Strengthening Secondary School Teacher Capacities for Higher Order Thinking with Inclusion and Equity

CL4STEM Bhutan Endline Report

Bhutan | Nigeria | Tanzania | India

The Connected Learning for Science, Technology, Engineering, and Mathematics (CL4STEM) project aims to pilot the Connected Learning Initiative (CLIx, https://clix.tiss.edu), a TPD innovation and research its effectiveness and potential scaling. It is designed to build the capacities of secondary school teachers in Science and Maths to help foster higher-order thinking with inclusion and equity (HOTIE) in their classrooms. The CL4STEM pilot engages teachers in curated Open Educational Resources (OER) based modules in Science and Maths and encourages participation in online Communities of Practice (CoP). It is a South-South collaboration among higher educational institutions to adapt and pilot the CLIx model of TPD in Tanzania, Nigeria, and Bhutan. CLIx has been successfully implemented at scale in India.

The research that accompanies the intervention focuses on two broad areas. First, being the Impact Study which analyses the impact of innovation on teachers' knowledge, attitudes, and practice for higher-order teaching and learning of science and maths in an inclusive and equitable manner. Second is the Innovation Diffusion Study, which generates knowledge on the processes of adoption of the innovation for specific local contexts and the conditions that support scaling.

The knowledge acquired from this project will be disseminated to concerned divisions of the Ministry of Education and Skills Development (MoESD) and other STEM education stakeholders to seed it into the policy agenda of these countries. Key insights from this project would be shared with other researchers and opinion leaders in the spirit of creating global public goods.

This study is funded by the International Development Research Centre (IDRC) under the Global Partnership for Education, Knowledge and Innovation Exchange (https://www.gpekix.org). ***Centre for Applied Sciences and Technology Research, Ibrahim Badamasi Babangida University, Lapai, Nigeria***, is the lead for the CL4STEM project consortium, which includes ***Samtse College of Education, Bhutan*** and the ***Open University of Tanzania*** as the country partners. ***The Center of Excellence in Teacher Education, Tata Institute of Social Sciences, India*** is the technical consultant to the project.

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Report is available for download at https://www.connectedlearningforstem.org/
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iii. Abbreviations

B.Ed	Bachelor of Education
B.Sc.	Bachelor of Science
BBE	Bhutan Board of Examinations
BEB	Bhutan Education Blueprint
BL	Baseline
CBAM	Concerns Based Adoption Model
CETE	Center of Excellence in Teacher Education
CL4STEM	Connected Learning for STEM
CLIx	Connected Learning Initiative
CoP	Communities of Practice
CPD	Continuous Professional Development
DT	Design Thinking
ECCD	Early Childhood Care and Development
EL	Endline
GB	GigaByte
GPE-KIX	Global Partnership for Education-Knowledge and Information Exchange
GPK	General Pedagogical Knowledge
HOTIE	Higher Order Thinking for Equity and Inclusion
IBBUL	Ibrahim Badamasi Babangida University, Lapai
ISCE	Indian School Certificate Examinations
ICT	Information and Communications Technology
IDRC	International Development Research Center
ITE	Inservice Teacher Education
KAP	Knowledge, Attitudes and Practice
M.Ed.	Master of Education
M.Sc	Master of Science
MoESD	Ministry of Education and Skills Development
OER	Open Educational Resources
OUT	Open University of Tanzania
PCK	Pedagogical Content Knowledge
PGDE	Post Graduate Diploma in Education
PTC	Primary Teaching Certificate
RGoB	Royal Government of Bhutan
RTICT	Reflective Teaching using ICT
SCE	Samtse College of Education
SMK	Subject Matter Knowledge
SNA	Social Network Analysis
SNDT	Shreemati Nathibai Damodar Thackersey
SoC	Stages of Concern
STEM	Science, Technology, Engineering and Mathematics
TE	Teacher Educator
TISS	Tata Institute of Social Sciences
TPD	Teacher Professional Development
TTI	Teacher Training Institute
TV	Television
UDL	Universal Design for Learning
UPS	Uninterruptible Power Supply

Unit 1: Introduction

Bhutan, a small landlocked country in the Eastern Himalayas, has a unique educational history dating back to the 17th century. Bhutan's first educational system was monastic education, which was conducted in monasteries and served as the country's sole means of education. Monastic education focused on spiritual progress, teaching students Buddhist philosophy and doctrine and practical skills such as meditation, calligraphy, and medicine (Dargye, 2014)[1]. However, only students who demonstrated academic merit or religious potential were eligible for monastic education (Schuelka, 2013)[2]. In the late 1950s, the introduction of a Western-style modern education system with English as the medium (Penjore, 2013)[3] was a significant event in Bhutan's history because it provided universal education to all citizens, regardless of social status (Phuntsho, 2000)[4]. In 1961, Bhutan's third King, Jigme Dorji Wangchuck (1952-1972), known as the "Father of Modern Bhutan," launched the First Five Year Plan, which marked the beginning of the country's modernization and development and laid the foundation for Bhutan's current education system. This plan placed significant emphasis on providing free and inclusive quality education to all Bhutanese children.

As a result, schools were established across the country, and a secular education system was established, offering a modern curriculum that included science, mathematics, social studies, and English, governed by education plans and policies developed by the Department of Education (Hirayama, 2015)[5]. Similarly, Bhutan established the first Teacher Training Institute (TTI) in Samtse in 1968, which is now known as the Samtse College of Education, to train national teachers for the Primary Teaching Certificate (PTC) program (Gyamtso, 2020)[6]. Apart from the national language (Dzongkha), the entire curriculum was borrowed from the Indian education system, and teachers were also recruited from India to teach English, mathematics, science, and social science subjects (Chhoeda, 2007)[7]. The Indian School Certificate Examinations (ISCE), New Delhi, used to administer exams in the 10th and 12th grades until 2000. Since 2001, the Bhutan Board of Examinations (BBE) has been the sole administrator of Bhutan's board examinations, and the country no longer uses Indian curricula but instead has its own, designed to meet national needs and aspirations.

