ideas, ask innovative questions, design experiments, and solve problems. Teachers who recognize this role can better foster a classroom environment that encourages students to think creatively and imaginatively in their scientific explorations and inquiries. The qualitative results from the interviews revealed that the CL4STEM project had a significant positive impact on enhancing creativity in the teaching of science subjects. Teachers reported that the CL4STEM project significantly enhanced their understanding of how to effectively integrate creativity into teaching science. According to their feedback, the project introduced a wide range of innovative strategies that allowed them to enrich their teaching practices. For instance, many teachers began incorporating locally available resources, incorporating technology (video) in teaching, using real-world applications, and using common local materials found in their communities to conduct experiments and demonstrations that made abstract scientific concepts more relevant to students' lives. The following quotations, shared by teachers during the baseline and endline interviews, provide evidence:

Physics

"…In my class, I motivate students by telling students the real applications of physics." Teacher 6319, Baseline.	"…to address the diverse learning needs of my students, I employ a variety of creative approaches in my teaching. For example, when teaching the topic of work, energy and power, I used locally available materials to demonstrate the concept of work-done according to the physics definition. I asked one student to lift a heavy object without moving and another to lift the same object and move. Afterwards, I prompted the students to discuss the differences between these two experiments and how they relate to the concepts of work-done in physics and real-life experiences. I also used a

	video from YouTube to enhance learning" Teacher 6319, Endline.

Chemistry

"…the common teaching methods I use are lecturing and group discussions." Teacher 6516, Baseline.	"… CL4STEM project has significantly enhanced my teaching by introducing innovative strategies that have made my lessons more engaging and practical. Now, I actively incorporate locally available materials into my lessons, linking theoretical concepts to real-life experiences to make learning more relevant for my students. For example, when teaching about hydrocarbons, I used materials that are commonly available in students' homes such as kerosene and charcoal to demonstrate the properties and uses of different fuels. This hands-on approach not only helped students grasp complex scientific concepts but also encouraged them to connect what they were learning to the real applications around them, thus promoting a deeper understanding of the nature of science." Teacher 6516, Endline.

Biology

"…most of the time I use the lecturing method so that I can complete teaching all topics." Teacher 6715, Baseline.	"… CL4STEM project has equipped me with skills to teach Biology more effectively. Now I encourage students to prepare materials for studying specific topics from their environment. This creative approach not only helps to make the lessons more relevant to the student's everyday lives but also empowers them to take ownership of their learning

	process. For instance, when teaching the concept of the 'balance of nature', I asked students to observe and analyze the natural surroundings in their environment. I asked students to collect different species such as local plants and microorganisms to better understand how these components interact and maintain equilibrium within an ecosystem." Teacher 6715, Endline.

The teachers' understanding of the role of creativity in teaching science was also evaluated through classroom observations. The findings reveal that teachers showed significant progress in incorporating creativity into their teaching methods. This improvement was particularly evident through various innovative strategies such as using interactive activities, locally available resources, real-world applications and hands-on experiments. For instance, teachers encouraged students to engage in role-playing exercises to demonstrate scientific concepts or to use visually locally available aids and technology such as video from the internet to make abstract ideas more accessible. These efforts not only enhanced student engagement but also promoted a deeper understanding of the scientific content.

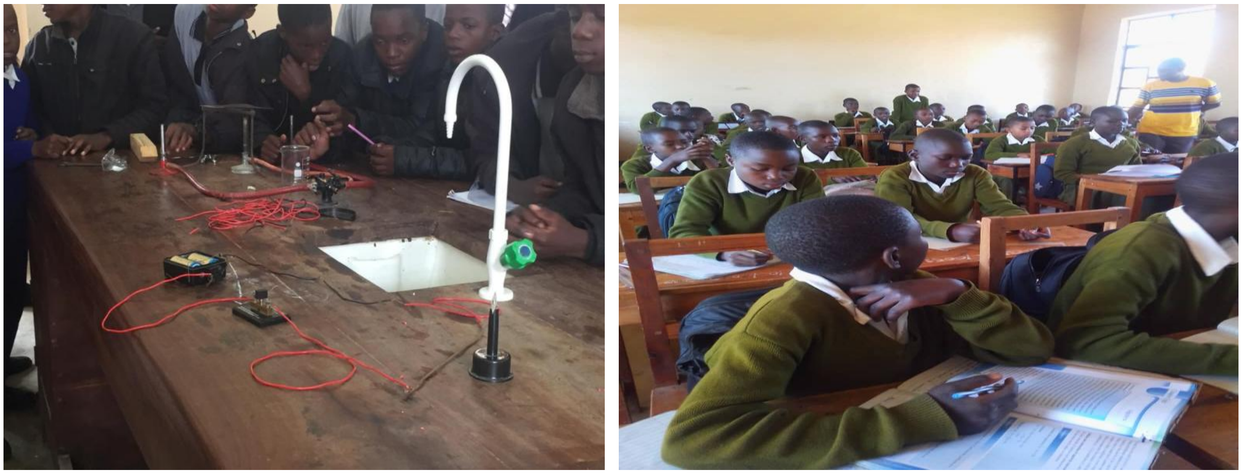


Image 3.1.5: Creativity in Teaching STEM Subjects

The nature of mathematics involves teachers' understanding of the fundamental processes in mathematics, which refers to teachers' knowledge of the core methods and techniques that are used in mathematics. This includes understanding how mathematical concepts are developed, applied and connected as well as the processes involved in solving problems, reasoning logically and identifying patterns. Qualitative results suggest that the CL4STEM project had a positive impact on the understanding of the nature of mathematics as mathematics teachers demonstrated improved abilities to explain key concepts related to problem-solving processes, logical reasoning and pattern identification. Teachers were better equipped to break down mathematical concepts into understandable steps, making it easier for students to understand the underlying principles of mathematics. The quote below confirms the impacts of the CL4STEM project:

"…I use drawing or virtual to develop mathematical concepts." Teacher 6109, Baseline.	"…when teaching mathematics, I ensure that each concept is explained clearly and logically, by breaking the concept down into manageable steps. I make a conscious effort to relate each topic to the local context, using real-life examples that are familiar to the students, using figures, charts, equations and video. This approach helps students to understand the basic principles of mathematics and see the

	practical applications of mathematics in their everyday live." Teacher 6109, Endline.

In addition to the qualitative findings, the quantitative results also support the conclusion that the CL4STEM project significantly improved teachers' understanding of the nature of mathematics. This enhancement is particularly noticeable in the teachers' responses to questions concerning the nature of mathematics as illustrated in Figure 3.1.3. After the intervention, the responses of the teachers revealed a deeper and more understanding of essential mathematical principles as well as the processes involved in mathematical reasoning and problem-solving. For instance, teachers' understanding that mathematics relies on logic rather than intuition rose by 7%, while their knowledge regarding the need to provide students with sequentially planned mathematical learning experiences to help them make connections between different math topics increased by 4%.

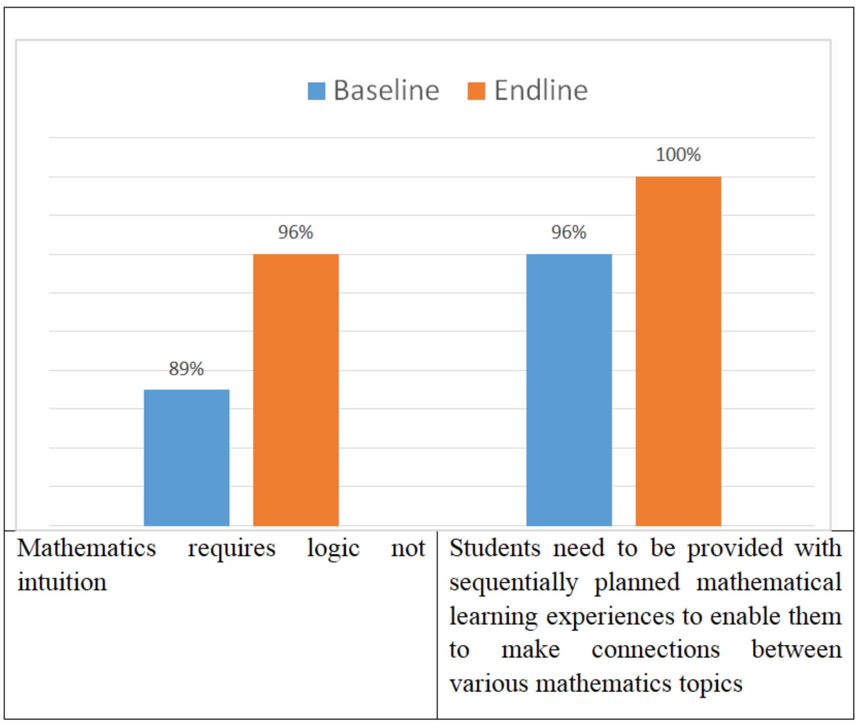


Figure 3.1.3: Responses of mathematics teachers who correctly answered questions assessing their understanding of the nature of mathematics.

The nature of science and mathematics was also examined by assessing the ability of the teachers to effectively communicate the nature and structure of science/mathematics to students. Qualitative data gathered from interviews indicate that, after the CL4STEM project, teachers showed a marked improvement in their ability to effectively communicate the nature and structure of science and mathematics to their students. Teachers were able to explain the fundamental principles, organization and processes of science and mathematics in a clear, concise and easily understandable manner to their students. The teacher demonstrated an enhanced ability to break down complex concepts into simpler terms ensuring that students understood the key ideas without confusion. The following quotations support this positive change:

Science (Biology):

"…I am using food tests to enable students to know the food nutrients available in the food sample given." Teacher 6719, Baseline.	"…In the classroom, I used a variety of strategies to effectively teach genetics. For example, I explained fundamental concepts such as DNA, genes and alleles by using familiar local examples that made the content easier for students. To help students visualize abstract concepts, I incorporated visual aids like diagrams of DNA and chromosomes as well as locally sourced models. In addition, I used everyday examples such as the hair or eye colour of family members to explain dominant and recessive traits. To further deepen students' understanding, I gave students hands-on activities in groups or individually." Teacher 6719, Endline.

Mathematics:

"…knowledge of mathematics could be obtained through	"…I understand that mathematics demands continuous practice rather than mere memorization. Mathematics also requires critical thinking and the ability to engage various

seminars and sharing ideas with peers.” Teacher 6120, Baseline.	learning domains to solve real-life mathematical problems. Therefore, when teaching topics such as algebra, proposition or transformation, I ensured that I explained each concept step by step and provided as many real-life examples as possible to help students achieve a clear understanding of the mathematical concepts.” Teacher 6120, Endline.

The observed positive changes in how teachers communicated the nature and structure of science and mathematics to students were further observed through classroom observations. These observations highlighted that teachers not only adopted more effective communication strategies but also demonstrated a clearer and more structured approach to presenting scientific and mathematical concepts. Teachers were using a variety of methods such as real-world examples, visual locally available aids and interactive activities to enhance students’ understanding. This shift in teaching style was evident in the increased engagement and comprehension among students as noted during the classroom observations. These findings underscore the impact of the CL4STEM project on teachers’ ability to effectively convey scientific and mathematical concepts.

Image 3.1. 6: Creativity in Teaching Mathematics

3.2 Pedagogical Content Knowledge

Pedagogical Content Knowledge (PCK) represents a crucial bridge between subject matter expertise and effective teaching. This section explores how the CL4STEM project enhanced participating teachers' knowledge, attitudes, and practices (KAP) to improve instruction. The study examined how teachers were empowered with PCK to effectively address students' misconceptions and learning difficulties, select and implement appropriate instructional strategies, consider the learning context, use effective representations of content, and demonstrate a deeper understanding of curriculum knowledge. Ultimately, the evidence provided by the project findings highlights the critical role of PCK in fostering deeper student understanding and achievement.

3.2.1 Students' Misconceptions and Learning Difficulties

Effective teaching and learning centre on understanding where the students are starting from. The CL4STEM project explored the change in teachers' knowledge, attitudes, and practices on the crucial role of students' prior knowledge, misconceptions, and learning difficulties in shaping the teaching and learning experience, based on the following three aspects:

● Knowledge of students' prior conceptions, misconceptions, and ways students think. ● Knowledge of concepts that students find difficult to understand. ● Ability to use students' errors to understand their ways of thinking and design learning experiences to support their STEM learning.

Regarding the first aspect of teachers' knowledge of students' prior conceptions, misconceptions, and ways in which students think, the project results reveal that interactions with the modules enhanced the participating teachers' knowledge of the specific approaches that can be used to assess students' prior knowledge. For example, the quotes below indicate that although the teacher appreciated the fact that students are not empty slates to be filled with concepts and ideas, she did not particularly describe the implications of this fact or how she could use it in designing teaching and learning experiences to address it. However, the endline interviews indicate a change of perspectives as the teacher now not only acknowledges the existence of prior knowledge but includes it in the actual practice.

"I know that students are not a tabula rasa; they have prior knowledge." Teacher 6709, Baseline	"Before starting a new topic or sub-topic, I ask them what they do to understand about the concept before I start teaching it." Teacher 6709, Baseline

This change of perspective on the importance of prior concepts was further evidenced by the survey results on some aspects of prior knowledge, as summarized in the Table below. The data indicate that after interactions with the modules, more participants appreciate the importance of using familiar scenarios as a starting point for drawing students to express their existing understanding of the concepts. The teachers recognized the need to assess how students use foundational knowledge as a bridge to grasp new ideas and to facilitate them to connect academic content to their everyday experiences, observations, or practical knowledge of the world around them. The percentage of mathematics teachers who strongly agreed on the importance of unravelling students' before teaching a concept increased significantly during the endline survey as compared to the baseline (Table 3.1)

Table 3.1: Mathematics Teachers' response to prior conceptions, misconceptions, and ways students think

Question	Baseline	Endline
During my lessons, new learning always starts with problems about the world outside	37%	41%
Students misconceptions are a fascinating source of information about how they think about a particular mathematics topic (Strongly Agree)	23%	32%

The CL4STEM Lesson Plan template had a specific component on "testing prior knowledge," which required the teachers to describe how they plan to test students' prior knowledge or ways through which students can demonstrate their thinking. This is an improvement from the traditional lesson plans that the teachers were used to. Section 5 of the lesson plan requires the teacher to identify the prerequisite knowledge that students should have for the specific topic at hand. For example, in planning his lesson, Teacher 6521 indicated that he would test the students' prior knowledge by dividing them into small groups and asking them to brainstorm on everything they know about organic chemistry. Then he would encourage them to share their ideas and build on each other's contributions. This collaborative activity activates prior knowledge, fosters discussion, and identifies common misconceptions.

Classroom observations of the participating teachers provided more evidence that supports their enhanced practice in this testing prior knowledge. For instance, Teacher 6507 was observed to appropriately address the aspect of students' prior conceptions by introducing the lesson with an activity of asking students to brainstorm in groups on their understanding of the concept of "transformer" in physics (Image 3.2.1). He listed down all the responses and later on used the answers to describe what was correct and what was not. This approach demonstrated the teacher's ability to assess students’ prior knowledge and to use their errors to understand their ways of thinking and design targeted learning experiences. By doing so, the teacher created a classroom culture where errors were viewed as opportunities for learning rather than failures and encouraged students to share their thoughts openly without fear of judgment. Peer explanations also provided alternative perspectives and reinforced collaborative learning.

In further classroom observations, Teacher 6712 administered a quick pre-lesson quiz to test students’ prior understanding of the concepts “organic chemistry” and “organic compounds” before introducing them to the students. The teacher then used the quiz results to adjust teaching strategies and address misunderstandings in real-time before proceeding deeper into organic chemistry concepts. This quick assessment provided valuable information to the teacher about students' prior knowledge and helped them to tailor the instruction accordingly. Additionally, it encouraged students to reflect on their mistakes and articulate what they learned from them.

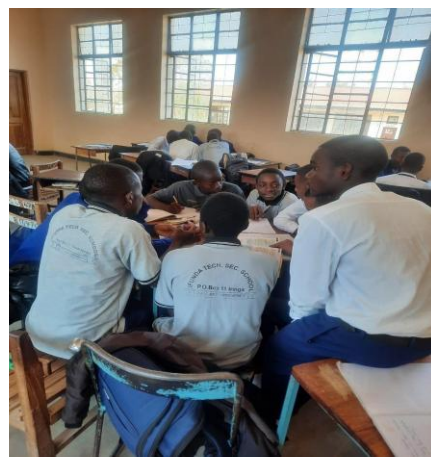


Image 3.2 1: Students working in groups

On the second aspect of knowledge of concepts that students find difficult to understand, the findings indicate that, before the intervention, some of the teachers could not clearly describe what constitutes students’ learning difficulties in its wider context. Most teachers could only identify the language barrier i.e., switching from Kiswahili in Primary school to English medium in Secondary school, as the main learning difficulty. Moreover, some of the participants could not clearly describe the relevance of students' learning difficulties in influencing the teaching and learning outcomes. For example, the summary below indicates the responses of a teacher participant during the baseline and endline interviews. Findings show that after engaging with the modules, the teachers were able to identify and elaborate on the challenges within specific subject areas and develop strategies to address them as evidenced by teacher 6712.

"The only learning difficulty I can think of for my Form One Biology students is the language barrier." Teacher 6712, Baseline.	"One of the most common learning challenges students face in biology is the fear of the subject, which stems from the widespread belief that biology is difficult. This fear often leads to a lack of effort and engagement as students feel overwhelmed before even trying. To address this issue, I employ a variety of strategies to help my students overcome their anxiety and build confidence in their abilities. For instance, in teaching cell structure, I divide complex concepts into smaller, more manageable parts to ensure that students grasp foundational ideas before progressing to more challenging materials. Additionally, I use real-world examples and interactive and hands-on learning activities, such as simple observations, to make the concepts more engaging and relatable. thus, making them feel intimidated." Teacher 6712, Endline.

The baseline surveys revealed that some teachers had negative attitudes towards learning difficulties, associating them with laziness, poor dedication, and unwillingness to work hard, as summarized in the following quotes that show the change of attitude:

"Students are lazy, and do not want to torture themselves by doing more practice in mathematics." Teacher 6109, Baseline.	"Students from low-income families may lack the necessary learning materials, such as mathematical sets, textbooks, etc. This may make them stressed and affect their learning." Teacher 6109, Endline.