The Royal Government of Bhutan (RGoB) has made significant investments in education, including the construction of new schools, the improvement of science laboratories and ICT facilities, the training of more teachers, the support of teachers' professional development, and the development of new curriculum materials. Bhutan currently has 598 (562 Government and 36 Private) schools with a total enrollment of 162,420 students, with 74,061 males and 83,398 females (http://www.education.gov.bt/). Bhutan's commitment to education has resulted in a significant increase in literacy rates, from 10% in 1961 to 71.4% today, and a youth literacy rate of over 93% (https://www.nsb.gov.bt/). The country continues to provide free education from Early Childhood Care and Development (ECCD) to

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[1] Dargye, Y. (2014). An Overview of Bhutan's monastic education system. Retrieved on July 6, 2023, retrieved from http://www.bhutanstudies.org.bt/publicationFiles/A

[2] Schuelka, M. J. (2013). Education for youth with disabilities in Bhutan: Past, present, and future. *Bhutan Journal of Research and Development, 2*(1), 65-74.

[3] Penjore, D. (2013). The state of anthropology in Bhutan. *Asian and African area studies*, 12(2), 147-156.

[4] Phuntsho, K. (2000). Two ways of learning. *Journal of Bhutan Studies, 2*(2), 96–126.

[5] Hirayama, T. (2015). A Study on the Type of School during the Dawn of Modern Education in Bhutan. Bulgarian Comparative Education Society.

[6] Gyamtso, D. C. (2020). Teacher education in Bhutan. Teacher education in the global era: Perspectives and practices, 81-97.

[7] Chhoeda, T. (2007). Chapter 4. Schooling in Bhutan. In A. Gupta (Ed.), *Going to School in South Asia*. Greenwood Publishing Group.

postgraduate levels in a wide range of disciplines, including general education, medical, engineering, vocational, monastic, and non-formal education. Likewise, all students in Bhutan, except those enrolled in non-formal education programs, are eligible for government-funded boarding and meal facility schools.

The Bhutanese education system has evolved over time to meet the country's changing economic and social landscapes. Some of the key milestones in the evolution of the Bhutanese education system include the Bhutan Education Blueprint (BEB) (2014-2024), a comprehensive plan that outlines a number of goals for the education system to adapt to the changing times of the new century. The main focus areas of the BEB are access to education, quality education, equity in education, and system efficiency. To achieve the transformational goals outlined in the blueprint, various strategies and action plans, such as teacher professional development programs, curriculum reforms, infrastructure development, the use of technology in education, and partnerships with national and international organizations, are constantly implemented. In 2016, all teachers in Bhutan were trained in Transformative Pedagogy, which is an approach to learning that emphasizes critical thinking, problem-solving, and collaboration (Wangdi, 2016)[8]. This training was adopted from Dr Spencer Kagan's collaborative learning structures, which were developed in response to the realization that traditional teaching methods were not meeting the needs of Bhutanese students in the 21st century.

Meanwhile, the integration of ICT into education had already begun with the initiative of the *iSherig1* Education Master Plan 2014-2018 (MoE, 2014)[9], which aims at creating an ICT-enabled knowledge-based society and achieving quality education. This was followed by the *iSherig2* Education Master Plan 2019-2023 (MoE, 2019)[10], which calls for the education system to capitalize on emerging technologies in order to prepare Bhutanese children to participate meaningfully and productively in the third Industrial Revolution (IR 4.0). Likewise, the draft National Education Policy (MoE, 2018) of the Kingdom of Bhutan, aims to provide overarching directions for building and nurturing an education system that prepares citizens who are nationally rooted and globally competent.

In recent years, the Bhutanese government has placed a strong emphasis on science, technology, engineering, and mathematics (STEM) education, which is seen as critical for preparing students for future jobs and for Bhutan's economic development. Despite the RGoB’s significant investments in education, the subsequent Pupil Performance Reports[11] Board examinations show that students' performance in STEM subjects in grades 10th and 12th board exams has been consistently poor. According to a study, issues associated with Bhutanese students' declining STEM subject performance include bulky content-laden curricula, abstract concepts, fragmentation, and discontinuity in the current curriculum (Child et al., 2012)[12]. Other potential causes could include the lack of qualified STEM teachers, an ineffective STEM curriculum, lack of students’ interest in STEM subjects, and other cultural and social factors. Some possible solutions to improving STEM education include providing more hands-on learning experiences, focusing on problem-solving, critical thinking skills, and effective

[8] Wangdi, T. (July 7th, 2016). Teachers introduced to transformative pedagogy. Retrieved on July 7, 2023 from https://kuenselonline.com/teachers-introduced-to-transformative-pedagogy/

[9] Ministry of Education[MoE]. (2014). iSherig-1 Education ICT Master Plan 2014-2018. Royal Government of Bhutan: Thimphu, Bhutan. ISBN 978-99936-776-4-2

[10] Ministry of Education [MoE]. (2019). iSherig-2 Education ICT Master Plan 2019-2023. Royal Government of Bhutan: Thimphu, Bhutan. ISBN 978-99980-41-00-4

[11] https://www.bcsea.bt/examinations-publications

[12] Childs, A., Tenzin, W., Johnson, D., & Ramachandran, K. (2012). Science Education in Bhutan: Issues and challenges. International Journal of Science Education, 34 (3), 375–400. doi:10.1080/09500693.2011.626461

communication, making STEM education more engaging and relevant to students' interests, and providing more support for teachers through professional development courses.