This provides evidence that the CL4STEM project provided teachers with professional development opportunities that addressed their own beliefs and practices to enable them to create supportive and encouraging learning environments where students feel comfortable asking questions, seeking help, and making mistakes without fear of judgment. This is evidenced by the change in perspective of the same participant during the endline survey. The participant now recognizes that some of the learning difficulties and the seeming lack of interest and laziness may originate from other inherent causes. Additionally, the participants demonstrated the ability to design learning experiences to overcome difficulties and support students' STEM learning. For example, during lesson planning, teacher 6712 recognized the kinds of learning difficulties anticipated in the topic of Cell structure. "*Normally students face difficulties in distinguishing some of the scientific terms in this topic. I have modified my lesson plan to ensure that I address these confusions before proceeding with the lesson*." This was further attested by Teacher 6703, who explained, "Some *students encounter difficulties in understanding the topic of genetics, primarily due to the specialized and technical language used in the subject. Biological terminology can be complex as it often features terms originating from Latin or Greek roots that are not familiar or part of everyday English. This makes it particularly challenging for students to fully grasp the content.*" In her lesson plan, the teacher included classroom activities that aim at addressing this challenge.

Through interactions with the three selected modules in each of the four subjects, the project enhanced the teachers' knowledge of areas that students find difficult to understand. This is supported by results from the surveys, as well as the classroom observations. It was interesting to note that, during the baseline interviews, about 77.3% of the participating teachers in all four subjects were able to identify concepts that students find difficult to learn in the specific modules. However, after interactions with the modules, the percentage of those who could clearly identify the anticipated areas of difficulty increased to 82.1%. Furthermore, the participants went further to use the knowledge to plan for some activities to address the difficulties. For example, one physics teacher identified inadequate mathematical competencies as one of the difficulties in learning physics concepts that require computations.

“Some students in my class have weak mathematics backgrounds, as such, they face difficulties when learning physics concepts that require the use of formulas and computations. As a result, some of them opt not to study physics as it is an optional subject. To address this challenge, I plan to use real-world examples to teach abstract concepts. I have designed classroom activities that emphasize problem-solving, critical thinking, and conceptual understanding rather than memorization” Teacher 6318, Endline.

Another example is chemistry teacher 6519, who during the implementation of the chemistry module “Atomic Structure” recognized that students face difficulties in distinguishing the subatomic particles protons and electrons, particularly concerning their charges and positions in the atom. To address this, he designed visual aids using locally available materials to represent an atom. Describing his lesson planning he said: “*Students are often unfamiliar with the overall abstract concept of the atom and its structure. To resolve this, I have designed my lesson to begin with a step-by-step introduction to the atom, starting with its fundamental components and gradually building up to more complex ideas. I also intend to incorporate hands-on activities such as constructing atomic models using simple local materials to make the concept clearer and more understandable*” Teacher 6519, Endline.

Further evidence regarding a change in teachers’ perspectives on their role in combating learning difficulties was obtained from the survey results. The chart below (Figure 3.2.1) shows that the percentage of science teachers that strongly agreed on the fact that learning difficulties are contributed by the teacher’s professional challenges rather than problems with students significantly increased during the endline survey as compared to the baseline.

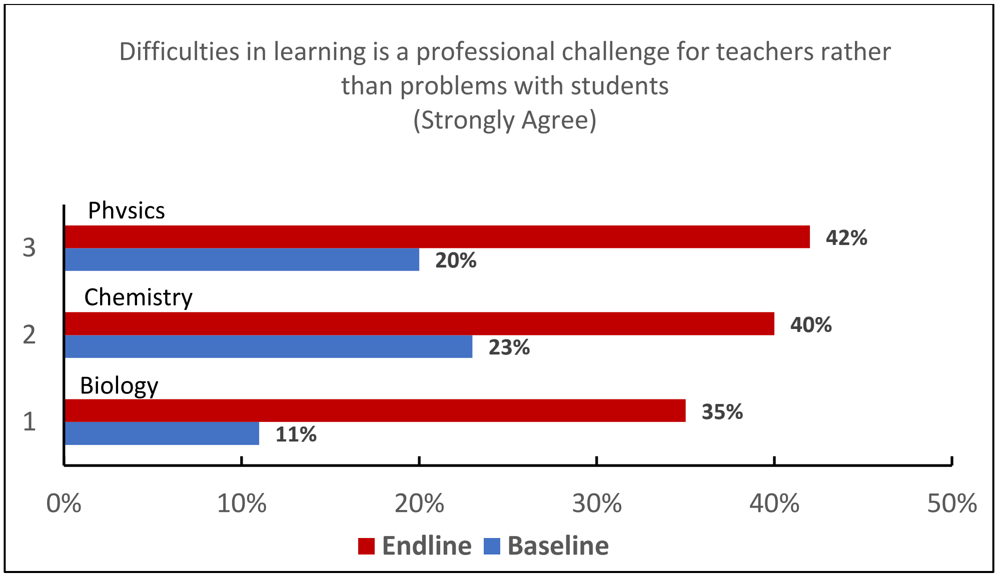


Figure 3.2 1: Teachers' Influence on Student Learning Difficulties

This change in perspective implies that the project has empowered the teachers to take greater ownership of students' learning. By acknowledging their professional challenges as significant contributors to learning difficulties, the teachers are more likely to seek solutions and engage in continuous professional development. The results strongly suggest a need for ongoing and high-quality teacher training programs that address the specific professional challenges identified by teachers, such as pedagogical skills, content knowledge, assessment skills, and technology integration.

Regarding the third aspect of teachers' ability to use students' errors to understand their ways of thinking and to design learning experiences that support their STEM learning, evidence from the project results indicates positive outcomes. Classroom observation revealed that the project enhanced' teachers' ability to actively use diagnostic teaching to analyse students' work to identify common errors. For example, Teacher 6718 created a more student-centred learning environment when teaching the topic "Genetics" in biology, specifically to identify any errors in the concept of hereditary disorders. The teacher engaged her students in inquiry-based learning and critical thinking by asking them to explain the sources of various disorders that they encounter in their communities. The teacher then gathered their perspectives on the issue and corrected the wrong information. Describing how she changed her practices based on student errors, the teacher reflects: "*Before this professional development, I often presented the concepts of dominant and recessive traits in a very simple way. I would provide definitions, give a few examples, and then have students practice solving simple problems. However, I noticed that many students were struggling to apply these concepts to more complex situations. For example, they consistently made errors in determining the possible genotypes and phenotypes of offspring in dihybrid crosses. Based on my analysis of their errors, I realized that many students were having difficulty visualizing the process of meiosis and how it contributes to genetic variation. I therefore intend to use more visual aids, such as diagrams and models of chromosomes and meiosis, to help them visualize the processes involved in inheritance*."

The key takeaway from this reflection is that the teacher identified specific errors that students are making in learning the concepts, analysed the root causes of these errors, identified specific changes to her teaching practices to address these challenges for future improvement, and reflected on the impact of these changes on student learning.

Overall, the results indicate that the CL4STEM project has increased the participating teachers' knowledge of the significance of students' prior conceptions, misconceptions, and concepts students find difficult to learn in the teaching and learning of STEM subjects. The results further evidence increased practice of incorporating students' misconceptions and conceptual difficulties in designing learning experiences for effective and efficient teaching of mathematics and science. The teachers demonstrated an increased capacity to use students' pre-existing knowledge to introduce new concepts. Furthermore, the participating teachers now possess a refined ability to identify specific areas of difficulty for individual students. This improved diagnostic skill set allows them to design more targeted instructional support. The project significantly enhanced teachers' understanding of key concepts and common students' misconceptions in the specific modules of science and mathematics subjects they interacted with. This deeper understanding has empowered them to address students' learning challenges more effectively. The teachers demonstrated a significant increase in confidence in their ability to address challenging content and support struggling learners. Ultimately, this project has empowered teachers with the knowledge and skills necessary to proactively assess and use students' prior knowledge, identify and correct misconceptions, and address student learning challenges, thus fostering a more equitable and successful learning experience for all. This newfound confidence will positively impact their overall teaching practice and enhance students' learning outcomes.

3.2.2 Instructional Strategies

Instructional strategies are the specific methods and techniques that teachers use to guide students' learning. Good instructional strategies are the key to making the learning of STEM subjects more engaging, effective, and relevant for students as they develop critical thinking, promote a deeper understanding of concepts, and cultivate collaborations. The CL4STEM project focused on promoting strategies that integrate content knowledge with effective pedagogy based on the following aspects:

- Knowledge of different instructional strategies and resources.
- Scientific thinking skills in experimentation, observation, inferring, and categorizing through data gathering, graph plotting, and problem-solving.
- Mathematical thinking skills in mathematization, reasoning, and argumentation.
- Knowledge of topic-specific pedagogical strategies and resources.
- Ability to use different instructional strategies and resources to address the diverse needs of learners, including students' misconceptions and learning difficulties.

Results from the project show that it has enhanced participating teachers' appreciation of the importance of instructional strategies and resources in achieving learning objectives. The chart below provides good evidence of significant change in perspectives on the impact of teacher's use of effective teaching methods.

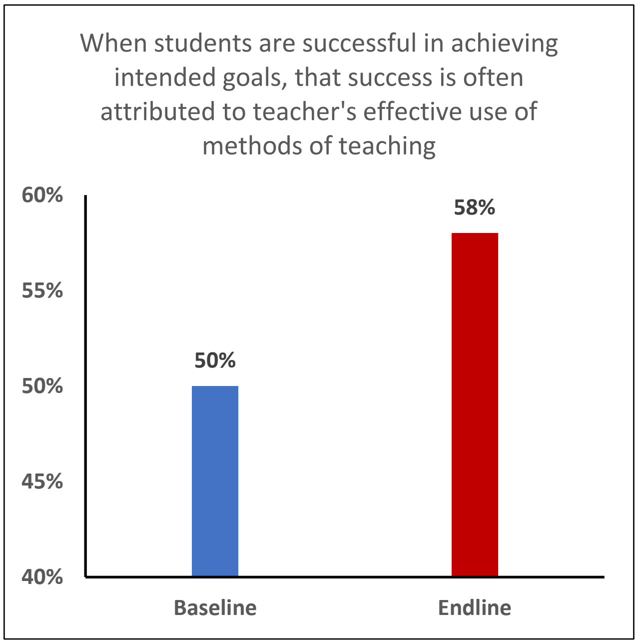


Figure 3.2.2: Teachers Belief and Understanding of Effective Pedagogy

This finding suggests a positive shift in science teachers' beliefs and understanding of effective pedagogy (Figure 3.2.2). The increase of 8% in the number of teachers strongly agreeing with the statement indicates a growing recognition of their crucial role in student success. They are more likely to see themselves as active agents of change in the learning process rather than simply facilitators of predetermined content. Additionally, the finding emphasizes the importance of focusing on high-quality instruction as a key aspect of student achievement. It shows the need for ongoing professional development that equips teachers with a diverse range of effective instructional strategies. The increased emphasis on effective instructional strategies likely reflects a shift towards more student-centered approaches to teaching and learning, such as demonstrations, group work, and hands-on activities. The teachers are more likely to experiment with new strategies, reflect on their effectiveness, and continuously refine their instructional approaches based on student needs and learning outcomes.

In another question, the percentage of science teachers who appreciated the importance of using real-life experiences as a major source of examples when teaching physics, chemistry, and biology concepts increased from 60% during the baseline to 66% during the endline (Figure 3.2.3)

Using real-world examples implies that the teachers will be able to design instruction strategies that aim at deepening student understanding of scientific concepts rather than mere memorization. When students see how science applies to their own lives and the world around them, they are more likely to grasp abstract ideas and retain information. When students can connect science to their own experiences, they are more likely to be engaged in the learning process and actively participate in class discussions. The strategy of connecting science to real-world issues is vital in assisting students to develop scientific literacy. Scientific literacy is essential for critical thinking that develops decision-making skills about various issues and societal challenges.

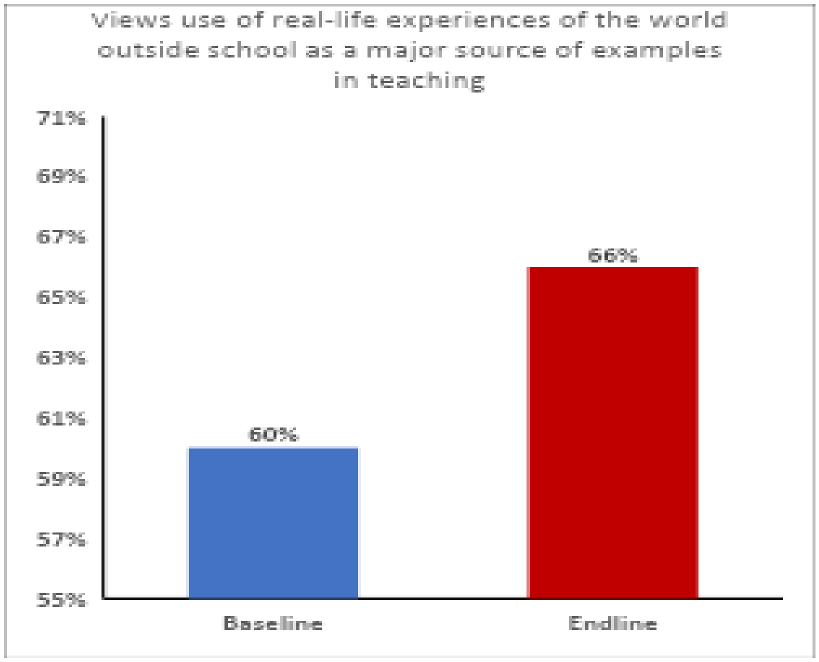


Figure 3.2 3: Real Life Experiences as the major source of example

These observed shifts in beliefs can translate into improved student engagement and deeper.

learning experiences in the classroom. For example, the following quotes of the responses from the baseline and endline interviews of the participating teachers show a significant change in perspectives. During the baseline interviews, teacher 6113 showed a preference for a teaching approach that relies heavily on examples and explanations. This strategy, while having some values, can have several weaknesses in a mathematics lesson. It implies that students primarily become passive recipients of information, which can lead to disengagement as they are not actively involved in the learning process. They might rely more on memorizing the examples rather than developing a deeper understanding of the underlying concepts. A learning environment dominated by verbal explanations and abstract concepts does not allow the engagement of diverse learners and their learning styles, such as visuals and hands-on. However, during the endline interviews, the teacher demonstrated enhanced knowledge in selecting instructional strategies that support multiple forms of student engagement. His attitude shifted towards valuing active learning strategies and multiple forms of representing content rather than the passive, teacher-centred approaches.

"I give a lot of examples and discussions in my lesson." Teacher 6113, Baseline.	"I employed simple classroom activities such as cutting oranges into parts to demonstrate the concept of "fractions" and tossing coins to demonstrate the concept "probability." I assigned these activities to students in groups to enhance participation and encourage peer learning while reinforcing the concepts." Teacher 6113, Endline.

This was further demonstrated by the responses from the coded baseline and endline interviews of teacher 6303. The quotes show progressive responses to the queries on instructional strategies.

"I mainly use group activities, where students are given work to do or solve problems in their small groups." Teacher 6303, Endline	"I use a variety of instructional strategies, such as observations (students observe demonstrations), experiments, plotting graphs, and problem-solving. I also use models where possible to reinforce how information is generated while giving explanations and examples that are familiar to the students." Teacher 6303, Endline

This is a positive development because the teacher was able to diversify instructional strategies beyond solely depending on group work. This has the advantage of increasing students' engagement since different students learn in different ways. By incorporating a variety of strategies like lectures, demonstrations, discussions, independent work, and technology integration, the teacher can better cater to the diverse learning styles within the classroom. This keeps students more engaged and motivated. Repetitive use of a single strategy can lead to boredom and disengagement.

Regarding the teachers' scientific skills in experimentation, observation, inferring, and categorizing through data gathering, graph plotting, and problem-solving, analysis of the project results indicates an increased teachers' awareness of electing and implementing the right instructional strategies. The participating teachers demonstrated an increased ability to create a dynamic and effective learning environment that helps students build a strong foundation of scientific skills in experimentation and observation. For example, Teacher 6700 when teaching "Cell Structure" in biology, employed a variety of instructional strategies such as categorization of different plants and animals' cells, observations of various plants through a microscope, and drawing diagrams of cells. He went beyond the sole use of textbooks and included actual materials in the lesson. This was demonstrated in the change of perspectives from the baseline to the endline surveys, in the three questions below:

Table 3.2: Change of perspectives from the baseline to the endline surveys

Question	Baseline	Endline
I always allow students to share their examples or illustrations from their own experiences	43%	45%
I always allow students to watch me demonstrate an experiment	52%	52%
I always design or plan experiments or investigations	29%	49%

These findings imply further evidence of an increase in instructional strategies that foster student engagement. The teachers encourage students to share their own experiences and illustrations to create a more engaging and inclusive learning environment. In such a learning environment, students feel valued and respected when their unique perspectives are acknowledged and incorporated into the learning process. Sharing and discussing personal experiences can promote critical thinking skills as students analyze, compare, and contrast different perspectives. Teachers need to be skilled at guiding students in sharing their experiences in a constructive and meaningful way. This may involve providing clear instructions, setting expectations, and facilitating respectful discussions. It was further observed that the percentage of teachers who always allow students to watch them demonstrate an experiment did not change. This suggests that while teachers may recognize the importance of demonstration in science education, their practices regarding student observation may not have significantly changed during the intervention. The baseline percentage was already high, indicating that allowing students to observe demonstrations was already a common practice among participating teachers. The increase in the percentage of teachers who always design or plan an experiment implies a positive shift in teaching practices towards more inquiry-based and hands-on science education. This suggests the development of scientific skills in observing, questioning, and investigating, which leads to a more meaningful and memorable learning experience.

Systematic observations of teachers' classroom practice showed evidence of active student engagement, varied instructional approaches, and effective use of technology and other resources, mostly obtained from the local environment. For instance, during a biology lesson by teacher 6712, students actively participated in learning activities, such as collecting specimens from the school compound, observing samples through microscopes, conducting discussions in small groups, and making presentations. Additionally, during classroom observation, biology teacher 6718 facilitated students in an activity of predicting various scenarios of the occurrence of hereditary disorders on springs based on combinations of parents' genetic profiles. By doing so, the teacher made effective use of inquiry-based learning and collaborative learning. The classroom was livelier and more engaging than if the teacher had used the traditional teacher-centred method, such as lecturing. The teacher demonstrated skills in guiding students in sharing their experiences in a constructive and meaningful way. This may involve providing them with clear instructions, setting expectations, and facilitating respectful discussions.

Mathematical thinking skills in mathematization, reasoning, and argumentation refer to a set of higher-order cognitive abilities that are crucial for success in mathematics and beyond. They include such things as the teacher's ability to translate real-world problems into mathematical models, identify the relevant quantities, formulate equations, create diagrams or graphs to represent the situation, use mathematical knowledge and skills to solve problems, link mathematics concepts to real-world contexts, and present a clear and coherent line of reasoning to support a mathematical claim.

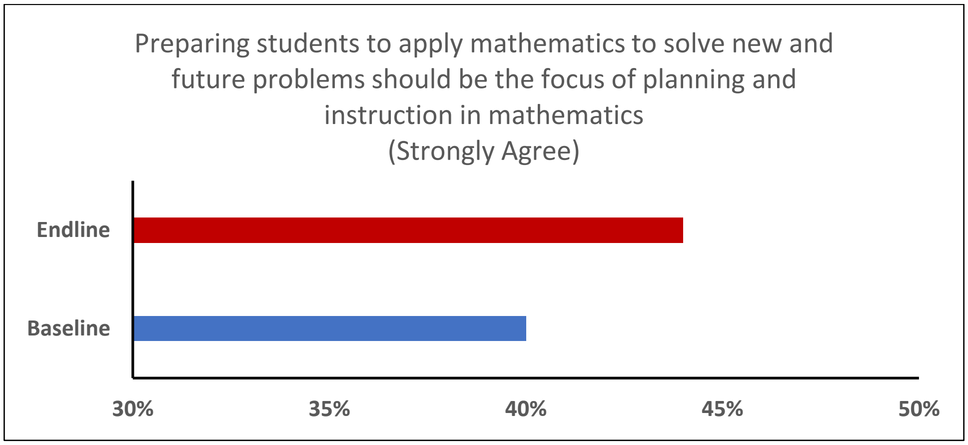


Figure 3.2.4:Responses on Students Application of mathematics to solve New and Future Problems

The percentage of teachers that strongly agreed on the importance of preparing students to apply mathematics to solve new and future problems as a focus of planning mathematics instructions increased. By recognizing the importance of the application of mathematics to solve novel and future problems, teachers are likely to equip students with the mathematical reasoning, critical thinking, and problem-solving skills that are needed for the increasingly technologically driven world. Additionally, evidence from the classroom observations of these skills to the participating teachers. For example, during classroom observation, teacher 6112 demonstrated mathematical reasoning by linking the concept "area" with everyday applications in building construction activities, telling students that a building is designed to fit the area of the ground on which it is built.

Regarding the knowledge of topic-specific pedagogical strategies and resources, classroom observation of the participating teachers while presenting the selected topics in physics, chemistry, biology, and mathematics proved that the teachers had gained the required knowledge and skills on how to apply a variety of engaging and effective topic-specific teaching methods. For example, during classroom observation of chemistry, Teacher 6518, in his lesson on the concept of "organic compounds," focusing on alkanes, employed concept mapping and model-building strategies. He started the lesson by providing students with key terms related to alkanes (e.g., hydrocarbon, saturated, single bond, isomer, homologous series). Then he instructed students to create a concept map, visually linking these terms and showing their relationships. This helped the students to organize information and identify connections between concepts. Then he guided the students in building models of simple alkanes such as methane, ethane, and propane, using local materials, while encouraging them to observe the differences in structure and discuss the patterns they notice. He further connected the concept to real-world applications by describing the uses of alkanes in everyday life, such as natural gas, gasoline, and petroleum products.

Another impressive example of the aspect of topic-specific instructional strategies was the classroom observation of physics teacher 6309 when he was presenting his lesson on "transformers." He used local resources to construct a simple model of a transformer (Image 3.2.2) and used it to demonstrate the internal structure and working principle of a transformer.

The students were able to examine the model, identify the primary and secondary coils, and trace the path of the magnetic field. This enabled the teacher to effectively explain the principle of electromagnetic induction and the operation of transformers. In this way, the teacher created a more engaging and effective learning experience for students, helping them develop a deeper understanding of transformers and their applications in the real world.

Image 3.2.2: Demonstration of a simple model of a transformer

Generally, these findings provide compelling evidence that the CL4STEM project had a positive shift in teachers' knowledge, beliefs, and practices on the aspect of instructional strategies. It has successfully enhanced teachers' ability to utilize diverse instructional strategies and resources to address the diverse needs of learners. The increased emphasis on student-centered approaches, such as incorporating real-world examples, utilizing inquiry-based learning, use of technology, designing and using teaching resources from local sources, and actively involving students in the learning process, demonstrates a growing understanding of effective pedagogy.

3.2.3 Context for Learning

The context for learning may refer to the factors that influence, shape, and support the learning process, including the physical, social, cultural, and institutional conditions within which learning occurs. Understanding the *context for learning* is essential for designing effective learning experiences that address the diverse needs of learners and overall academic success. Barab and Duffy (2000), argue that the physical environment of learning—including the availability of resources such as classrooms, science labs, and technology—plays a significant role in shaping educational outcomes. Thus, a teacher's understanding of the *context for learning* significantly impacts student learning outcomes because it shapes how they approach teaching, design lessons, manage classroom interactions, and engage with resources.

Below are outlined the categories explored under the theme of Context for Learning and the insights derived from interviews conducted between Baseline and Endline.

- Knowledge of the larger school/regional infrastructural, discursive context which shapes their pedagogical choices.
- Knowledge of the environmental/ lab/ material resources available in the context that can be utilized to promote science/math learning
- Ability to adapt resources/use locally available materials to meet the needs of learners
- Ability to connect different topics in science/math to everyday experiences/ daily life practices of the students

When interviewed during baseline and endline interviews, most participating teachers indicated improvement in contextualizing their planned lessons. The data from individual subjects showed improvement in the knowledge of the larger school environment and context that shaped their pedagogical choices of which they were not mindful before. The differences in responses from participating teachers during the baseline and endline interviews highlighted increased mindfulness in their pedagogical choices. For instance, the Chemistry teacher (6503) and the Physics teacher (6302) shared the following insights.

There are generally few resources to simplify teaching. There are few laboratory materials and resources to aid the teaching of Chemistry. Chemistry Teacher 6503, Baseline	I use a variety of ways to represent the concepts I am teaching, I use lectures, photos, diagrams, figures, and video clips. Chemistry Teacher 6503, endline
There are few laboratory materials and resources to aid the teaching of Physics. Some experiments are not done due to unavailability of resources. Physics Teacher 6302, Baseline	During lesson preparations, I seek assistance from school administration, and fellow teachers to mobilize the necessary T/L resources, respectively. I use videos and locally available resources. Links the common knowledge of the learners with the new knowledge. Physics Teacher 6302, endline

These observations were also noted during the implementation of the lessons as most teaching and learning resources were obtained from the surrounding environments. Data from classroom observation also suggested a positive change in the participating teachers for they showed knowledge of the larger school/regional infrastructural, discursive context which shaped their pedagogical choices. For example, chemistry teacher 6514 used small balls with different colours which were glued on the various circles drawn on the manila card to explain the subatomic particles (Image 3.2.3). Additionally, he used two layered wrapped materials to separate the nucleus from the electrons, the outer layer consisted of maize flour (electrons) while the inside layer consisted of bolls of two different colours (Protons and Neutrons)—these assisted students in conceptualizing the structure of an atom.

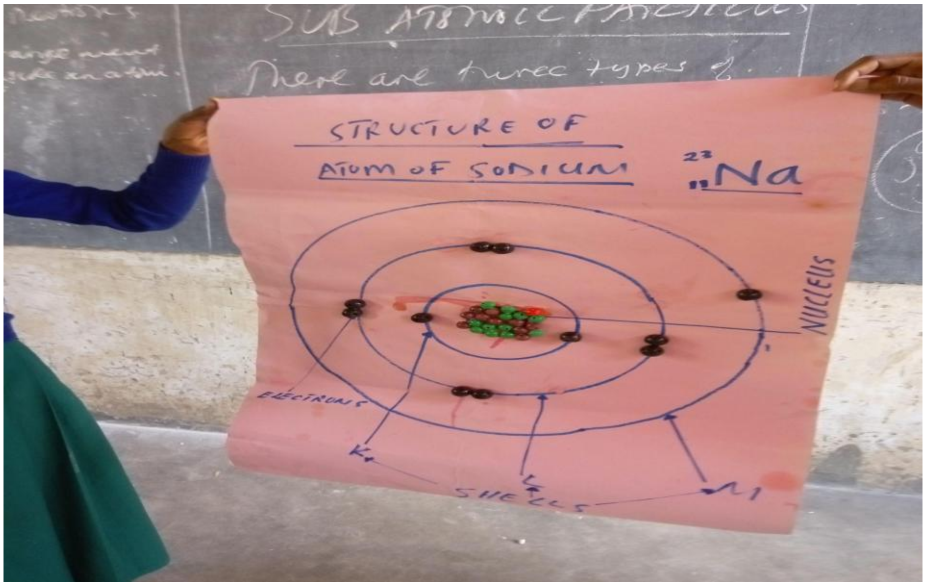


Image 3.2.3: Self-designed aid for teaching subatomic particles in an Atom

Data from surveys indicate general positive changes in consideration of discursive context, which shapes participating teachers' pedagogical choices of all STEM subjects under question, as shown in Figure 2. Upon intervention, an increase of 4%, 8%, and 22% among participating mathematics teachers was noted across baseline and endline on items 12, 13, and 17, respectively (Figure 3.2.5) below.

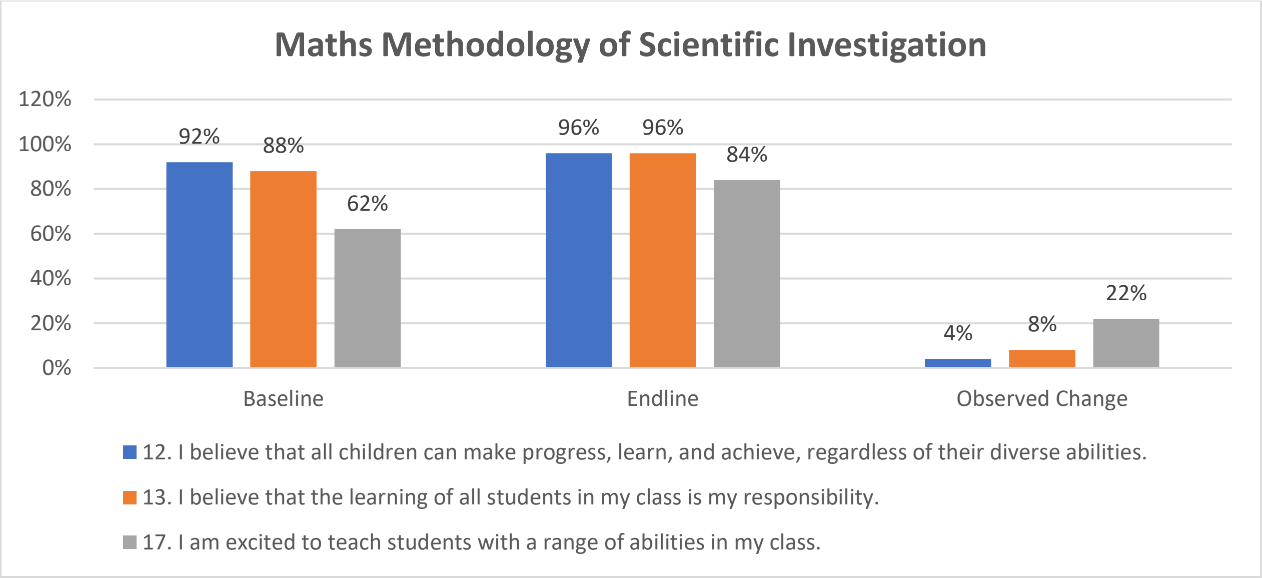


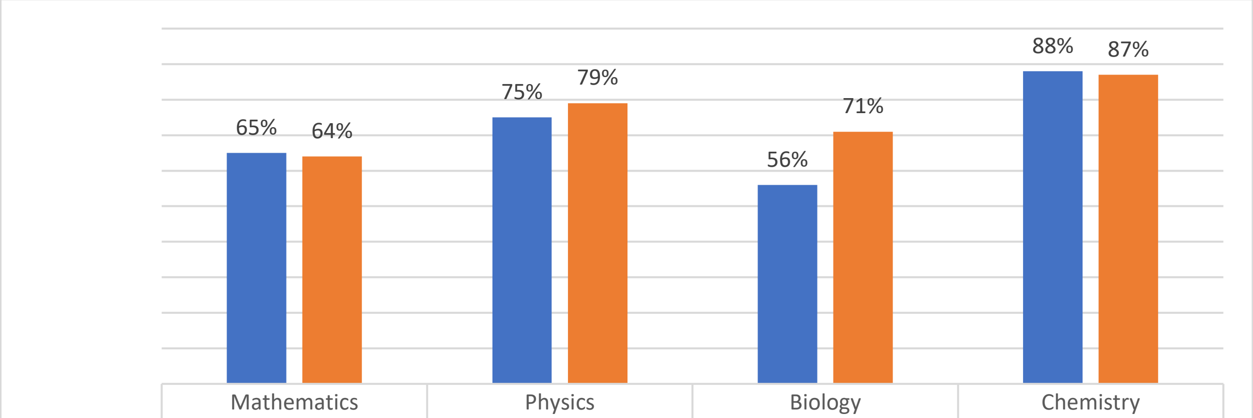
Figure 3.2.5: Consideration of Methods of Scientific Investigation for Mathematics

The differences in responses between the baseline and endline surveys indicate that participating teachers became increasingly aware of the school environment, as well as the available laboratory and material resources, recognizing how these could be utilized to enhance science and math learning. For example, the mathematics teacher (6120) shifted from relying on school administration to predominantly using personal initiatives, considering the materials available in the local context and employing a variety of multiple representation strategies. Similarly, the Chemistry teacher (6521), during the baseline, was unable to consider using internet-based materials when locally available resources were scarce. Their reflections are presented below:

The teaching-learning processes are usually held in the classrooms. I consider the prior knowledge of the learners before the new knowledge. I seek assistance from fellow teachers when preparing the lesson. In other instances, I may consult the school administration to mobilize the necessary	I employ multiple presentations, like lectures, and different teaching aids such as diagrams, figures, and demonstrations. Mathematics teacher 6120, Endline

teaching and learning resources. Mathematics teacher 6120, Baseline	
Checking and use of locally available materials in the surrounding environment which are beakers and chalks. I used books, notices, and a periodic table. Chemistry teacher 6521, baseline	Some of the materials in the syllabus cannot be easily taught using locally available materials, in such cases I use materials from the internet. Chemistry teacher 6521, endline

Survey data reveal mixed trends in the overall percentage of STEM teachers accessing and utilizing internet-based teaching and learning materials. While the use of internet-based teaching and learning materials increased among Physics and Biology teachers across baseline and end-line, the use of internet-based teaching and learning devices for Mathematics and Chemistry participating teachers remained largely unchanged, as shown in Figure 3.2.6. This might be attributed to the fact that the intervention encouraged Mathematics and Chemistry teachers to rely not only on internet-based materials but also on other locally available teaching aids and resources.



	Mathematics	Physics	Biology	Chemistry
Baseline	65%	75%	56%	88%
Endline	64%	79%	71%	87%

Figure 3.2 6: Percentage change in considering the use of materials from Internet sources

Collected data across baseline and endline indicates positive change among participating teachers in the adaptability and use of locally available materials to meet the needs of learners as exemplified by the biology teacher 6709 and physics teacher 6109.

Most biology topics require the use of real objects or models, but appropriate teaching models are often lacking. The government should provide more models to schools. I rely on actual models or charts and search various videos. Instruments like microscopes and local materials, such as leaves, are used, along with tools like a skeleton statue model and pens of different colours as teaching aids. Biology Teacher 6709, Baseline.	The teacher concentrates on illustrating the big picture of how Biology applies to students' everyday lives and uses local and familiar materials to teach challenging concepts like alleles and traits in Genetics. I can locate teaching and learning resources in the school environments, like insects or plants around the school environment. Biology Teacher 6709, Endline.
The teacher indicated that slow learners must be treated separately by concentrating on them rather than giving equal weight to all students. Physics teacher 6109.	I use local materials like folded papers to represent figures e.g., rectangles/triangles, etc to assist students in realizing their real-life situations and applying them to solving real-life situations in everyday life, such as measurements, etc. I also assign assignments or activities to allow students to practice what they have been taught. Physics teacher 6109.
Real things make learners recognize what they are required to learn, Mathematics Teacher 6123, Baseline.	It is now becoming easy to teach Mathematics by engaging in video games and improvising materials from our surroundings at the school, and students enjoy seeing them, as they play while

	learning. Mathematics Teacher 6123, Endline

The observations during classroom visits further supported interview findings, as all participating teachers made significant efforts to incorporate locally available materials to meet the learners' needs. For example, a physics teacher (6319) used plastic bottles and wires to demonstrate the concept of Magnetism and the conversion of magnetic fields into electricity, and vice versa.