Consequently, following the release of the *Royal Kasho* (Royal Edict) on Education Reform on December 17, 2020, Bhutan has placed a strong emphasis on STEM education, with the goal of improving students' performance in these subjects and preparing them for the future. Two paramount excerpts from the Royal Address on Education Reform, which emphasize the importance of educational reform and STEM subjects in preparing students for 21st-century challenges are presented here, as translated by Bhutan's national newspaper Kuensel:

> Therefore, our generation has the sacred responsibility of radically rethinking our education system and transforming curriculum, infrastructure, classroom spaces, and examination structures. Educationists and experts have identified what twenty-first century competencies mean for children everywhere. By developing their abilities for critical thinking, creative thinking, and learning to be life-long learners, we have to prepare them to be inquisitive, to be problem-solvers, to be interactive and collaborative, using information and media literacy as well as technological skills. We must prioritize self-discovery and exploration, and involve learners in the creation of knowledge rather than making them mere consumers of it. We must make STEM subjects part of their everyday language (Kuensel, 2021).
>
> In preparing our youth for the future, we must take advantage of available technologies, adapt global best practices, and engineer a teaching-learning environment suited to our needs. Technology is the argument of our time and a major indicator of social progress. The irony in our context is the absence of technology in classrooms for a generation of students who are exposed to, and live in the digital age. To ensure that teachers are not disconnected from their students, the professional development of teachers should integrate technology, digitalisation, artificial intelligence, and automation (Kuensel, 2021).

As part of the Education Reform efforts, the Ministry of Education and Skills Development (MoESD) has started a number of initiatives aimed at improving the quality of STEM education, such as developing a robust curriculum and assessment systems, developing infrastructure, increasing access to STEM materials, and providing opportunities for continuous professional development (CPD) for teachers. Recognizing the need of the hour in participating in education reform exercises and also to realize His Majesty's vision for quality STEM education Samtse College of Education (SCE), Bhutan's only secondary teacher education institute, collaborated with Ibrahim Badamasi Babangida University, Lapai (IBBUL), Nigeria, and the Open University of Tanzania (OUT), with the Tata Institute of Social Sciences (TISS), India, as the lead consultant, to support the CPD of the selected secondary STEM teachers through the Connected Learning for STEM (CL4STEM) project. The research project was funded by the International Development Research Centre (IDRC), Canada, through the Global Partnership for Education Knowledge and Innovation Exchange (GPE-KIX).

The project’s overall objectives were as follows:

1. Develop a selection of OERs that will be curated and adapted for suitability to local contexts and needs;
2. Integrate OERs for technology and pedagogical content knowledge (PCK) and inclusive education into the Initial Teacher Education (ITE) programs and Newly Qualified Teachers (NQTs);

3. Develop certificate courses for STEM teachers for integrating OERs for technology, PCK, and inclusive education; and
4. Build vibrant Communities of Practice (CoP) for the capacity development of the STEM teachers in the respective partner institutions.

The implementation of the innovation took place in three stages:
Stage 1: Knowledge transfer of the CLIx (Connected Learning Initiative) approach to Teacher Professional Development (TPD)
Stage 2: Adaptation and development of contextually relevant designs of innovation
Stage 3: Development of a contextually relevant implementation and plan for roll-out

Knowledge Transfer

The knowledge transfer process under Stage 1 was led by the faculty of TISS. Teacher educators from the three collaborating universities participated in virtual workshops and created 13 modules for TPD based on the conceptual framework theory of change (See Figure 2.1). The workshops focused on the following elements:

1. Mathematics and science PCK
2. Beliefs regarding inclusion, active and hands-on learning
3. Skills in integrating hands-on learning into the classroom, integrating ICT (where available), using resources to improve student talk and the quality of questions asked in order to develop higher-order thinking, and adopting inclusive practices
4. Management of a subject-based online CoP to share experiences and build contextual PCK collaboratively
5. Use of ICT in education and its role in peer learning and the professional development of teacher educators

The knowledge transfer was completed in five phases (Figure 1.1).

Phase 1 was designed for TEs to experience online practice-based reflective teaching courses for teachers along with CLIx and other exemplar OERs for high school students. The experience was designed for TEs to explore the pedagogical ideas adopted to design the OERs and to enhance their PCK. While the TEs were taking the course, weekly synchronous sessions were held. They also participated in subject-specific CoPs created on Telegram chat throughout the course.

Figure 1.1 Timeline of Knowledge Transfer

Phase 2 focused on Universal Design for Learning (UDL) as the underlying principle of the project. It was designed to enhance teachers' PCK for an equitable and inclusive teaching-learning process. The sessions were facilitated by faculty from Shreemati Nathibai Damodar Thackersey (SNDT) Women's University in Mumbai.

Phase 3 consisted of a synchronous workshop to introduce the Design Thinking (DT) process and explore its potential to create meaningful and pedagogically valid teaching-learning resources and modules for teachers. The process of using DT was envisaged to help TEs while they develop STEM modules.

Phase 4 of knowledge transfer involved TEs from all 3 countries, along with the subject teams from TISS developing 13 contextually relevant modules for teachers in their respective countries.

Phase 5 was meant to consolidate the experience of being a part of CoP through all the phases and introduce TEs to the management of a mobile-based CoP for teachers, which enables the development of a social learning environment[13].

In total, 13 modules were collaboratively developed, contextualised and implemented in all three participating countries. Each teacher was enrolled in four modules on the Moodle platform; one Common Pedagogy module and 3 modules from one of the subjects -- Mathematics, Biology, Chemistry and Physics. They had to respond to the designed assignments embedded in the modules. The assignments were practice-based reflective assignments. The teachers had to submit lesson plans on the topic, implement them with students and then write a reflective report based on the teaching experience. Following is the list of subject modules.