Data from both the pretest and post-test surveys, which included subject-specific items, revealed a positive change in three subjects. However, a slight negative change was observed in physics, as shown in Figure 3.2.7

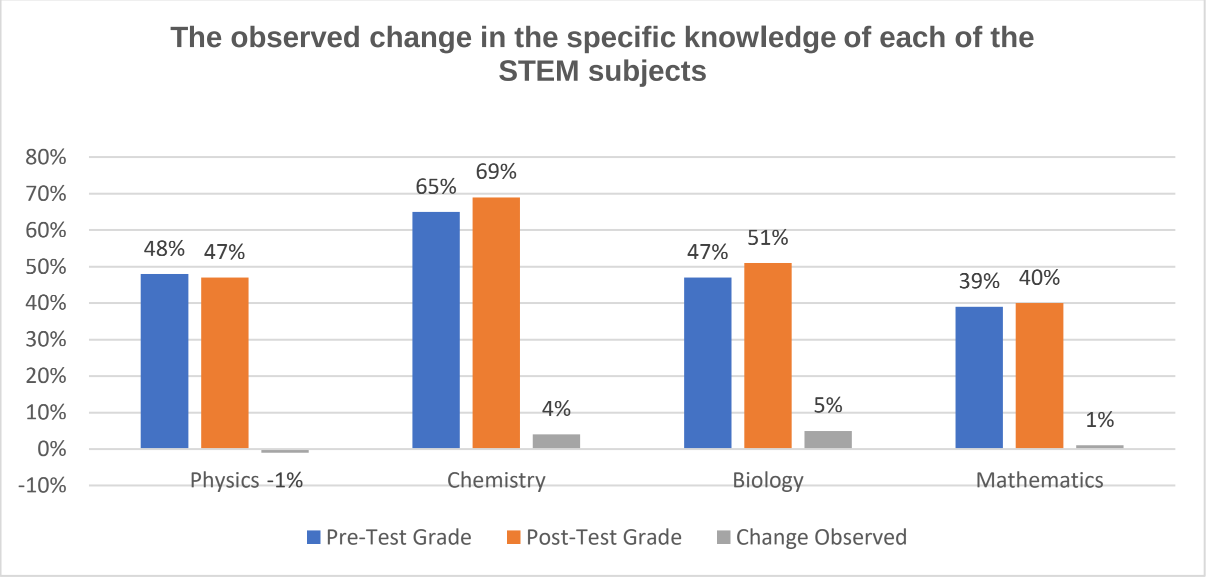


Figure 3.2 7: The observed change in the specific knowledge of each of the STEM subjects

Data collected from the baseline and endline interviews indicate changes in the way participating teachers connected different science and math topics to students' everyday experiences and daily life practices. For instance, the biology teacher (6709) and the Math teacher (6113) provided more detailed explanations in the endline interviews compared to their responses during the baseline interviews. This trend was observed among most teachers during lesson implementation.

I connect the study of biology to everyday life through nutrition, diseases in society, and environmental conservation. Through observing the biology clubs and how they conserve the environment. Biology Teacher 6719 Baseline	For example, when teaching the topic of the balance of nature, I use plant and animal species, and community gardens to illustrate the interdependence of organisms from the surrounding environment. I incorporate examples from local agriculture, such as the inheritance of traits in crops like maize or beans, which are commonly grown in the area. Biology Teacher 6719 Endline
The teacher connects mathematics to students' daily lives, such as using linear programming for farming or statistics to understand government population data. These connections help students see the relevance of mathematics in real-world applications. Math Teacher 6113, Baseline	I use local materials like folded papers to represent figures e.g. rectangles/triangles etc to assist students in realizing their real-life situations and applying them to solving real-life situations in everyday life, such as measurements, etc. I also assign assignments or activities to students to practice what they have been taught. Math Teacher 6113, Endline

Classroom observations supported, for example, mathematics teacher 6123 when teaching the topic of proportions related to the knowledge taught with daily real-life applications by the use of labels on different containers indicating the percentage composition of substances within each container. Various containers with labels of percentage composition of the contents of the containers were given to students for discussion to find out the relative weight of the substances in those containers. Students understood the concept of proportions by connecting it with relative percentages of the substances in the containers. Furthermore, positive changes in the use of everyday life experiences were evident and strongly supported by the survey data from both baseline and end-line assessments. When asked about the major sources they accessed and used in teaching their subjects, teachers reported a notable increase in the use of real-life science experiences and current events related to science. Specifically, there were increases of 22%, 9%, 15%, and 20% for Mathematics, Physics, Biology, and Chemistry, respectively (Figure 3.2.8)

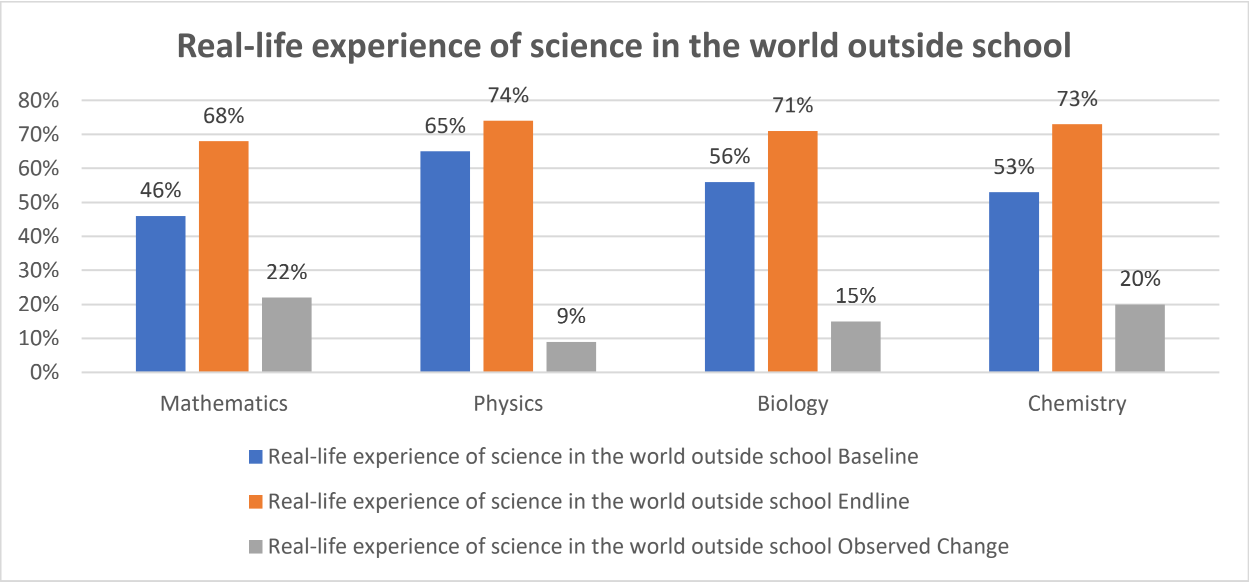


Figure 3.2 8: The use of real-life science experiences

In terms of incorporating current events into lesson planning and delivery, positive increases of 6%, 9%, and 8% were observed in Mathematics, Chemistry, and Biology, respectively. However, Physics saw a slight negative change of 1% (Figure 3.2.9)

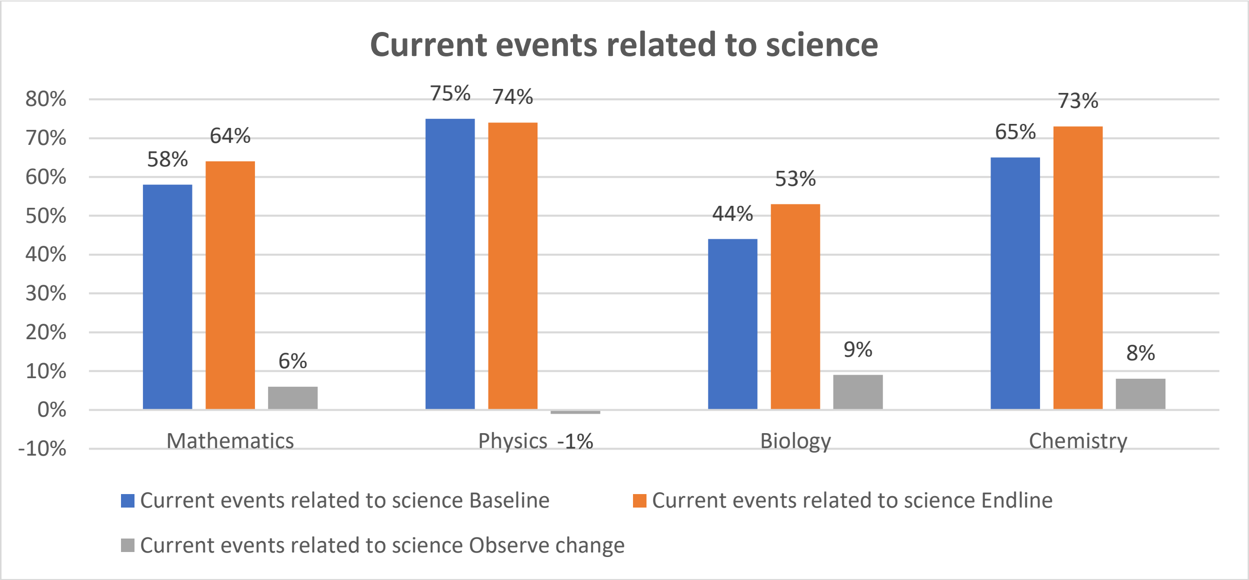


Figure 3.2 9: The use of current events related to science

These results suggest that the project intervention had a positive impact on integrating real-life science experiences and current events into the teaching of STEM subjects, as illustrated in Figures 3.2.8 and 3.2.9.

Research findings derived from interviews, classroom observations, lesson plans, and surveys across baseline and endline suggest positive outcomes of the project. Participating teachers demonstrated significant improvements in their understanding of the learning context. Additionally, there were clear positive impacts on student learning outcomes. Participating teachers made notable progress in their teaching methods, lesson design, classroom interactions, and fostering student engagement with teaching and learning resources. Participating teachers increasingly understood the context that shaped their pedagogical choices. They used locally available materials to meet the needs of the learners and improved significantly in connecting different topics in science and math to the everyday experiences and daily life practices of the students.

3.2.4 Representation of the content

Content representation in teaching refers to how instructional material is organized, presented, and structured for learners to understand and engage with. It affects how students understand and engage with the material. Representation of the content involves selecting and organizing knowledge in a manner that is comprehensible and accessible to students. Effective teaching requires more than just delivering information; it necessitates presenting it in ways that foster deep learning and critical thinking. Content representation may be verbal, visual, or hands-on. In the framework of Universal Design for Learning (UDL), content representation focuses on offering multiple means of presenting content so that all learners, regardless of their learning styles or disabilities, can access and engage with the material in a way that suits their needs. Meyer, Rose, & Gordon (2014) maintain that by providing varied methods of content delivery, teachers can enhance understanding and retention for a diverse student population. In this study, the categories that were explored under the theme of *representation of the content* during baseline were as outlined below.

- Knowledge of multiple forms of representation of content - E.g., analogies, equations, gestures, graphs, diagrams and illustrations, models, tables, texts, videos, simulations, photographs
- Knowledge of the limits of models and illustrations in representing content.
- Ability to use multiple representations of content to meet the diverse needs of students

Teachers indicated a positive change in the representation of the contents when interviewed and observed during classroom sessions. They kept on improving as they were implementing the modules, they used various forms of representation of the content and chose the best way to represent the content. For example, Mathematics teacher 6123 when interviewed during baseline said *"I use lecturing and diagrams with different things*" but when interviewed during the endline said "*I use graphs, shapes, diagrams, pictures, and integrated ICT by use of a smartphone"* as presented below:

I use lectures, charts, and diagrams of bacteria and animal cells. Biology teacher 6709, Baseline	In genetics, for instance, I use observations, diagrams, and videos and also integrate ICT, e.g., using my phone to download pictures, videos, and equations suitable for the students. Biology teacher 6709, Endline
I use lecturing, diagrams with different things Mathematics teacher 6123, Baseline	I use the chalkboard to draw various graphs, shapes, diagrams, pictures, or figures in areas and perimeters to form ones. I can integrate ICT to download pictures and mathematical games, use plays in class, and play videos for students to see different mathematical problem-solving steps in real situations. Mathematics teacher 6123, Endline
The content can be represented as virtual, such as real-life things. Biology teacher 6700, Baseline	Uses interactive teaching aids, videos, group discussions and demonstrations, use of real objects like plants, to ensure a better understanding of concepts. Biology teacher 6700, Endline

Data from classroom observation supported this observation as all participating teachers in all STEM subjects employed the strategy of multiple representations of the content. They used real objects, experimentations, diagrams, graphs, pictures, figures, tables, video clips including demonstrations. For example, a biology teacher 6709 when implementing the lesson, used a smartphone to show examples of unicellular and multicellular living things as unicellular organisms cannot be easily seen without the use of a microscope. The use of a smartphone allowed pupils to conceptualize the scientific processes of differentiating unicellular organisms from multicellular organisms. Besides, using tables, diagrams, and real objects. Additionally, the teacher asked probing questions which promoted higher order thinking right away from the introduction up to the lesson's conclusion. For example, she asked questions like what is the cell? Can we see all types of cells? What are the major categories of cells of living organisms? Are all major categories of cells represented here (showing samples of living things brought in the class)?

Knowledge of the limits of models and illustrations in representing content is crucial for effective Science and Mathematics teaching because it helps teachers guide students through the process of understanding both the strengths and the shortcomings of these teaching aids. In a pre-classroom interview, one biology teacher 6714 emphasized that "*to help students overcome learning difficulties and misconceptions, teaching aids should be realistic, combining theory, diagrams, and videos to enhance students' understanding of concepts*. She provided an example from the topic of growth (cell division), which is somewhat abstract. *In this case, videos demonstrating how chromosomes and chromatids divide are essential. The integration of theory, diagrams, figures, photographs, and videos is key.* During baseline interviews, a math teacher 6120 showed no awareness of the limitations of the planned teaching aids. However, during endline interviews, the teacher demonstrated an understanding of these limitations as evidenced below:

I use lectures and different teaching aids. Mathematics teacher 6120, baseline.	I use materials from the local environment to present some concepts in mathematics, for example, using tape measures and rulers to measure different objects and calculate their areas and perimeters to show the difference between "Area" and "Perimeter" 2). But I also incorporate technology in teaching mathematics by using some internet materials to counterbalance any weaknesses of locally available teaching aids. Mathematics teacher 6120, Endline.

Results from interviews indicated positive impacts of the project as participating teachers indicated significant improvements in the use of multiple representations of the content to meet the diverse needs of the students. For example, a biology teacher 6715 during a baseline interview admitted to only using lecturing, demonstrations, and videos. Three categories of representing content could be inferior in meeting the diverse needs of the students when compared to several ways of content representation. More ways of content representation were noted when interviewed during the endline when a mix of video clips, lecturing, group discussion, and use of figures was opted as evidenced below:

I will use lecturing, demonstrations, and videos. Baseline Biology teacher 6715.	A mix of using video clips, lecturing, use of figures on manila paper, and group discussions though I am interested in using large screens to display materials for all learners to see small organisms like bacteria. Biology teacher 6715.

Results from classroom observation also supported the above interview results for most teachers were eagerly presenting the content in multiple ways to meet the diverse needs of students. For example, Mathematics teacher 6117 while implementing the lesson on the topic of transformation employed lecturing, photos, diagrams, and strategic questions and took students through how to rotate a shape by 90° and 180° around a point. Data from surveys were also in support of results from interviews and classroom observations as participating teachers indicated a positive change in the consideration of what they thought were their beliefs about methods of scientific investigation. For example, participating mathematics teachers indicated a positive change of 4% up to 22% across baseline and endline regarding their belief in assisting students with diverse abilities in their classes (Figure 3.2.10).

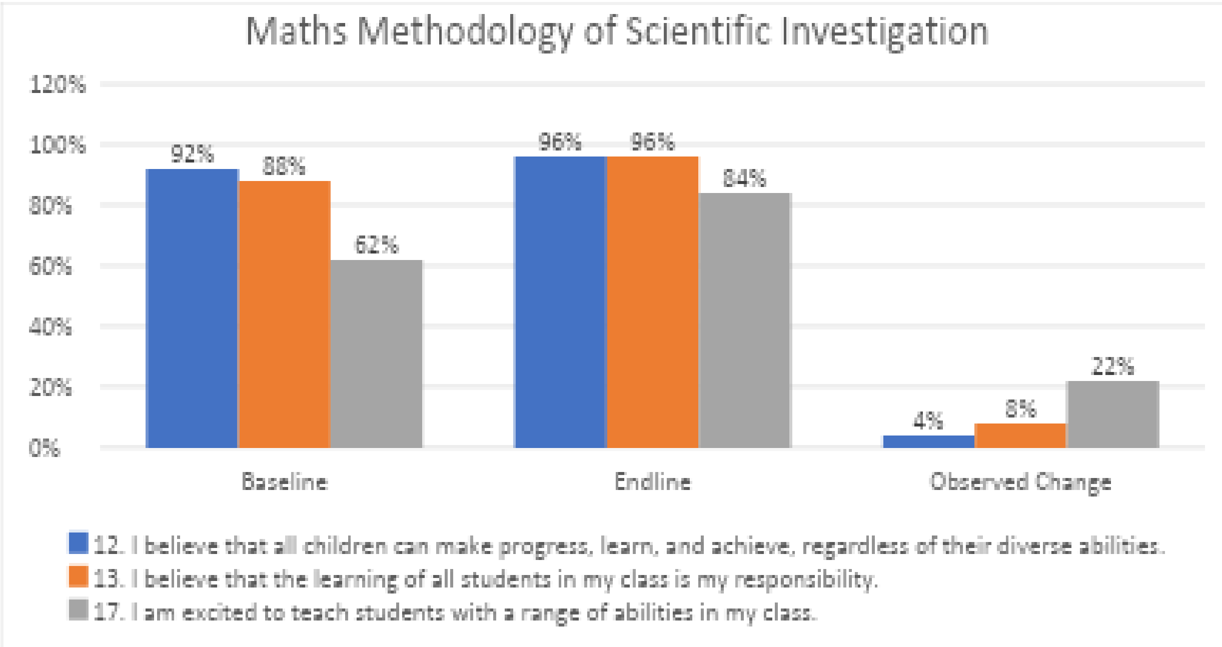


Figure 3.2.10: Mathematics teachers' beliefs about assisting students with diverse abilities in their classes

Survey data from both baseline and endline indicate a generally positive shift in how all STEM teachers perceive the presence of learners with diverse needs in their classrooms, recognizing it as their responsibility to ensure all students benefit from the learning process. Results from both qualitative and quantitative data have shown that there were significant improvements in the way participating teachers were thinking, planning, and implementing STEM lessons across baseline and endline. All participating teachers scientifically designed and represented the contents verbally, visually, or in the form of hands-on activities. They used locally available materials to represent the content multiply. They employed lecturing, diagrams, pictures, demonstrations, group discussions, probing questions, videos, real objects, and site visits. Generally, the results suggest a positive impact on the project.