Table 1.1 CL4STEM Subject Specific Modules

Subjects	Mathematics	Science		
		Biology	Chemistry	Physics
Topics	Proportions	Genetics and Heredity	Atomic Structure	Electromagnetism
	Algebra	Introduction to Ecology	Chemical Bonding	Force and Motion
	Geometry	Cell Structure & Organisation	Organic Chemistry	Work, Energy and Power

Communities of Practice (CoP) was an essential element of CL4STEM TPD model as they offer a social learning space for all the participating teachers, the principals of their schools, and the teacher educators to interact and discuss their experiences with the modules. All of these participation activities lead to a greater likelihood of reflective classroom practice. One common Telegram group was created for all subject teachers and 4 separate subject groups. Each participating teacher was connected in two groups; common CoP and subject-specific CoP. Teacher educators were assigned as the course instructor for each of the twelve subject modules and the common module. This implied that respective teacher educators were responsible for the teachers' participation in their modules. Adequate access to online modules and an online CoP was ensured for all participating teachers. This implied installing Moodle and Telegram on their smartphones and also making them accessible through their laptops/desktops whenever feasible.

The associated research focused on two broad areas. First, the Impact analysis focused on the impact of innovation on teachers' Knowledge, Attitudes, and Practice (KAP) for higher-order teaching

[13] [14] Thirumalai, B. R., & Sarangapani, P. M. (2023). Designing a mobile-messaging app-based teachers' community of practice in India. *Bulletin of Science, Technology & Society*, 02704676231165652.

and learning of science and mathematics inclusively and equitably. Second, innovation diffusion research generates knowledge on the processes of adoption of the innovation for specific local contexts and the conditions that support scaling. Knowledge generated from this project would be disseminated to stakeholders in MoESD and relevant agencies to seed it into the policy agenda of these countries. Further, key insights from this project would be shared with other scholars and opinion leaders in the spirit of creating global public research outcomes.

Unit 2: Methodology

This section provides an overview of the implementation of CL4STEM project activities, a description of research tools, data collection strategies, and the analyses that were conducted on the data collected.

Research shows that the application of teacher professional knowledge is contextual and value-based, where teacher learning is social and situated in context (Sarangapani, 2011[14]; Winch, 2004[15]; Cochran-Smith & Lytle, 1999[16]). Thus, the CL4STEM design focused on supporting the teachers' professional development through modules (where they gained new professional knowledge) and communities of practice (where they engaged in social learning). Figure 2.1 below presents the CL4STEM theory of change that grounded the implementation and all research activities.

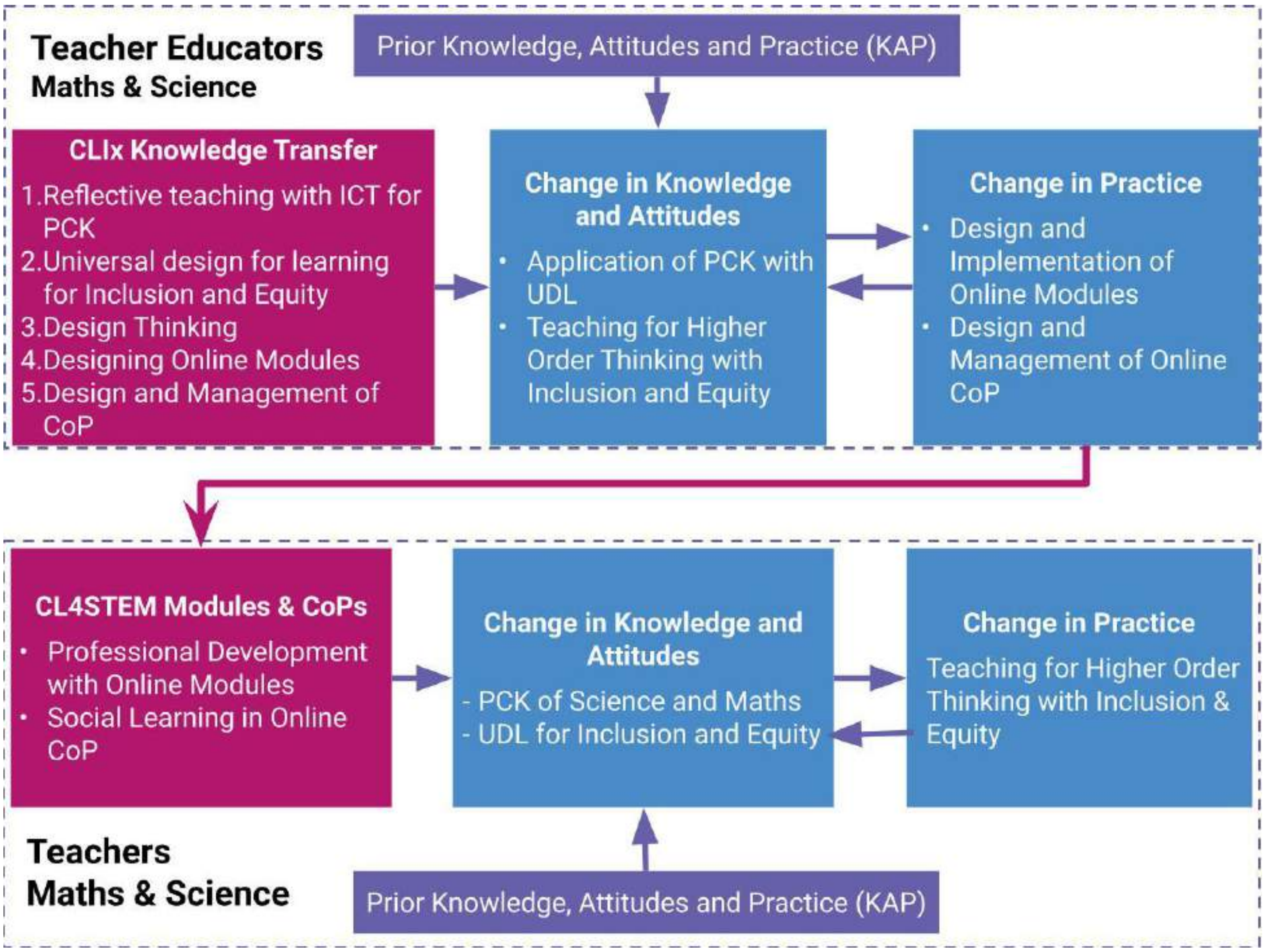

Figure 2.1 CL4STEM Theory of Change

The salient features are as follows:

1. Teacher educators' knowledge, attitudes, and practices (KAP) about higher-order teaching with equity and inclusion (HOTIE) will improve when they meaningfully engage with the online PD

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[14] Sarangapani, P.M. (2011). Soft disciplines and hard battles. *Contemporary Education Dialogue 8*(1) 67–84.
[15] Winch, C (2004) What do teachers need to know about teaching? A critical examination of the occupational knowledge of teachers, *British Journal of Educational Studies, 52*(2), 180-196
[16] Cochran-Smith, M., Lyte, S.L. (1999). Relationships of knowledge and practice: Teacher learning in communities. Review of Research in Education, Vol. 24, pp. 249-305. American Educational Research Association.

through Knowledge Transfer (described earlier) and online CoPs, and engage in the designing, implementation and monitoring of the online TPD modules.

2. Teachers' KAP about HOTIE will improve when they meaningfully engage with the online PD modules (designed by teacher educators), implement the lesson plans, reflect on their practice, and participate in online CoPs to support their PD.

To support this theory of change and to explicitly assess the participants' KAP towards pedagogical content knowledge and equity & inclusion, a conceptual framework was developed (Table 2.1) . It was based on the literature of Shulman (1986)[17], Ball, Hill, & Bass (2005)[18], Grossman (1990)[19], Kind (2009)[20], Ramchand (2022)[21] and CAST (2018)[22]. The conceptual framework is aimed towards Science/mathematics Teacher Knowledge for promoting HOTIE. The conceptual framework consists of subject matter knowledge (SMK), pedagogical content knowledge (PCK) and general pedagogical aspects. This framework guided all analyses with regard to the impact of CL4STEM on teacher practice.

Table 2.1 Conceptual Framework for Higher Order Thinking with Inclusion and Equity (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 science or mathematics disciplines - '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; that it is situated in a particular historical, social, economic context; it requires creativity and imagination; 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 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, mathematization, 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 students' misconceptions and conceptual learning difficulties
4. Students' Misconceptions & Conceptual Difficulties	• Knowledge of students' prior-conceptions, errors, misconceptions/alternative conceptions, ways of students' thinking, and concepts students find difficult to learn • Knowledge of areas that students find challenging

[17] Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.
[18] Ball, D. L., Hill, H. H., & Bass, H. (2005). Knowing mathematics for teaching: Who knows mathematics well enough to teach third grade, and how can we decide? American Educator, Fall, 14-46.
[19] Grossman, P. (1990) The Making of a Teacher, New York: Teachers College Press.
[20] Kind, V. (2009). Pedagogical content knowledge in science education: Perspectives and potential for progress. *Studies in Science Education, 45*(2), 169-204.
[21] Ramchand, M. (2022). Pedagogic content knowledge of science: A framework for practice and construct for understanding teacher preparation. *Contemporary Education Dialogue, 19*(2), 281-303.
[22] CAST (2018). Universal design for learning guidelines version 2.2. Retrieved from http://udlguidelines.cast.org

	• Ability to use students' errors to understand their ways of thinking and 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 limits of models and illustrations in representing content • Ability to use multiple representations of content to meet 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 which can be 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 hierarchical sequence of foundational concepts for teaching and its inter connection with other concepts/topics in 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 (UDL) • Ability to provide equal opportunities to all students to participate in the classroom interaction • Ability to use UDL principles to design and implement lesson plans, resources and assessments to meet diverse needs of learners
9. Classroom Management	• Knowledge of multiple modes of classroom interaction eg. organising inquiry learning/project-based learning/problem-solving to promote students' agency, a variety of grouping practices to support collaborative learning, use of activities for multiple ways of 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

Online CoPs are the other significant aspect of CL4STEM design, along with the HOTIE framework. CoPs are a well established concept of social, situated and professional learning through the regular interaction of the community members (Wenger, 1998)[23]. They draw on the idea of situated learning (Lave & Wenger, 1991)[24] which states that professional learning happens by participation in social processes that are situated within specific socio-cultural contexts.

For understanding the perceptions and participant understanding of CL4STEM overtime, research on innovation diffusion was conducted. The widely accepted Concerns Based Adoption Model (CBAM)

[23] Wenger, E (1998) Communities of practice: Learning, meaning, and identity. Cambridge: Cambridge University Press.
[24] Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge university press.

(Hall, 1974)[25], was used to study the diffusion of the innovation using the HOTIE rubric, Levels of Use (LoC) (Hall, Dirksen & George, 2006)[26], and Stages of Concerns (George, Hall & Stiegelbauer, 2006)[27] questionnaires and surveys. CBAM focuses on understanding the addressing the various perspectives of teachers with regards to CL4STEM during their participation. Stages of Concern (SoC) measures the participants' knowledge and attitudes towards CL4STEM and consists of seven developmental stages with each previous stage leading to the next one. These stages are described below:

- Stage 0 (Unconcerned), the participant has no concern about the innovation
- Stage 1 (Informational), the participant has limited knowledge about the innovation but has not participated in it
- Stage 2 (Personal), the participant has concerns about the demands of the innovation, rewards for participating in the same, and potential conflicts with the existing structures
- Stage 3 (Management), the participant has concerns about efficiency, organizing, managing and scheduling the participation in the innovation
- Stage 4 (Consequence), the participant is concerned about the impact of the innovation on student learning
- Stage 5 (Collaboration), the participant is focused on collaborating with others regarding the use of the innovation
- Stage 6 (Refocusing), the participant is concerned about making the innovation more beneficial, or making major changes to it

Levels of Use (LoU) evaluates the behaviour of the participants with respect to CL4STEM. LoU has eight different levels, with each level representing a cumulative behaviour. These levels are described below:

- level 0 (nonuse)
- level 1 (orientation), the participant had some information about the innovation
- level 2 (preparation), the participant is preparing to participate in the intervention
- level 3 (mechanical use), the participant uses the innovation to just master the tasks with little opportunity for reflection
- level 4a (routine), the participant is comfortable with using the innovation, and gives little thought to its use or consequences
- level 4b (refinement), the participant uses the innovation, while varying the use to improve the impact of the intervention
- level 5 (integration), the participant brings the innovation to their colleagues to increase the impact of the innovation
- level 6 (renewal), the participant revaluates their use of the innovation and seeks modifications to increase the impact, examine new opportunities and new goals for the innovation

[25] Hall, G. E. (1974). The Concerns-Based Adoption Model: A Developmental Conceptualization of the Adoption Process Within Educational Institutions.
[26] Hall, G. E., Dirksen, D. J., & George, A. A. (2006). Measuring implementation in schools: Levels of use. Austin, TX: SEDL. Available from http://www.sedl.org/pubs/catalog/items/cbam18.html
[27] George, A. A., Hall, G. E., & Stiegelbauer, S. M. (2006). Measuring implementation in schools: The stages of concern questionnaire. Austin, TX: SEDL. Available from http://www.sedl.org/pubs/catalog/items/cbam17.html

The HOTIE rubric explicitly presented the different levels of teachers' KAP to evaluate the impact of the intervention. Stages of Concern (SoC) and Levels of Use (LoU) were used to capture the varying needs and concerns of participants during the pilot implementation. These insights would lead to the development of the scaling and sustainability strategies. Along with CBAM, Moore and Benbasat's innovation diffusion framework (1991)[28] was also used to understand the teachers' perceptions. This framework comprised of 7 characteristics:

1. Voluntariness: perceived degree to which participants voluntarily participate
2. Relative advantage: extent to which the teachers perceived CL4STEM suggested strategies to be better than the existing ways of teaching
3. Compatibility: degree to which CL4STEM is compatible with the existing context of the teachers
4. Image: Refers to how the participation of teachers affects their social or professional status
5. Ease of use: the ease and convenience of teachers to participate in CL4STEM modules and CoPs and implement the lesson plans as well
6. Results Demonstrability: degree to which the results from participation in CL4STEM could be tangibly demonstrated and communicated to others
7. Visibility: extent to which the results of participation in CL4STEM would be observable in the schools

2.1 Data Collection

This section explains the data collection process adopted to write this report. Data were collected in three phases, Baseline, Midline, and Endline. Each of these phases had two specific foci - to study the impact of the implementation on change in teacher KAP, and to study teachers' perceptions of CL4STEM as they evolved over time.

Teachers teaching STEM subjects in secondary schools in one of the southern dzongkhags (district) were the main participants in the implementation. The pilot intervention included 83 teachers in all, with 20 in Physics and Chemistry, 23 in Mathematics, and 19 in Biology. Out of the 83 teachers, 20 teachers, 5 each from Physics, Chemistry, Mathematics, and Biology were in the focus group. The only difference between the focus group and other teachers was that focus group teachers were NQTs (teachers with less than 6 years of experience) and were interviewed at every stage of data collection (Baseline, Midline, and Endline). Table 2.2 shows the number of participants who responded to each research instrument.

Table 2.2 Number of Participants Responding to Baseline Research Instruments

Baseline Tools	Teacher Profile	Teacher Perceptions Survey	Subject Impact Survey	Interviews
Focus Group	5 (Phy, Chem, Bio, & Math)	5 (Phy, Chem, Bio, & Math)	5 (Phy, Chem, Bio, & Math)	5 (Phy, Chem, Bio, & Math)
Others (General + Preservice)	15 (Phy & Chem), 14 (Bio), & 19 (Math)	15 (Phy & Chem), 14 (Bio), & 19 (Math)	15 (Phy & Chem), 14 (Bio), & 19 (Math)	0
Total per subject	19 (Bio), 20 (Phy & Chem), & 24 (Math)	19 (Bio), 20 (Phy & Chem), & 24 (Math)	19 (Bio), 20 (Phy & Chem), & 24 (Math)	5 (Phy, Chem, Bio, & Math)
Total (all subjects)	**83**	**83**	**83**	**20**

[28] Moore, G. C., & Benbasat, I. (1991). Development of an instrument to measure the perceptions of adopting an information technology innovation. *Information systems research*, 2(3), 192-222.

The Baseline tools consisted of the following:

1. Teacher and school profile surveys to collect the demographic data about the participants and understand the context in which teachers would be working.
2. Teacher perception surveys to capture the expectations of teachers before they participated in CL4STEM. This tool was designed on Moore and Benbasat's (1991) characteristics of innovations. SoC and LoU from CBAM were not used in Baseline data collection as the participants were not exposed to the intervention at all at that time frame.
3. Subject impact surveys that assessed the teachers' existing SMK, PCK, and general pedagogical knowledge for their subject. This survey was based on the HOTIE framework described earlier.
4. Interviews to complement the subject impact and teacher perception survey data. Interview questions focused on understanding the teacher's conceptual understanding of Science/Mathematics, knowledge and attitudes towards general pedagogical knowledge, PCK, equity and inclusion, ICT-based TPD, online CoP, and perceptions towards implementation of CL4STEM. The interviews were conducted with the focus group participants i.e., NQTs who had less than six years of experience.

Baseline data collection happened in June and July 2022. As indicated in Table 2.2 above, Baseline survey data was collected for all sets of teachers: focus, general, preservice, and control group teachers. However, interview data was collected only from focus group teachers. The perception questions were developed by adapting the Moore and Benbasat (2007) paper on the adoption of innovations, and CBAM developed by Hall (1974).

Midline data collection focused on capturing the classroom practice during lesson implementation by the participating teachers. For the classroom observation, even though the initial intention was to observe only the NQTs, but due to the faraway locations of the schools, the research fellows could visit only 3 schools out of the 7 schools which were part of the study. Thus for the classroom observation, 14 teachers were observed which included 4 focus group, 6 general group teachers and 4 pre-service teachers. For each focus group participant, 3 classrooms, for pre-service, 2 classrooms and for the general group, only one classroom was observed. For the focus group, it was possible to observe three of their classes, but with general group and pre-service teachers, it was not possible to observe all three classes. Table 2.3 shows the frequency and number of teachers observed.