Research findings generally indicate that the intervention had a positive impact on how participating teachers represented content. Teachers enhanced their ability to present knowledge in multiple forms, including analogies, equations, graphs, diagrams, illustrations, models, tables, texts, videos, simulations, and photographs. Furthermore, they recognized the limitations of using models and illustrations to represent content, while also improving their ability to use multiple representations to meet the diverse needs of all students in their classes.

3.2.5 Curriculum knowledge

- Knowledge of the goals and purposes of teaching science/mathematics.
- Knowledge of the hierarchical sequence of foundational concepts for teaching and its interconnection with other concepts/topics in the curriculum across grades.
- Knowledge of linkages between science and mathematics and other school subjects.
- Ability to use knowledge of curriculum to design integrated learning experiences for students.

This section explores the knowledge, skills, and attitudes of participants (teachers) regarding their curriculum knowledge. The interviews with teachers revealed their growing understanding of the goals and purpose of teaching science/mathematics. While in the baseline some teachers said the purpose of learning science/mathematics is to deliver knowledge and understanding in general terms, in Endline they could elaborate on the purpose of teaching science, especially critical thinking and problem-solving. For instance, Teacher 6719 had this to say during Baseline and Endline interviews,

“I'm planning my lesson by observing the scheme of work, observing the syllabus, observing the notes and observing how I can manage time during teaching and also how I can deliver the knowledge”. Teacher 6719 Baseline	“To develop a deep understanding of the goals and purposes of teaching Biology to my students in every lesson I clearly outline the objectives of the lesson to guide students' learning. While teaching the topic of plant biology, I start by explaining the goal of understanding plant growth, photosynthesis, and the role of plants in the local ecosystem. By stating these objectives at the beginning, the students understood the relevance of the lesson and how it helped

	them both their academic development and real-world applications”. Teacher 6719 Endline

To emphasize the problem-solving skills teacher 6319 has this to say, ‘I assigned students in groups to calculate energy consumption in local households or predicted power usage in local factories, allowing them to apply the formulas they learned in class to real-life scenarios. By using these varied strategies, I ensured that students not only understood the theoretical aspects of work, energy, and power but could also apply”.

Throughout the interviews, the teachers displayed concern about preparing lessons keeping in mind the goals and objectives of the curriculum. They narrowed it down to the individual topic/subtopic and the lessons taught in the classroom.

For instance, Teacher 6505 had this to say during Endline - “Before going to class I plan a lesson, I look at the syllabus especially which topic and which subtopic. Then the objective of that topic and Plan well the T/L strategies and the flow of materials and apply the appropriate techniques for assessment of the student's progress”.

Interview data also revealed that teachers’ understanding of the interrelationships between different math and science concepts and the hierarchical nature of concepts has improved significantly. As an analogy of building a ladder, it is very important to use the previous concepts in teaching as is evident from these two quotes of both the mathematics teacher and biology teacher as well:

“I focus on building foundational knowledge, such as fractions and percentages, before introducing advanced topics like ratios. " Teacher 6115, Endline.
“Sequential approach to teaching, requiring foundational knowledge of cell biology first before progressing to genetics”. Teacher 6716, endline.

They were also able to understand the interconnections of scientific ideas and real-life applications as evidenced by the following quote, '*It is important to link the content to students' everyday experiences, such as using local examples of indigenous plant species or agricultural practices in the area. For instance, when discussing the process of pollination, we incorporated local crops like maize and beans, showing how they rely on specific pollinators, such as bees, which are common in the local environment. This approach helped students understand the broader purpose of Biology—how it connects to their immediate surroundings and the importance of science in understanding the world around them*." Teacher 6719, Endline.

The classroom observations demonstrated that the teachers were concerned about curriculum knowledge while preparing lesson plans, teaching, and assessments. Teachers also align the ideas incorporated in CL4STEM modules to subject-specific contents and classroom activities.

For example, Teacher 6301, connected the lesson's objectives with the syllabus while planning the lesson and executing activities in a real classroom setting. The teacher shows a good understanding of the curriculum requirements in the Physics subject. The mastery of step-down and step-up transformers was effectively developed and delivered following the syllabus and the lesson plans.

Teacher 6700, shows expertise in the curriculum requirements of cell structure and differentiation. The teacher knows the goals and objectives of the lesson as stipulated in the curriculum and executes them very well. The concept of cell differentiation, examples of cell differentiation, and the importance of cell differentiation in organisms as postulated in the syllabus was well planned and well presented.

The Physics Teacher 6303, demonstrates how electromagnetic induction helps to generate power without using an external source of electrical energy, as postulated in the Physics syllabus. The plan was to teach the students to know the meaning and the laws which govern electromagnetic inductions and the application of electromagnetic induction in daily life. He also uses textbooks/reference books, which government officials recommend to go hand in hand with the syllabus.

Teacher 6503 applies his teaching skills to make his students realize the importance of an Atom as the building blocks of atomic structure. He knows the goals and objectives of the topic and Chemistry as a whole. He strives to deliver them in his teachings considering the textbooks and reference books pointed out in the syllabus.

On the other hand, the survey findings revealed that most teachers have gained a deeper understanding of the curriculum and regard it as a crucial source of various elements necessary for the educational process and student development. For instance, responses from Biology and Mathematics teacher participants in both the baseline and endline surveys showed a significant positive change. The understanding has increased to 94% and 96% in the endline survey of biology and mathematics respectively compared to 89% and 88% in the baseline survey (Figure 3.2.11).

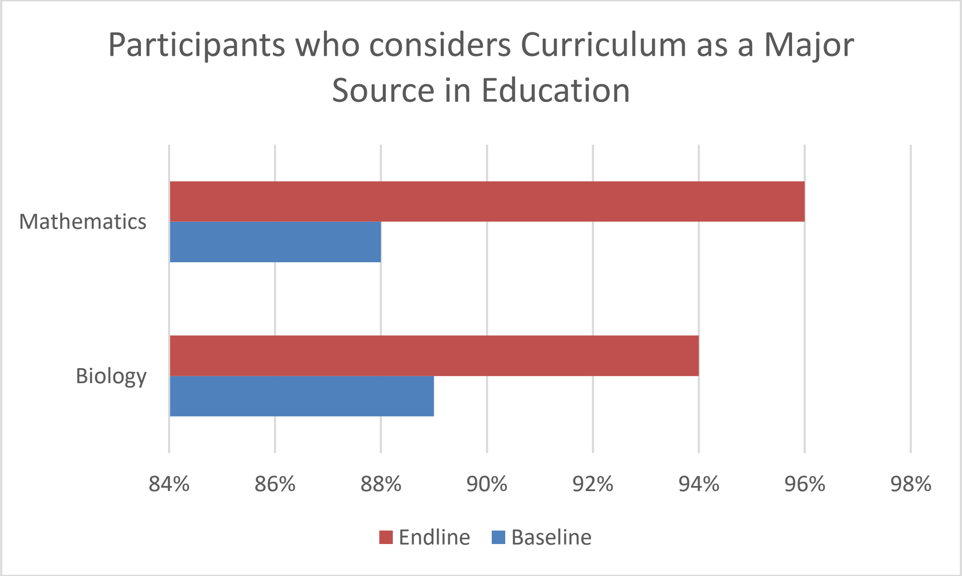


Figure 3.2.11: Teacher Participants' Responses on the Importance of using curriculum in teaching STEM subjects

In summary, interviews, classroom observation, and pre and post-survey results suggest that the intervention has positively impacted the curricular knowledge of science and mathematics teachers. Research findings indicated that teachers showed significant improvement in applying curriculum knowledge to lesson planning, teaching, and assessments.

3.3 General Pedagogical Knowledge

3.3.1 Equity and Inclusion

- Knowledge of Universal Design for Learning (UDL).
- Ability to provide equal opportunities for all students to participate in classroom interaction.
- Ability to use UDL principles to design and implement lesson plans, resources and assessments to meet the diverse needs of learners.

An inclusive classroom is one where all students feel intellectually and academically supported, fostering a sense of belonging regardless of their identity, learning preferences, or other distinguishing factors. For instance, an inclusive classroom may include a diverse mix of gifted students, auditory and visual learners, students with physical and cognitive disabilities, and individuals from various cultural backgrounds. Equity, in contrast, focuses on ensuring that all students have access to the necessary support and resources to succeed, creating a level playing field within the education system. It addresses the unique needs of underprivileged and underserved students, helping them overcome disadvantages. Equity also recognizes and supports diverse learning styles, enabling each student to learn in the way that best suits them.

Interviews, classroom observations, and surveys were conducted to explore the impact of the CL4STEM project on teachers' knowledge, attitudes, and practices related to inclusion and equity. The findings from the interviews indicated that teacher awareness of equity and inclusion strategies significantly improved by the Endline phase compared to the Baseline.

‘In my class, there are three types of groups of students, some of them are fast learners, moderate and the last are the struggling students’. Teacher 6719 Baseline	‘When teaching the balance of nature, I encouraged students from different cultural backgrounds to share their local knowledge and perspectives on ecosystems such as how certain local plant species are vital for maintaining soil health or how traditional farming practices help preserve biodiversity. This approach promoted inclusivity and valued diverse viewpoints, helping students to see the broader implications of ecological balance in various cultural contexts.’ Teacher 6719 Endline

The findings indicate that there was a notable improvement in teachers' awareness of approaches that accommodate the diverse needs and abilities of all students throughout the learning process. Additionally, teachers demonstrated enhanced skills in applying Universal Design for Learning (UDL) principles to design and implement lesson plans tailored to meet the varied needs of their students. Qualitative data from interviews further revealed that the CL4STEM project significantly improved teachers' capacity to provide equal opportunities for all students to engage in classroom interactions. Evidence supporting these claims is detailed below:

‘This is a boy’s school but is home to a diverse student body, including slow and fast learners and students from a range of socio-economic backgrounds. We also have a few students with physical disabilities who require special attention. I am committed to ensuring that these students receive the individualized attention they need, like mixing them in group discussions. This supports their learning and sends a powerful message that they are noticed and can learn just as effectively as any other student’. Teacher 6109 Endline.

Classroom observations, generally, indicated that the CL4STEM project improved teachers' understanding of the importance of providing equal opportunities for all students to participate in classroom interactions, as evidenced by several examples:

Teacher 6301: formed groups consisting of a balanced mix of both boys and girls, ensuring that all students were given equal chances to ask questions, answer queries, present group work, or demonstrate and clarify issues during class discussions. Similarly, teacher 6700: employed inclusive language while teaching and provided equal opportunities for both boys and girls during demonstrations, question-and-answer sessions, and group activity presentations.

It was also highlighted by teacher 6122: “My students always get the time for them to participate in groups and some will be selected to perform the calculations. I normally decided to call those students who didn't raise their hands, to alert everyone that anyone can be appointed at any time. Groups are formed by considering the level of understanding or performance in the class.”

The teacher 6517 insisted “I expect more participation from students than me giving them information. They will be doing some questions in groups. I select students in such a way that even those who don't know, I try to make them answer the question. Groups are formed by considering the gender and the issue of their ability in the classroom.”

Teacher 6718 also demonstrated strong knowledge of inclusion and equity by ensuring equal learning opportunities for all students. Specifically, the teacher accommodated the needs of a student with mild hearing impairment by actively including her in the lesson and directing questions to her as to other students. To further promote equity, the teacher used a random selection method for calling on students, avoiding any unintentional bias. During group work, the teacher created mixed-gender groups and integrated students with varying academic abilities, pairing stronger students with those needing more support to encourage collaboration and mutual learning. These practices demonstrate a comprehensive approach to creating an inclusive and equitable classroom where all students can succeed.

Teacher 6317 described categorizing students as "fast" or "slower" learners based on prior experience teaching them the previous year. This familiarity, the teacher explained, allowed for more effective tailoring of teaching strategies to meet individual needs. The teacher also used random student selection for answering questions to ensure all students had an equal opportunity to participate, promoting engagement and inclusivity. This method aimed to build confidence in slower learners while keeping faster learners engaged. Similarly, Teacher 6519, reported using random student selection across all lesson activities to ensure inclusivity and equal participation regardless of gender or learning ability. This approach aimed to create a supportive and equitable learning environment where all students could actively engage.

Teacher 6106 emphasized the importance of considering students' diverse socioeconomic backgrounds in the learning process. The teacher uses group discussions to facilitate peer learning between "slower" and "faster" learners. Additionally, lesson materials are structured to accommodate students with weaker mathematics backgrounds, progressing from simple to complex concepts to ensure no one is left behind. As mentioned previously, Teacher 6519, uses random student selection for lesson activities to ensure inclusive and equal participation, regardless of gender or learning ability. This practice aims to create a supportive and equitable environment where all students can actively engage. For instance, the chemistry endline survey showed increased awareness among participants regarding the learning abilities of students with disabilities (Figure 3.2.12).

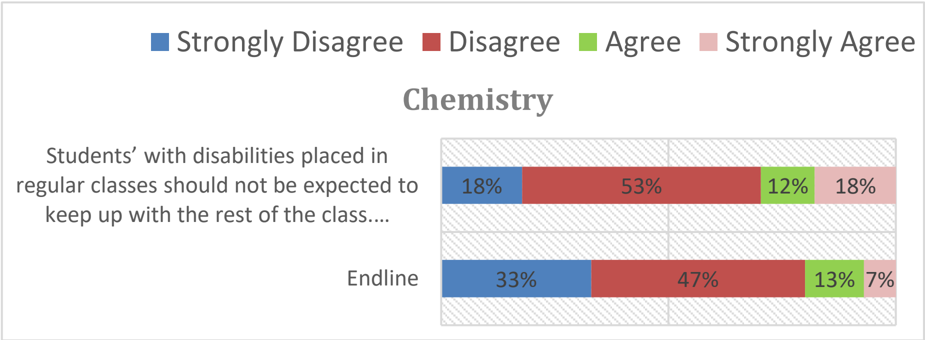


Figure 3.2 12: Teachers' Views on Students with Disabilities' Learning

In conclusion, teacher awareness of equity and inclusion has significantly increased. For instance, at the endline, 80% of chemistry teachers believed that students with disabilities in regular classrooms could keep pace with their peers, compared to 71% at the baseline.

3.3.2 Classroom Management

Classroom management strategies are essential for shaping students' performance by creating an organized and supportive learning environment that fosters engagement and minimizes disruptive behaviours. Effective classroom management involves various components, including how teachers interact with students, the functioning of the class, collaboration among students and teachers, management of classroom discipline, and the overall teaching and learning processes. Therefore, teacher effectiveness is often evaluated based on their ability to utilize diverse classroom management techniques to guide students toward achieving learning objectives (Asiyai, 2011; Bua and Ada, 2013; Manafa, 2021; Owusu *et al*., 2021). Considering this, the CL4STEM project has focused on exploring three key pedagogical themes to promote effective classroom management as follows.

- Classroom management of instructional materials.
- Classroom instructional methodologies that promote positive interactions.
- Classroom Monitoring of students' behaviour and discipline management practices.

Classroom instructional resources are materials designed to enhance and streamline the teaching-learning process within classroom settings. These resources play a crucial role in interpreting and conveying the teacher's lessons in a manner that is easily comprehensible to students. By doing so, they significantly contribute to the achievement of classroom objectives, making learning more effective and engaging (Arop *et al*., 2015; Tuimur and Chemwei, 2015; Kija and Msangya, 2019).

Findings indicate that participating teachers initially lacked the skills and innovative approaches to effectively utilize nearby environments as the source of instructional resources. They primarily relied on traditional pedagogical methods such as oral questioning, field observations, and discussions, with limited integration of physical teaching and learning materials. However, a post-project survey indicated a shift in their pedagogical choices, with teachers recognizing the value of readily available resources and the immediate school surroundings to support student learning. The following teacher excerpts and photographs further illustrate this evolving perspective.

"Learners are actively involved in the teaching and learning processes through oral questions and answers, doing experiments/practical, field observations and working in their respective discussion groups." Teacher, 6718, Baseline.	"I remember, when I was describing a structure of the DNA when I gave them an example of a jacket using a zip, I was pleased, and my students were interested and understood the concept I was teaching. The reason for this is the fact that I used a real and familiar example to them." Teacher, 6718, Endline.

The biology teacher further showcased their resourcefulness by constructing models of genetic material from plant materials. These models served as visual aids to effectively demonstrate and explain the intricate structures of genetic components (Image 3.3.1 and 3.3.2).

Image 3.3.1: A model of genetic material structure made of plant parts

Image 3.3.2: A model of DNA structure made of plant materials

Furthermore, findings from the interviews indicated that participating teachers have gained a deeper understanding of their school surroundings and context, which has influenced their pedagogical choices and encouraged the use of locally available materials to better meet the needs of their learners. For instance, during the baseline interview, Teacher #6707 expressed concerns about students' lack of cooperation in classroom activities. However, in the endline session, the same teacher reported a significant increase in student engagement when the teaching-learning process was enhanced by incorporating the immediate school environment, locally available materials, and various types of laboratory specimens to illustrate key concepts.

The teacher believes that students do not want to participate in classroom activities. Teacher 6707, Baseline	Regarding resource management, they incorporated locally available materials such as plants, soil samples, or water from nearby streams, to illustrate biological concepts in real-world contexts. For example, when teaching about cell structure, the teacher used magnifying glasses and locally sourced plant cells for students to observe, alongside educational videos and models. Teacher 6707, Endline

Biology Teacher #6709 initially voiced concerns about the lack of adequate teaching and learning resources, particularly models and charts, echoing similar observations reported in Zimbabwe by

Ruparanganda (2021). During the baseline study, this teacher appealed to the government for these resources, explaining, “In most instances, they need examples of real objects like models or charts. But we do not have them. So, the government should provide them to schools.” However, by the endline study, the same teacher demonstrated a marked improvement in their ability to utilize a wider range of instructional materials. This included not only incorporating locally available resources but also leveraging technology, such as mobile phones, to find relevant pictures, videos, and equations to support the curriculum.

Effective classroom instructional methodologies are techniques used by a teacher to ensure that teaching and learning go as expected. Teachers need a complex collection of instructional methodologies to involve a wide range of students. Students who are actively involved are more likely to do better academically than students who are not. An instructor can also use a range of instructional strategies to ensure that students accomplish their objectives without difficulty and with high efficiency (Aluko, 2008; Solomon *et al*., 2017; Sæleset & Friedrichsen, 2021).

Classroom observations and interview data revealed that teachers recognized the importance of enthusiasm in teaching and employed diverse strategies to stimulate and sustain student engagement. For example, during the baseline study, the physics teacher (#6306) identified the lack of teaching aids as a significant obstacle to effective teaching and learning, leading them to primarily rely on group activities, student-led demonstrations, and collaborative problem-solving. However, classroom observations during the endline study showcased this teacher's expertise in seamlessly transitioning between various instructional methodologies, including demonstrations, simulations, experiments, illustrations, observations, videos, and photographs. Furthermore, they effectively integrated technology into their teaching, utilizing the internet to download videos and images for display on a TV monitor. The following account exemplifies this shift and reflects the perspectives of many participating teachers post-intervention.

“I recognize multiple teaching methods, like experimentation, lecturing, etc.; and I know specific	“….. I can ensure all students are learning by using good teaching methods that involve the use of computers and TV for elaborations and demonstrations of some

teaching resources for a particular concept in Physics." Teacher, 6302, Baseline.	concepts. I also employ group discussions, individual and group assignments." Teacher, 6302, Endline.

Classroom observations revealed a shift in teachers' instructional methods from teacher-centred to learner-centred strategies (Image 3.3.4 and 3.3.5). Teachers enhanced their instructional practices by integrating varied strategies such as visual aids, interactive activities, and dynamic teaching methods, tailoring their approaches to the topic and available resources. These learner-centred approaches cultivated a more engaging learning environment, boosting student interest and participation (Tzenios, 2022).

Image 3.3.3: Group discussion in session

Image 3.3.4: A group representative presenting on behalf of other members

Feedback from participating teachers also highlighted improvements in their knowledge, skills, and attitudes related to using multiple forms of content representation and integrating technology for this purpose. For example, mathematics teacher #6109 demonstrated significant growth in classroom management through the refinement of their instructional methodologies. During the baseline study, group discussion was their primary instructional strategy. However, by the endline study, this teacher had expanded their repertoire to include classroom discussions, the creation of graphs and figures, and the use of downloaded videos to support student learning and practice in mathematics. Essentially, learners were actively engaged in inquiry-based learning, fostering problem-solving skills and independent thinking.

Table 3.3 presents quantitative data on learners' active engagement in classroom interactions through science experiments, revealing a decrease that, while seemingly counterintuitive, represents a positive shift in teaching practices. This decline likely reflects teachers' expanded repertoire of pedagogical approaches, gained through project exposure, which now enables them to engage learners through diverse and interactive methods beyond traditional experiments and lectures. Previously, their instruction relied heavily on these limited methods. The project has successfully broadened their teaching strategies, allowing them to diversify their methods and reduce their reliance on experiments as the primary mode of instruction. Observations of teachers implementing new interactive learning strategies, such as group projects, observations, videos, and photographs, support this interpretation. Furthermore, classroom observations of Teacher #6306, and reports from many other teachers, indicate increased confidence in using diverse teaching techniques.

Table 3.3:Teacher Responses Regarding the Implementation of Science Experiments in Class

Subject	**Baseline**		**Endline**	
	Yes	**No**	**Yes**	**No**
Physics	90%	10%	84%	16%
Chemistry	100%	0	74%	26%
Biology	78%	22%	94%	6%

Figure 3.3.1 supports the importance of equipping teachers with effective teaching methods to stimulate learners' natural abilities and focus their attention on achieving subject goals. Attentive learners are more likely to observe classroom discipline and orders. Teacher responses regarding the 'sources for the achievement of the intended subject goals' indicate that the combination of effective teaching methods alongside students’ inherent abilities are major contributing factors. However, a slight negative change in response in the endline survey indicates a contradiction with qualitative data on the theme of classroom management and the ability of teachers to apply multiple instructional approaches. This discrepancy, therefore, requires further investigation.

Figure 3.3.1: Factors for the achievement of the intended subject goals or objectives

Effective classroom discipline, the ability to coordinate learner behaviour to promote teaching and learning, is crucial for positive outcomes. Incidents of indiscipline disrupt the learning process by diverting attention, creating a chaotic atmosphere, and hindering effective communication. Thus, classroom teachers must ensure that every student is focused on the assigned tasks and not engaging in off-task behaviours such as wandering around the classroom, talking out of turn, or disrupting other students (Rahimi and Karkami, 2015). To minimize misbehaviour, particularly in crowded classrooms, teachers focused on creating a positive learning environment that encouraged appropriate behaviour and facilitated effective learning. Strategies employed included assigning individual or group exercises. The following accounts from two participating teachers illustrate these strategies:

"….. here we have a big class, form 1s for example, there are more than 200 students. I try to manage this class by forming groups with a large number of students though it isn't recommended but, I can force it. For example, instead of having two students sharing a book, the number may increase to six students to ensure that all are accommodated." (Teacher, 6317, Baseline).

"I ensure that all students are getting their rights equally, irrespective of their differences in academic capabilities and socio-economic status. To cater for all groups of students, in some instances, I try as much as possible to use simple language to explain some concepts. Also, I make them into groups; and give them tasks like exercises, assignments and concepts for discussions. Weak students are given special consideration." (Teacher, 6516, Endline).

Another effective strategy for maintaining classroom discipline is organizing students with mixed abilities into groups, allowing them to support one another while ensuring active participation from all members. This approach not only helps manage classroom behaviour but also fosters academic growth, particularly for students with learning difficulties. The following account illustrates the effectiveness of mixed-ability grouping in managing classroom behaviour and supporting student learning:

"………….. slow learners must be treated separately; be concentrating on them, rather than give all students equal	"This school is the home to diverse student groups, including slow and fast learners, and students from a range of socio-economic backgrounds. We also have a few students with physical disabilities who require special attention. I am

weight." Teacher 6109, Baseline.	committed to ensuring that these students receive the individualized attention they need, like mixing them in group discussions. This supports their learning and sends a powerful message that they are valued and can learn just as effectively as any other student." Teacher 6109, Endline.

Survey responses regarding the frequency with which teachers used mixed-ability groups showed that, generally, all students received equal opportunities for classroom interaction in nearly every lesson. However, a decline in the use of mixed-ability groups was observed between the baseline and endline surveys for chemistry and biology teachers (Figure 3.3.2). This suggests that, from a quantitative perspective, the intervention did not consistently reinforce the value of mixed-ability grouping for some teachers in those subjects.

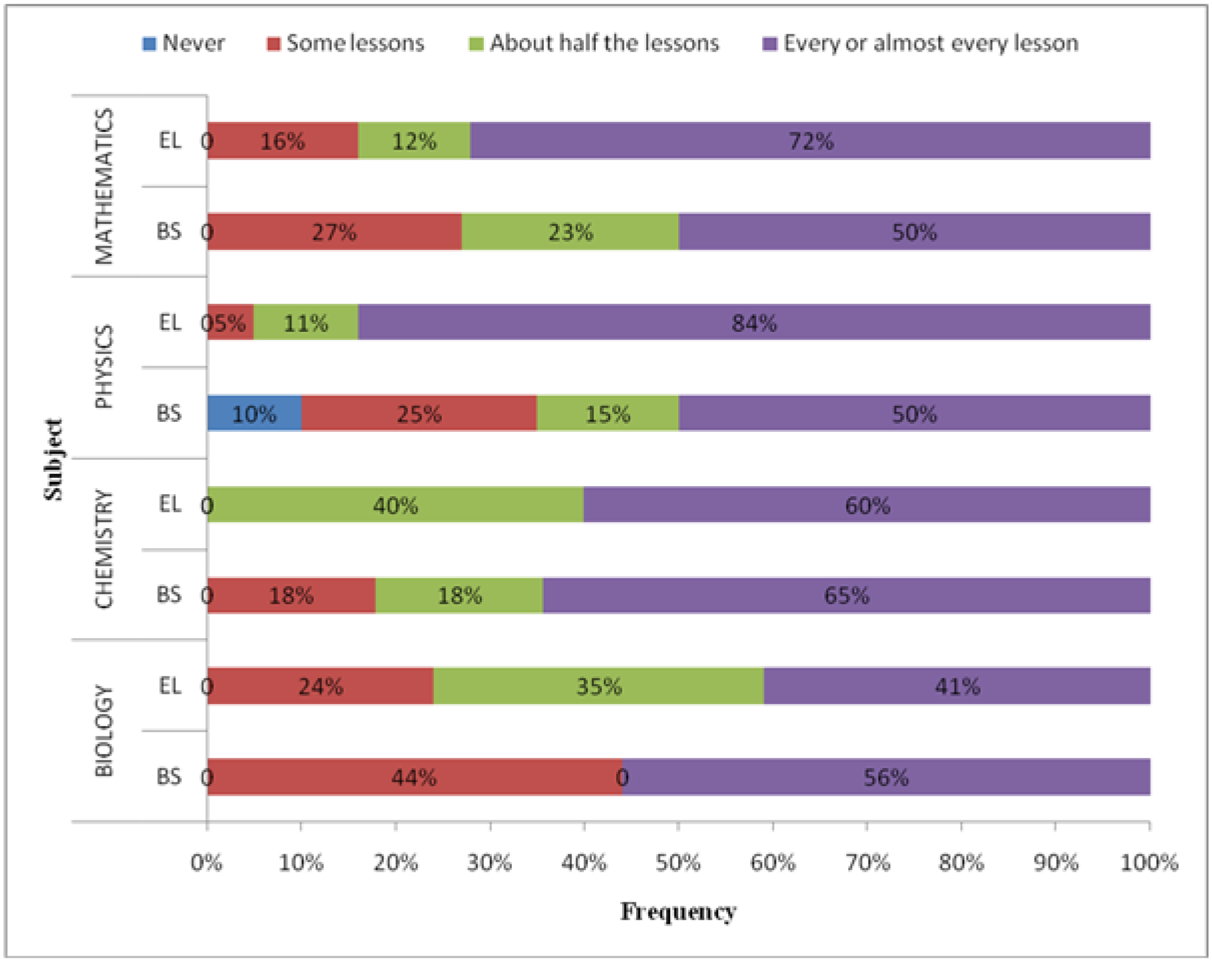


Figure 3.3.2: Participation of students with mixed abilities in classroom interaction

Furthermore, Figure 3.3.3 presents responses regarding the frequency of teachers using mixed-gender groups. The data shows an increase in classroom interactions through mixed-gender grouping, ranging from 9% to 21% in physics, mathematics, and biology. However, chemistry experienced an 8% decline. Despite this decrease, the overall frequency of mixed gender grouping in chemistry remained high, suggesting that chemistry teachers were already implementing this approach more frequently at the baseline compared to other subjects.

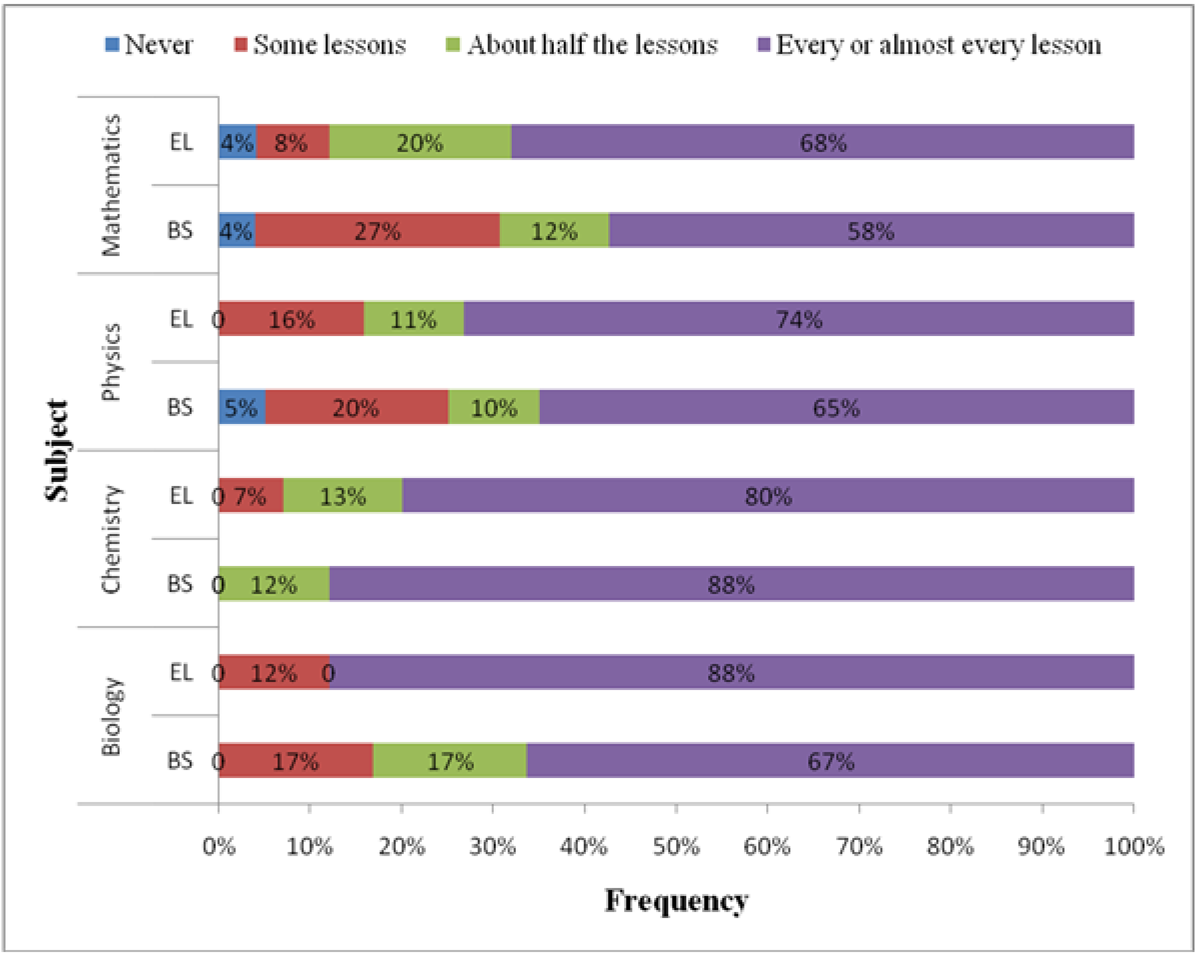


Figure 3.3. 3: Participation of students with mixed gender in classroom interaction in classroom interaction

Although the objective of employing punishment as a classroom management strategy was to instruct students on proper conduct during the learning process, several studies have suggested that its utilization should be avoided as it may hinder students' academic performance. Therefore, it is recommended that teachers should use reinforcement and antecedent strategies since they play a dual role in managing behaviour and promoting the academic performance of students (George *et al.*, 2017). Thus, to promote an effective teaching and learning atmosphere, teachers in this project employed proactive strategies rather than reactive strategies in implementing classroom management.

To address the challenge of low student motivation, often stemming from perceptions that science subjects are difficult and misconceptions about key concepts, teachers employed several proactive strategies. Common strategies included the application of diverse instructional approaches, such as the use of videos and readily available resources to clarify complex concepts, the formation of student study groups to encourage peer learning, and flexibility in teaching approaches, such as differentiating instruction. For example, chemistry teacher #6505 reported that low student motivation, due to misconceptions about periodic classification, required her to spend significant time on clarification and incorporating engaging resources. Moreover, interviews and classroom observations revealed that teachers manage discipline by ensuring all students have equal opportunities to participate in learning activities, such as group work, presentations, and demonstrations. The following excerpt provides further evidence of these practices:

"I opt to use lecture and observation methods. All students are given chances to interact and answer questions. Teacher 6700, Baseline.	"I manage large class sizes through effective grouping and tailored teaching approaches. I always use considerate, inclusive language with all students given equal opportunities in demonstrations, asking/answering questions, and group activity presentations." Teacher 6700, Endline.

In general, the findings indicate that teachers experienced positive changes in various aspects of classroom management, with a significant improvement in their competence, as recorded in endline surveys, interviews, and classroom observations for module three. Specifically, qualitative data revealed that teachers enhanced their classroom management strategies, including effective use of learning resources, application of positive discipline techniques, and improvement in instructional methods. Additionally, the implementation of CL4STEM project principles and guidelines positively influenced teachers' self-efficacy in classroom management, highlighting the success of the intervention program in supporting the professional development of in-service teachers in Tanzania.

3.3.3 Assessment

Assessment is central to effective teaching and learning, serving as a key mechanism for understanding student progress and informing instructional decisions. It plays a crucial role in education, allowing educators to measure students' understanding, track their progress, identify areas where intervention may be necessary, and evaluate the effectiveness of their teaching practices. Effective assessment provides feedback to both learners, informing them of their progress, and teachers, indicating whether instructional objectives have been met and learning has occurred. While assessment primarily serves to inform instruction and track student learning, it can also indirectly contribute to classroom management by keeping students engaged and motivated (Maki, 2002). Within the CL4STEM project, the assessment was primarily structured around the following themes:

- Knowledge of multiple practices and tools for the assessment of students' progress in class.
- Ability to design and use a variety of techniques and tools of assessment, including competency-based approaches.

Qualitative findings from interviews and classroom observations revealed changes between the baseline and endline data collection periods. The following accounts from participating teachers illustrate this shift:

"I assign various tasks to my students to measure their understanding." Teacher 6700, Baseline.	"I conduct formative assessments during lessons and use end-of-topic tests to measure students' understanding and progress." Teacher 6700, Endline.

"I'm assessing my students through quizzes, exercise and homework." Teacher 6719, Baseline.	"Employing multiple assessment techniques allows for a more comprehensive evaluation of student learning, catering to different strengths and learning styles." Teacher 6719, Endline.
"The common assessment tools include oral questions and answers, monthly tests and exams, quizzes and exercises before winding up the session." Teacher 6719, Baseline.	"Combines experimental work, assignments, and formal assessments like tests to evaluate learning." Teacher 6719, Endline.

Participating teachers demonstrated improved skills in conducting learner-centered assessments. This often involved having a representative student from each group present their discussion findings to the class, a practice observed frequently during endline classroom observations. Furthermore, endline interviews revealed increased teacher recognition of the importance of competency-based assessment. The following account from a chemistry teacher illustrates this perspective:

"………. I can provide questions, or I may assign them a practical in the laboratory and mark them. In other instances, I can administer oral questions and answers sessions." (Teacher 6508, Endline).