During the classroom observations, the research fellows wrote detailed descriptions of the lesson that they had observed. They also conducted a pre- and post-observation interview with the teacher to understand the context of the lesson. Along with classroom observations, qualitative interviews that focused on their knowledge and attitudes towards SMK, PCK & GPK, participation in online Telegram CoPs, and the teacher's perceptions of CL4STEM were also part of the routine. The perception questions also included questions on LoU and SoC CBAM, along with Baseline questions on adoption. Midline data collection went on from September 2022 to November 2022.

Table 2.3 Midline Data Overview

Midline Tools (per subject)	Classroom Observation	Interviews
Focus Group	4 (3 observations/ teacher)	5
Preservice	4 (2 observations/ teacher)	-
General	6 (1 observation/ teacher)	-
Total (all subjects)	**24**	**20**

Finally, the Endline Tools consisted of the following:

1. Subject survey, which was a repetition of the Baseline subject impact survey and measured the teachers' knowledge and attitude towards HOTIE by assessing their SMK, PCK, and GPK.
2. Innovation diffusion survey, which too repeated the innovation diffusion survey conducted in the Baseline. It also included questions on the LoU and SoC with regards to CL4STEM, as asked in the Midline data collection phase.
3. Interviews, with the same set of teachers who were interviewed in Baseline and Midline. These interviews focused on innovation diffusion, by capturing teachers' perceptions about the innovation after the completion of implementation. The interviews also focused on capturing teachers' KAP around HOTIE to supplement the survey data. These interviews also captured teachers' experience in the project, as well as their reflections on participating in the module and online CoPs.

Endline data collection happened between November 2022 to January 2023. An overview of the Endline data collected is shown in Table 2.4 below:

Table 2.4 Number of Participants Responding to Endline Research Instruments

Endline Tools	Innovation Diffusion Survey	Subject Impact Survey	Interviews
Focus Group	4 (Chem), 5 (Phy, Bio, & Math)	4 (Chem), 5 (Phy, Bio, & Math)	4 (Chem), 5 (Phy, Bio, & Math)
Others (General + Preservice)	15 (Phy & Chem), 14 (Bio), & 19 (Math)	15 (Phy & Chem), 14 (Bio), & 19 (Math)	4 (Chem), 5 (Phy, Bio, & Math)
Total per subject	19 (Bio & Chem), 20 (Phy), & 24 (Math)	19 (Bio & Chem), 20 (Phy), & 24 (Math)	4 (Chem), 5 (Phy, Bio, & Math)
Total	82	82	19

2.2 Data Analysis

For analysis of all the collected data, common steps were followed across all three phases. Survey data and interview data were analysed separately.

The survey data was analysed using descriptive statistics. The data was categorized into common, subject-wise, gender, and teacher-type segments, aligned with the corresponding framework to facilitate the exploration of potential themes within each category. By using such analysis techniques, researchers were able to identify the commonalities and differences between the findings from quantitative survey data and the qualitative interview and observation data.

All interview data were transcribed and deductively coded using the 1) HOTIE framework for capturing the subject level impact; 2) Moore and Benbasat's (1991) 7 indicators of innovation, and CBAM's Stages of Concern (George, Hall & Stiegelbauer, 2006) & Level of Use (Hall, Dirksen & George, 2006) for perceptions around the innovation. All classroom observations and the pre- and post-tests administered to teachers, and interviews were deductively coded using the CL4STEM HOTIE framework and perceptions' frameworks, to capture the holistic picture of teacher practice. After deductive coding into the themes, the qualitative data was summarised by the researchers to condense it into major findings which are presented in the bulk of this report.

Social Network Analysis (SNA) was chosen as the methodology for studying the mobile-based CoPs data along with qualitative thematic analysis. SNA allows an exploration of the relationships between the members in these socio-cultural contexts. Social network research suggests that "informal webs of relationships are often the chief determinants of how quickly change efforts take place, hold, diffuse, and sustain" (p.2, Daly, 2010)[29]. The SNA graphs were created using Gephi software[30]. Each node on the graph shows a participant in that CoP, whereas a line between two nodes shows the interaction between the participants. Three parameters were used to evaluate the nature of the social network: density, average degree and maximum degree. Density refers to how many interactions happened between the participants of any group at that point in time. The maximum possible density is 1, indicating that every node in the network is connected to every other node directly, or that every participant has interacted with every other participant at least once. Average degree is the average number of interactions each node has participated in. Maximum degree is the maximum number of connections a node has in the concerned social network. The node with the maximum degree would belong to the participant who has interacted the most in the Telegram CoP.

Bhutan's Specific Modifications to Research Design

According to the project's objectives, the targeted stakeholders were in-service NQTs (teaching experience <6 yrs.) and general in-service teachers (teaching experience >6 yrs.) from secondary schools. However, due to the country's underlying COVID situation and safety protocols at the time, Bhutan had to include pre-service teachers enrolled in an 18-month Post Graduate Diploma in Education (PGDE) and limit the study area to one dzongkhag (equivalent to a district in other countries) only. Similarly, survey questionnaires were contextualized based on educational terminologies used in the Bhutanese education system.