Figure 3.3.4 illustrates teacher responses regarding the assessment methods they use. Physics teachers showed increased use of nearly all assessment practices studied, with endline survey responses showing higher rates of adoption compared to the baseline. The use of questioning individual students in class increased from 75% at baseline to 84% at the endline. Their ability to develop and administer their assessments also increased, from 90% to 95%. This suggests a positive impact of the intervention on physics teachers' assessment practices. For chemistry teachers, the development and administration of their assessments remained at 100% throughout both the baseline and endline surveys, indicating pre-existing high proficiency in this practice.

Figure 3.3.4: Teachers' responses on how often they have been using various assessment methods

Findings from this project indicate that teachers improved their use of assessments to gauge student understanding, allowing for immediate feedback and adjustments to instruction. Traditionally, pen-and-paper tests/exams were administered mainly at the end of a topic or term for feedback and continuous assessment marks. However, during the CL4STEM project intervention, participating teachers demonstrated an increased understanding of different assessment techniques to determine students' learning progress and recognized the value of administering competency-based assessments. In particular, more teachers recognized and valued the importance of competency-based assessments, and they commended the CL4STEM intervention for exposing them to multiple modes of classroom interaction, especially competency-based assessment approaches in group work activities. These changes suggest a significant shift towards more effective and learner-centered assessment practices.

4.0 Social Learning

Social learning theory explains how people learn in social-cultural settings, bridging traditional behavioural and cognitive learning approaches. It emphasizes the interaction between environmental and cognitive factors, combining behaviour and its consequences to create an interactive learning experience.

In CL4STEM, social learning was facilitated through online, mobile-based WhatsApp Communities of Practice (CoPs). Five CoPs were established, one for each subject (Mathematics, Physics, Chemistry, and Biology), and a Common Pedagogical Principles and Practice (PPP) CoP. The PPP CoP provided a forum for general pedagogical discussions, cross cutting all subjects, and facilitated communication between teachers, educators, researchers, and the CL4STEM administration in Tanzania. The CL4STEM design leveraged CoPs to facilitate knowledge acquisition and learning through peer-to-peer interaction, collaborative problem-solving, and the sharing of best practices and resources. Teacher educators played a crucial role in fostering active participation by initiating discussions on relevant topics, posing thought-provoking questions, and facilitating the sharing of experiences and expertise. Participating teachers interacted freely, sharing ideas, problem-solving strategies, opportunities, and teaching resources in a friendly and supportive environment. They facilitated social interaction and provided a platform for ongoing professional development, the sharing of teaching resources, and a sense of community and support among geographically dispersed teachers. They also provided a safe space for teachers to ask questions, share challenges, and learn from each other's experiences. As a critical part of the CL4STEM design and implementation, CoPs also allowed participating teachers to seek support and celebrate project milestones authentically while building relationships with their peers and teacher educators. Thus, CoPs helped to overcome the physical barriers of communication while providing an up-to-date means of social interaction and promoting the use of ICT devices. In summary, the CoPs proved to be a valuable component of the CL4STEM program, fostering a sense of community, supporting professional growth, and bridging geographical barriers to facilitate effective collaboration and knowledge sharing among participating teachers and educators.

Research has demonstrated that there are generally a few different levels of participation in CoPs:

a) **Core:** Those participants who drive the CoP and are the central actors. It refers to those members of the CoP who are continually active on almost anything and everything in the CoP communications. They are a small group of people who devoted their time and energy to driving a CoP.
b) **Active participants:** Those involved in the CoP in important matters or discussions on their interest. They are also active but not the core participants in driving matters in the CoP.
c) **Occasional:** Those participants who interact in the CoP only when there is something special or specific to contribute, but not always.
d) **Peripheral:** Those participants interested in the CoP but do not participate actively in the CoP.

This study used Social Network Analysis (SNA) to examine the evolution of participation within the CoPs throughout the project. SNA provides a valuable framework for visualizing and quantifying social interactions within online communities, allowing researchers to understand how communication patterns evolve and identify key influencers. SNA revealed varying levels of engagement, ranging from passive observation to active participation in discussions, including sharing views, seeking assistance, providing clarifications, and contributing resources. These evolving participation patterns within each CoP are illustrated below:

a) Physics Chatline

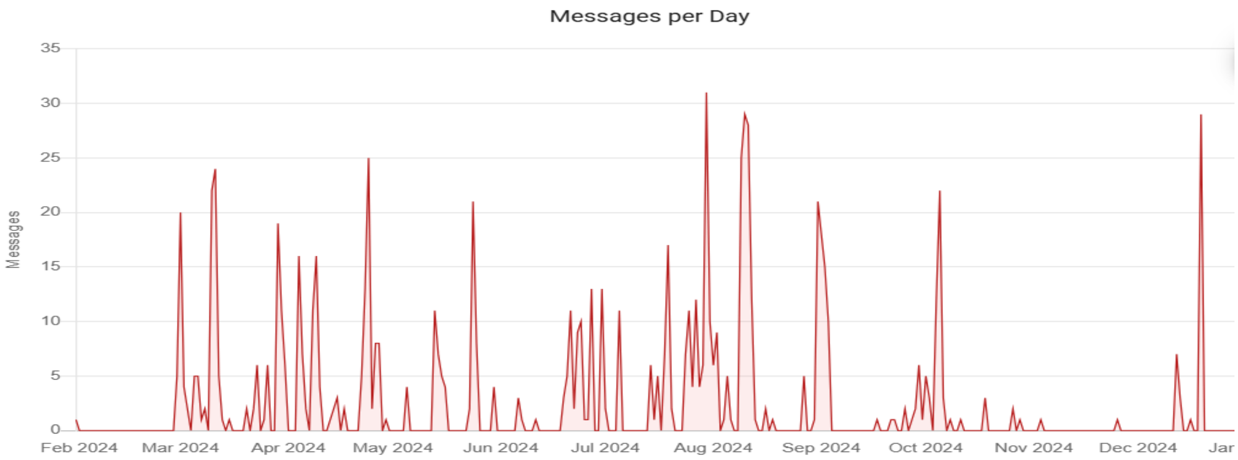


Figure 4.1: Physics chatline Jan-Dec 2024

b) mathematics Chatline

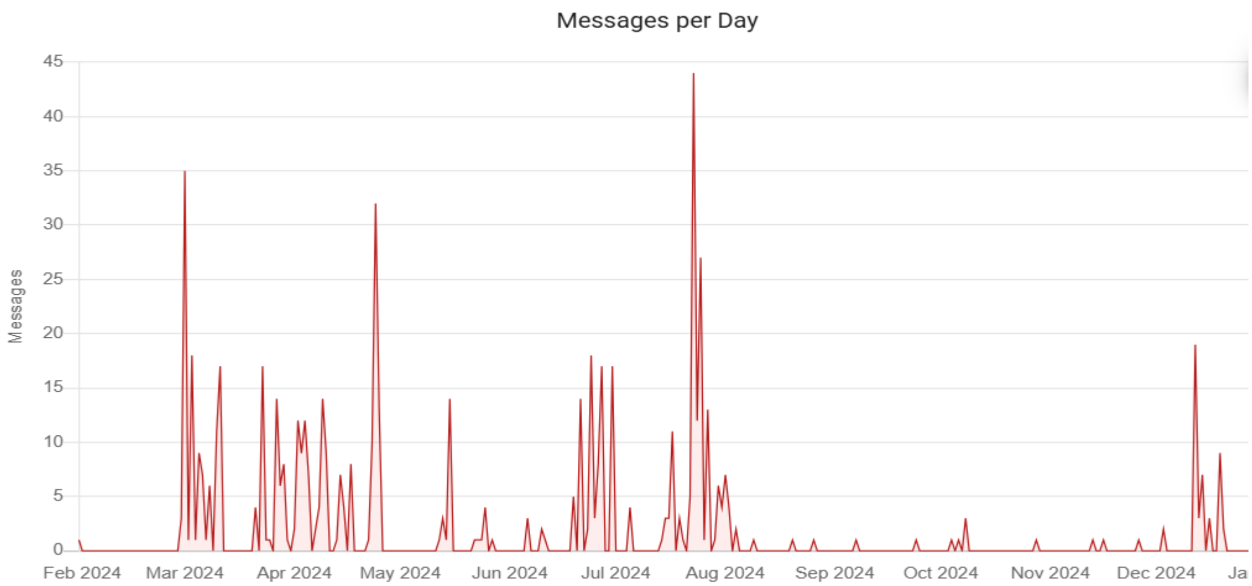


Figure 4.2: mathematics chatline Jan-Dec 2024

c) Chemistry Chatline

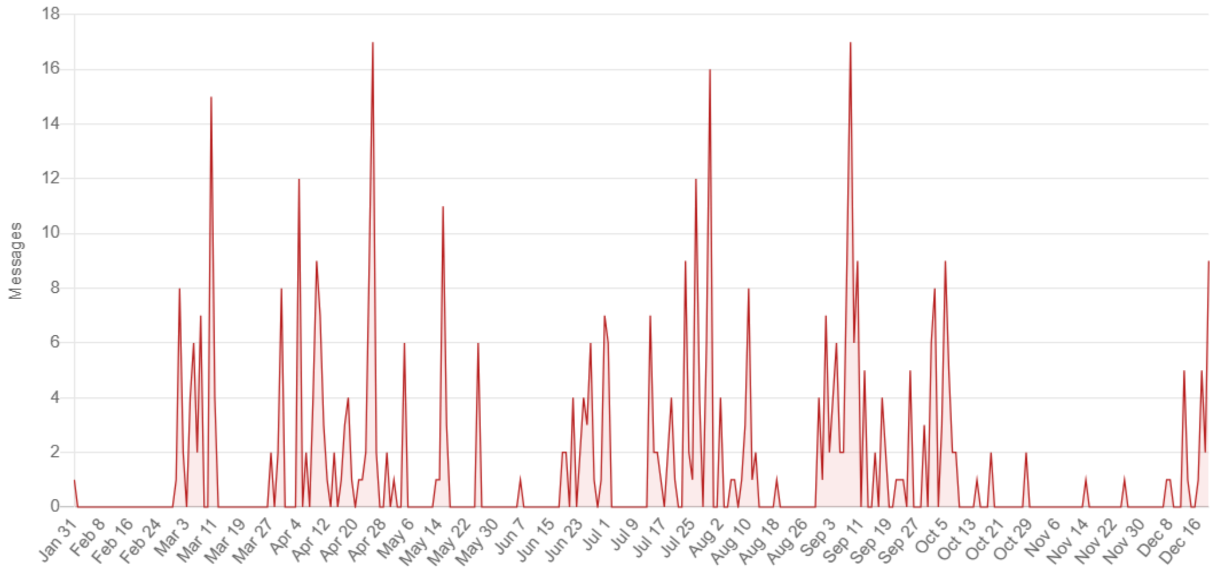


Figure 4. 3: Chemistry Chatline Jan-Dec 2024

d) Biology Chatline

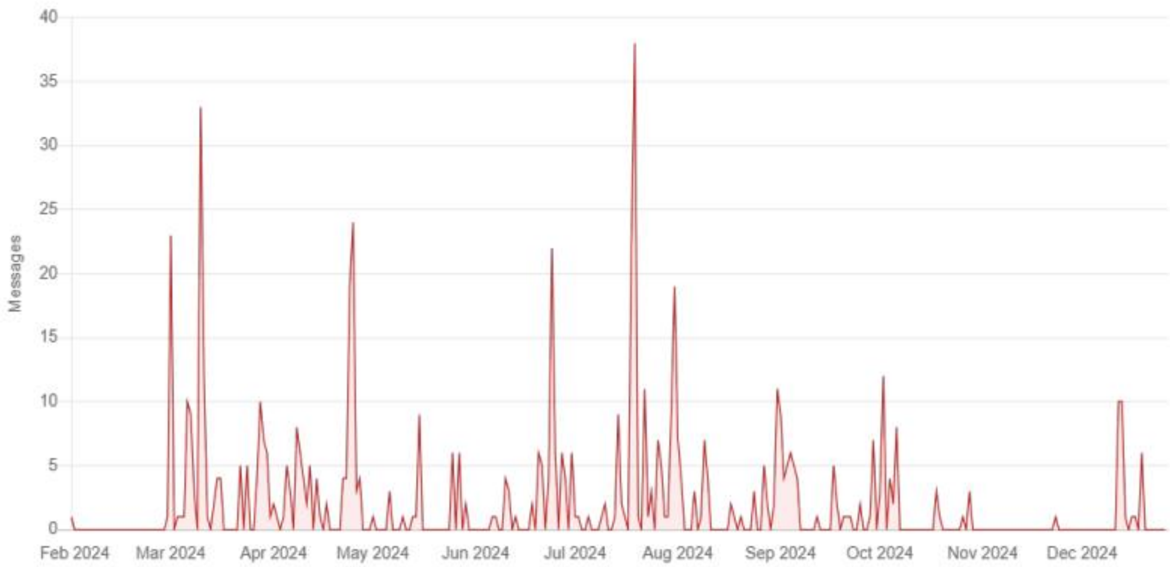


Figure 4.4: Biology Chatline Jan-Dec 2024

(Figure 4.1-4.4 Evolution of Teacher Online Communities of Practice during CL4STEM Implementation)

The above chatlines *(Physics, Mathematics, Chemistry and Biology)* show fewer engagements in January and February as it was the time set for the collection of baseline done mainly by teachers, educators and research fellows while allowing teachers get familiarised with the CL4STEM online engagements and Moodle orientations, but picked pace from March to August and September as it was the period of many activities in the CL4STEM Moodle platform as teachers were required to complete assignments, post reflections and peer reviews thus seeking more clarifications and assistant to teacher educators and among themselves. The evolution of the chatline also shows little engagements in October and November as most of the students were done or finishing the pending activities and then picked up pace in December when endline data were collected, making teachers seek more assistance to complete the same.

It is essential to know that the lack of interaction in the CoP in some months (as described above) did not mean that the participants did not consider the CoP valuable, but these participants would be regarded as peripheral participants, as described by Wenger-Trayner.

From the perspective of qualitative analysis, all subject CoPs showed some common types of interactions. These interactions are explained below, and the respective screen grabs of the chats are shared here. Three main types of interactions were seen across all subjects: Teachers sharing practice, reminders and support and feedback.

1. *Teachers sharing practice:* In Tanzania, teachers across subjects shared their practice by sharing photos and details of their school's lesson plan implementation, as seen in the pictures below in Figure 4.5). This created a platform for the teachers to showcase their lessons and discuss their participation in the project (Figure 4.6).

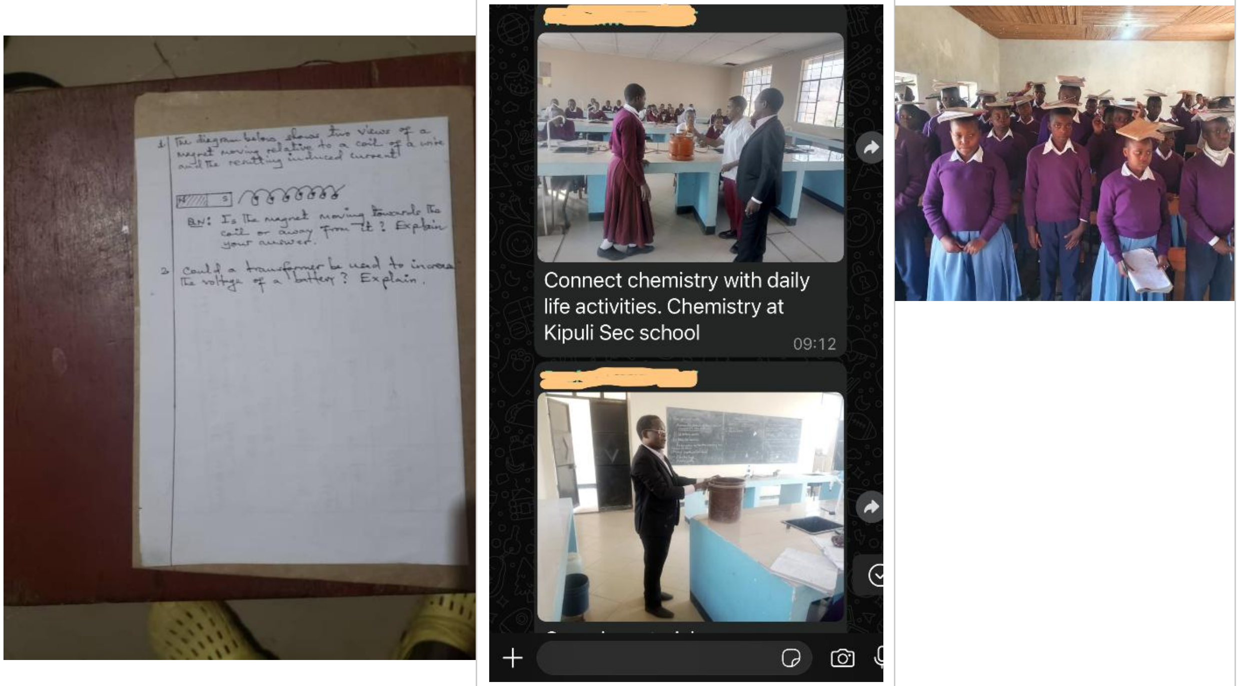


Figure 4. 5: Examples from CoP on Teachers Discussing Practice

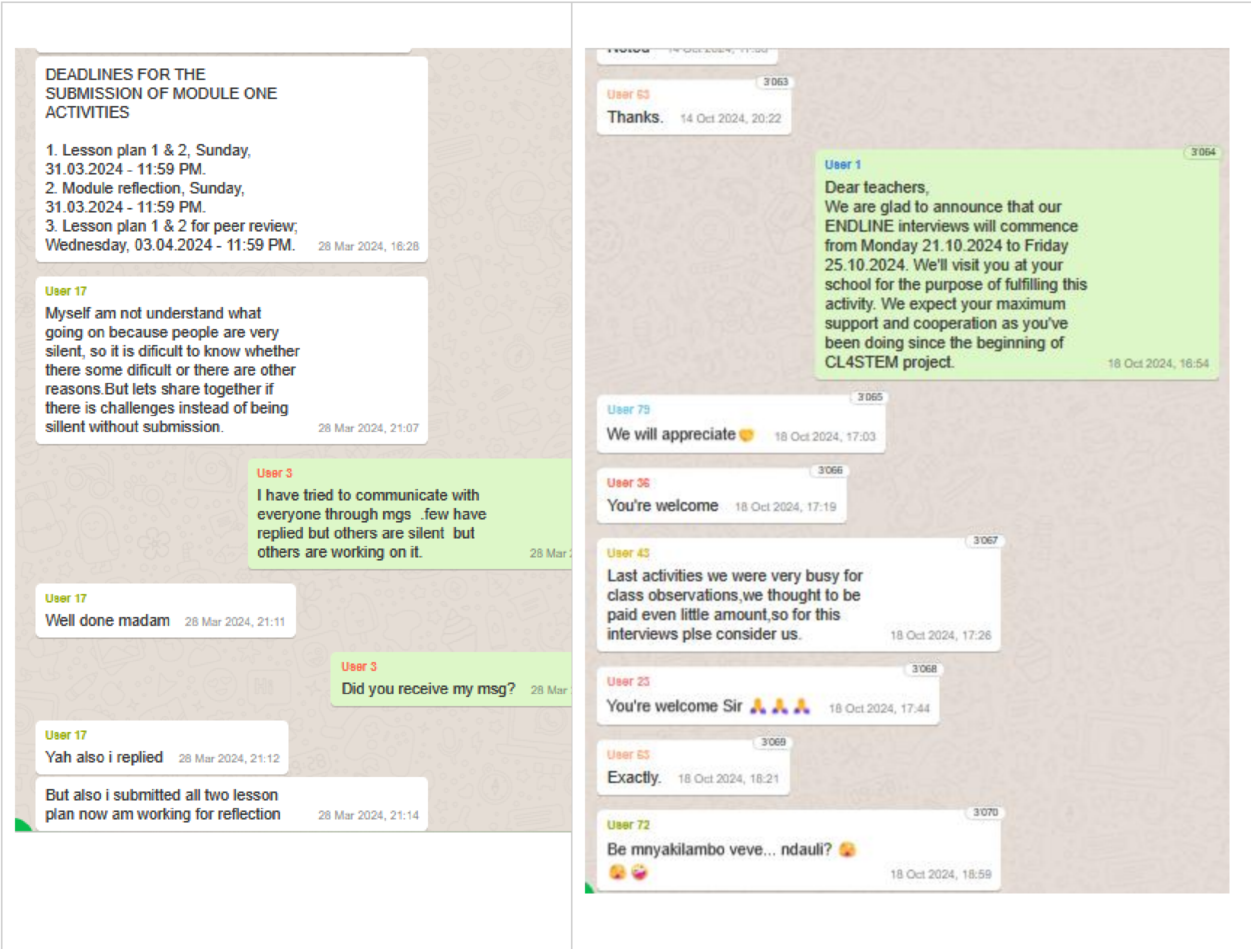


Figure 4.6: Examples of Teachers Discussing Participation in the CL4STEM Project.

2. *Reminders:* Teacher educators and subject leaders often shared reminders in the CoPs encouraging teachers to keep making progress in module implementation. Reminders could be general messages to the community or directly tag targeted participants (Figure 4.7). They would also use lists of participants to explicitly call out people to participate.

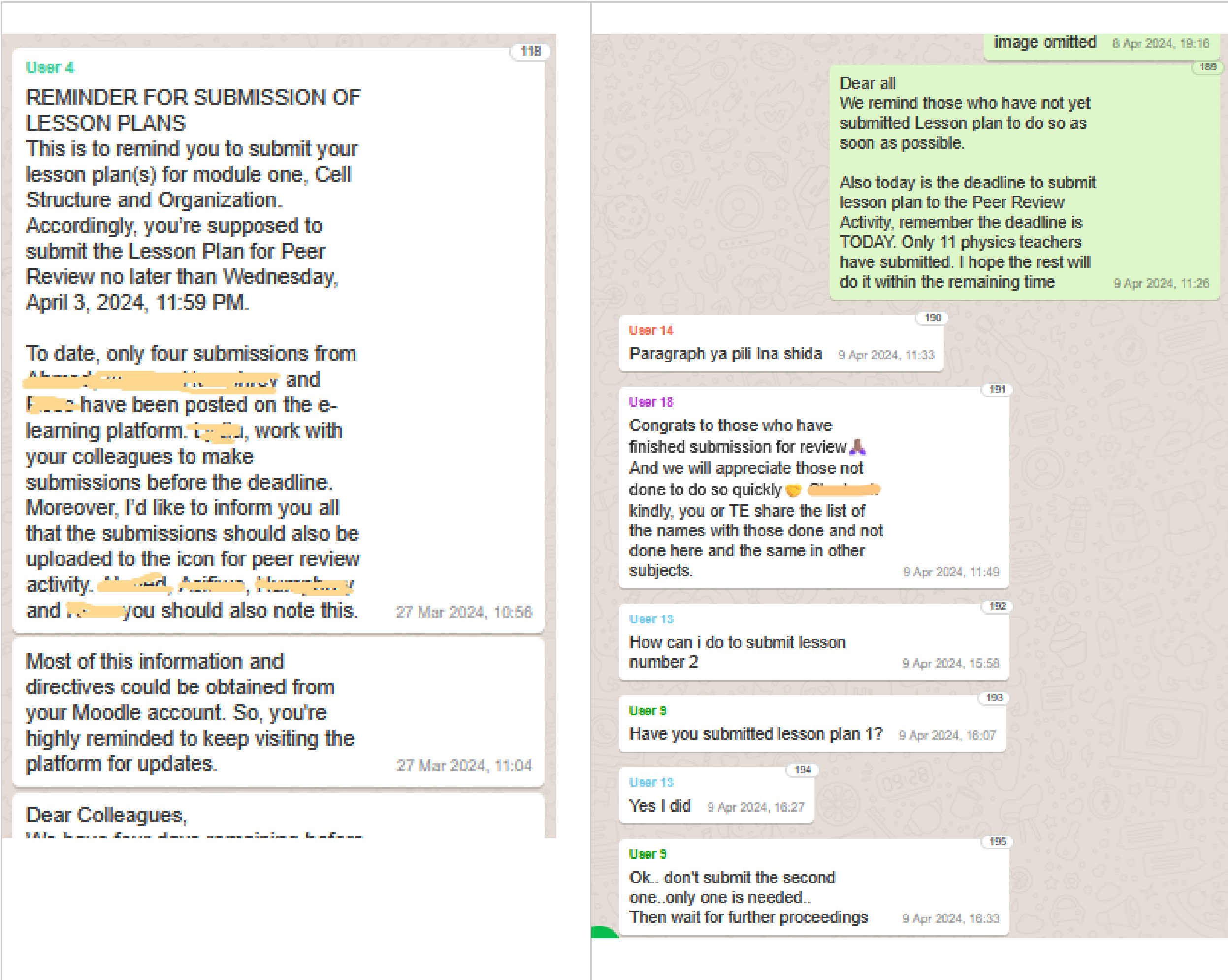


Figure 4.7: Examples of Teacher Educators Using Reminders to Encourage Participation.

3. *Support and feedback:* Teachers and teacher educators both shared messages seeking and offering support. Teachers would seek support to access Moodle-based modules. Figure 4.8 shows a teacher educator providing feedback on the submission of an activity meanwhile, a teacher is getting assistance from their fellow teacher on how to access the Moodle platform to proceed with the activity submission. Similarly, Figure 5.6 shares examples of teacher educators encouraging teachers to accomplish tasks.

In Figure 4.9, we can see the Math teacher educator engaging with teachers on how to use local resources to teach specific Math concepts. Figure 5.7 shows another instance from Math CoP where both the teacher and the teacher educator are jointly reflecting on the project and the relevance of its design.

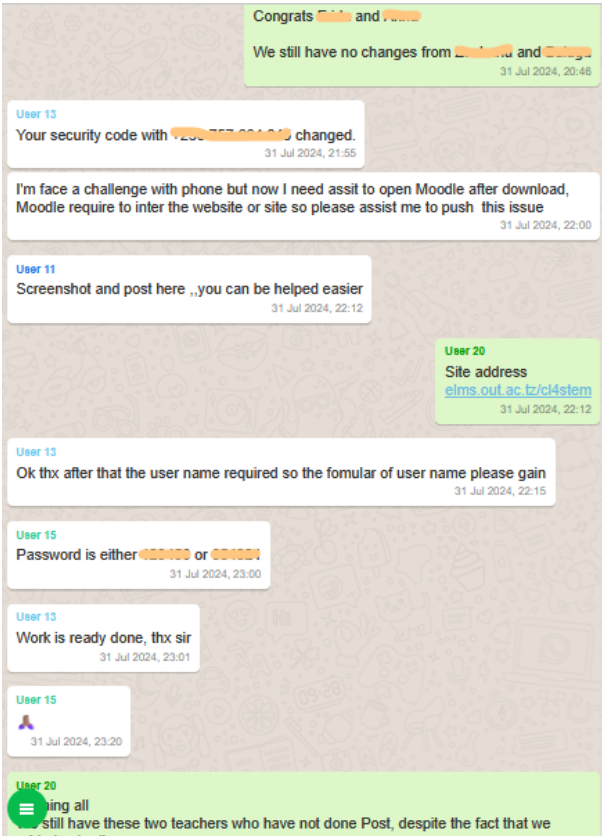


Figure 4.8: Conversation between teacher educator and Teacher about Submission of tasks

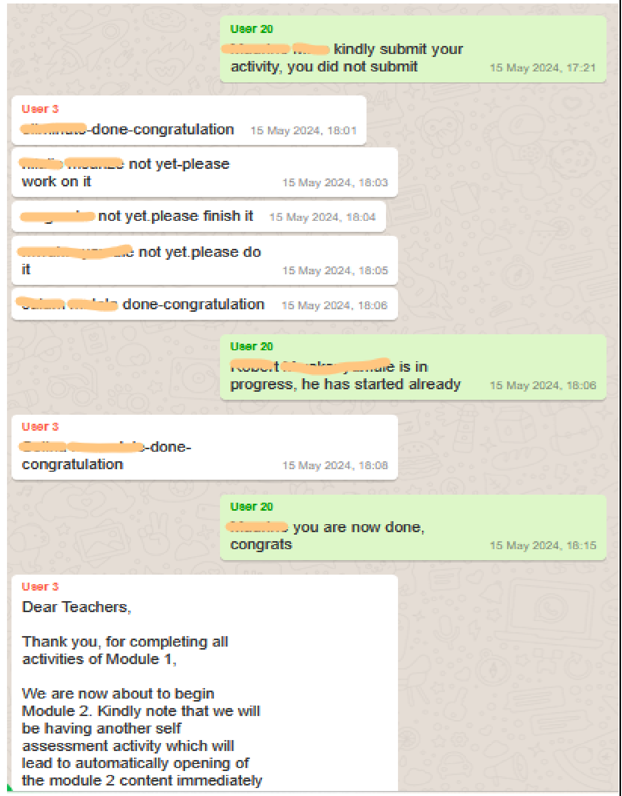


Figure 4.9: Teachers and Teacher Educators Encouraging Others to Participate in the CL4STEM Activities

Thus, these online groups served as communities in which teachers and teacher educators could engage in an authentic community, exchange ideas, tinker with new tools and technologies, discuss their practices, learn from each other, and share their achievements.

5.0 Conclusion

This section summarizes the key inferences from the CL4STEM scaling-up initiative project, structured around the Knowledge, Attitudes, and Practices (KAP) framework. The inferences are organized and analysed using the KAP framework, which includes ten themes categorized under Subject Matter Knowledge, Pedagogical Content Knowledge, and General Pedagogical Knowledge. Each conclusion is discussed concerning its corresponding theme, providing a comprehensive overview of the project's findings and their implications.

Subject Matter Knowledge

The CL4STEM project significantly improved teachers' understanding of the interconnectedness of scientific and mathematical concepts, and their ability to justify knowledge within these fields. Teachers demonstrated a clear improvement in recognizing relationships between various science and mathematics topics. The project also fostered the ability to effectively justify the relevance of key concepts, equipping teachers to explain why specific ideas are foundational and their real-world significance. Participating teachers gained confidence in explaining complex principles and emphasizing their practical applications. These improvements reflect the project's success in deepening teachers' expertise and enhancing their capacity to improve student learning.

The intervention significantly enhanced participating teachers' understanding of science and mathematics, leading to improvements in both their conceptual knowledge and teaching practices. Teachers now emphasize the empirical foundations of science, actively incorporating experimentation and observation into their lessons. They also foster creativity and imagination in scientific inquiry, employing innovative approaches to explain complex concepts. In mathematics, teachers have improved their ability to explain key methods such as problem-solving, logical reasoning, and pattern recognition, with a focus on sequential learning. Classroom observations confirm the increased use of real-world examples and interactive activities, resulting in greater student engagement. Overall, the project significantly strengthened teachers' ability to convey scientific and mathematical principles, enriching both their teaching methods and student learning experiences.

Pedagogical Content Knowledge

The CL4STEM project has significantly enhanced teachers' pedagogical content knowledge, which includes understanding students’ prior knowledge, misconceptions, and learning difficulties in STEM subjects. Participating teachers improved their ability to design lessons that address these challenges, using students’ existing knowledge as a foundation for introducing new concepts. The project boosted teachers’ confidence in addressing complex content and supporting struggling learners. Overall, it equipped teachers with the skills to proactively assess and correct misconceptions, improving their teaching practice and fostering better learning outcomes.

The project also significantly enhanced teachers' use of student-centred instructional strategies, such as demonstrations, group work, and hands-on activities, promoting deeper learning. Teachers recognized the importance of connecting scientific concepts to real-world applications, boosting student engagement and critical thinking. They became more skilled at using diverse methods to cater to different learning styles, creating dynamic, participatory environments. Emphasizing inquiry-based learning and the use of local resources enriched the learning experience. Overall, the project has improved teaching practices, leading to greater student engagement, deeper content understanding, and the development of critical scientific and mathematical skills.

Regarding context for learning, the study found significant improvements in teachers' understanding and application of environmental, social, and material factors in their pedagogy. Teachers increasingly utilized local resources, integrated everyday life experiences, and connected current events to lessons, making content more engaging for students. Classroom observations and interviews showed a greater focus on adapting teaching methods to local contexts. The intervention successfully enhanced teachers' ability to improve student engagement and improve learning outcomes, particularly through real-life applications and local materials, though variations in subject-specific resource use were noted. Overall, the project fostered a more dynamic and contextually relevant approach to teaching.

The research also showed that the intervention positively impacted teachers' content representation skills. Teachers improved their ability to present knowledge in various forms such as analogies, equations, diagrams, videos, models, and hands-on activities to meet students' varied needs. They also became more aware of the limitations of models and illustrations and enhanced their ability to use multiple representations to address the diverse needs of all students, incorporating Universal Design for Learning (UDL) principles, and using local resources and technology to enhance understanding. Overall, the project improved teachers' ability to create a more engaging and effective learning environment for all students.

Furthermore, teachers demonstrated significant improvements in applying curriculum knowledge to lesson planning, teaching, and assessments, especially in science and mathematics. They developed a deeper understanding of subject goals and conceptual interconnections which facilitated the integration of real-world applications. This proficiency reflects the intervention's positive impact on professional development. Increased survey results highlight the project's success in strengthening teachers' curriculum knowledge, leading to improved student learning experiences.

General Pedagogical Knowledge

Through the project's professional development, teachers became more attuned to diverse student needs, including those with disabilities. They adopted inclusive strategies, such as random selection, mixed-ability groups, and culturally responsive practices, creating a supportive learning environment for all. Survey responses show increased recognition that students with disabilities can thrive in mainstream classrooms. This shift reflects a commitment to inclusivity, ensuring every student receives the support needed to thrive academically and personally.

Research findings reveal positive changes in teachers' classroom management skills, with notable progress observed in endline surveys, interviews, and classroom observations, specifically for module three. Teachers demonstrated enhanced competence in managing learning resources, applying positive discipline techniques, and refining instructional strategies. The implementation of CL4STEM principles boosted teachers' self-efficacy in classroom management, highlighting the intervention's positive impact on the professional development of in-service teachers in Tanzania.

The CL4STEM project improved teachers' assessment skills, enabling them to better gauge student understanding and provide immediate feedback and instructional adjustments. The project broadened teachers' understanding of assessment techniques to track student progress beyond traditional end-of-topic or term exams. Notably, many teachers recognized the value of competency-based assessments, particularly in group work activities, and appreciated how the intervention introduced multiple modes of assessment during lesson implementation.

Table 5.1: Summary of Change in Teachers' Knowledge, Attitudes, and Practice

Theme	Change	Results
Subject Matter Knowledge	Yes	Teachers increasingly became confident in explaining complex principles and emphasized their practical applications.
Nature of Science/Mathematics	Yes	Teachers showed appreciation for the empirical basis of science, emphasizing experimentation and observation in their lessons.
Instructional Strategies	Yes	Improvement in teachers' use of interactive and student-centred instructional strategies, such as demonstrations, group work, and hands-on activities, promoted deeper learning.

Students Misconceptions and Conceptual Learning Difficulties	Yes	Positive impact was noted on teachers' understanding and use of students' prior knowledge, misconceptions, and learning difficulties in STEM subjects.
Representation of the Content	Yes	Teachers' ability to present knowledge in various forms to meet students' varied needs improved (analogies, equations, diagrams, videos, models, and hands-on activities) An increase in the use of locally available materials in teaching was noted.
Context for Learning	Yes	improvements in teachers' understanding and application of environmental, social, and material factors in their pedagogy were noted.
Curriculum Knowledge	Yes	Some improvements in teachers' application of curriculum knowledge in lesson planning, teaching, and assessments were observed.
Equity and Inclusion	Yes	An increase in the use of equity and inclusive strategies, such as random selection, forming mixed-ability groups, culturally responsive practices, and creating a supportive learning environment for all was evident.

Classroom Management	Yes	Teachers increasingly demonstrated competence in managing learning resources, applying positive discipline techniques, and refining instructional strategies.
Assessments	Yes	many teachers have recognized the value of competency-based assessments, particularly in group work activities, and appreciate how the intervention introduced multiple modes of assessments.

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