2.3 Demographic Profile of Participating Schools

2.3.1 Overview of the Bhutanese Secondary School System

The CL4STEM project was focused on supporting the CPD of secondary-level STEM teachers in Bhutan, and thus enrolled five higher secondary and two middle secondary schools as partner schools. In Bhutan, secondary education is divided into three levels: lower secondary (grades VII-VIII), middle secondary (grades VII-X), and higher secondary (grades VII-XII). The secondary school system in Bhutan emphasizes a child's holistic development and strives to nurture students' intellectual, physical, and social well-being. The system promotes a well-rounded education that goes beyond academic excellence, encouraging students to develop critical thinking, creativity, innovation and problem-solving skills. It also emphasizes the importance of co-curricular activities and community engagement. The schools follow a nationally designed curriculum framework that is divided into key stages and includes various strands or areas of study specific to the associated secondary levels. At the lower secondary level (Key Stage III), students are offered science, mathematics, and ICT as STEM subjects, while at the middle and higher secondary levels (Key Stages IV and V), students study physics, chemistry, biology, mathematics, and ICT. Secondary school students are evaluated through continuous and summative assessments, including the national board exams in classes VIII, X, and XII, in which they must pass and meet the set cut-off points to be admitted to the next higher grade.

[29] Daly, A. J. (2010). Mapping the terrain: Social network theory and educational change. *Social network theory and educational change*, 1-16.
[30] https://gephi.org/

2.3.2 Description of Partner Schools

The CL4STEM project successfully collaborated with seven secondary schools in the Samtse Dzongkhag to implement the innovation. All of these schools were government institutions that played critical roles in piloting the CL4STEM activities, including the enrolment of some in-service teachers in the project. Four of them are central schools with some administrative and management autonomy. The school 007 offers academic programs to students with special educational needs (SEN) in grades pre-primary to XII.

Table 2.5 Description of Partner Schools

School Codes	Location	Grade Levels	Type of School	Day/Boarding School	Teaching staff	Non-teaching staff	STEM teachers
001	Urban	IX to XIII	Government coeducational central school	Day school	30	12	10
002	Rural	VII to X	Government coeducational central school	Boarding school, but students are free to attend as day students	32	11	12
003	Semi-urban	Pre-Primary to X	Government coeducational middle secondary school	Day school	43	16	18
004	Semi-urban	IX to XII	Government coeducational central school	Boarding school, but students are free to attend as day students	32	7	8
005	Semi-urban	Pre-Primary to XII	Government coeducational higher secondary school	Day school	69	8	23
006	Semi-urban	Pre-Primary to XII	Government coeducational higher secondary school	Day school	65	7	18
007	Semi-urban	Pre-Primary to XII	Government coeducational higher secondary school	Boarding school, but students are free to attend as day students	84	9	17

Figure 2.2 The Geographical Locations of CL4STEM Sample Schools in Samtse, Bhutan

2.3.3 School Principal

All the school principals of CL4STEM pilot schools are male, with teaching experiences ranging from 19 years to 33 years. Before taking up the principal's post, they were school teachers. They have been serving as principals for 5 to 30 years. All the principals are qualified with Master's degrees. Out of the seven principals, five of them have a degree in Master of Education and the remaining two have a Master's degree in Public Administration and Management.

2.3.4 Physical Infrastructure

The physical infrastructures of the partner schools were evaluated based on the following criteria: access to an all-weather road, all-weather school building, playground availability, a separate principal's office, an independent staff room, safe drinking water, distinct toilets for males and females, kitchen garden, and inclusive access. Most partnering schools met the physical infrastructure criteria, except for schools 002 and 004 which lacked an all-weather road, and schools 002, 004, and 006 which lacked inclusive access. The day schools 001, 003, and 006 did not have a kitchen garden. Agriculture is carried out in boarding schools, where students also contribute to the labour involved, and the agricultural produce, mainly vegetables, is supplied to the school mess.

2.3.5 Student Welfare Programmes

All of the partner schools were government schools and school welfare programs were evaluated using criteria such as free school lunch, free textbooks, free uniforms, free health check-ups, and free transportation. All students were provided with free health check-ups and textbooks, with the exception that they were required to purchase certain educational accessories like calculators and geometry boxes. Likewise, all the boarding students were given free meals, while the day students were required to bring their own lunch to school. Two day schools (005 and 006) were reported to be providing free transportation to students travelling from distant locations.

2.3.6 Facilities

All the schools have well-designed and functional physics, chemistry, biology, and computer laboratories except one (004). It has a general science laboratory and subject-specific laboratories are under construction. All the schools have libraries. None of them have a mathematics resource room, which can be attributed to the lack of funding, awareness, space, qualified staff, and demand. Additionally, it is possible that schools may not be aware of the benefits of having a mathematics resource room and haven't prioritized its establishment. However, mathematics resource rooms can play a valuable role in supporting the teaching and learning of mathematics. They can provide students with access to a variety of resources, such as manipulatives, textbooks, and software. They can also provide teachers with a space to collaborate with other teachers, plan lessons, and host workshops and professional development sessions for teachers. Therefore, schools should ideally plan to establish mathematics resource rooms within their capacity and make available resources to support student success in mathematics.

Secure electricity and internet connections are available in all the schools. The internet speed ranges from 10Mbps to 90Mbps. Computers are available for office use as well as for the students in the laboratories. The survey did not capture the number or sufficiency of projectors, printer/scanners, and copiers found in all of the schools. Only three schools have reported as having smart boards/smart TVs

(001, 005, and 007). Again, the survey tool failed to determine the specific kinds of smart devices and their sufficiency in comparison to classroom ratios.

2.4 The Demographic Profiles of Participants

A total of 83 participants for the study were recruited in three categories: Focus, General, and Pre-service Group. This constituted 20 each in the focus group and general group, and 43 in the pre-service group, respectively. One chemistry participant from the focus group dropped out after completing two modules because her teaching contract did not get renewed, and the total number of participants decreased to 82 during the Endline data collection period.

2.4.1 Gender and Age

Since this project was well-situated to address equity and inclusion, the gender composition of the study participants was also considered when selecting in-service participants, while all pre-service participants of PgDE (Post Graduate Diploma in Education) were enrolled without distinction. Figure 2.3 below depicts the gender diversity of participants. In general, the age of the participants ranged from 21 to 55 years with the maximum (n=59) in the age group of 21-30 years.

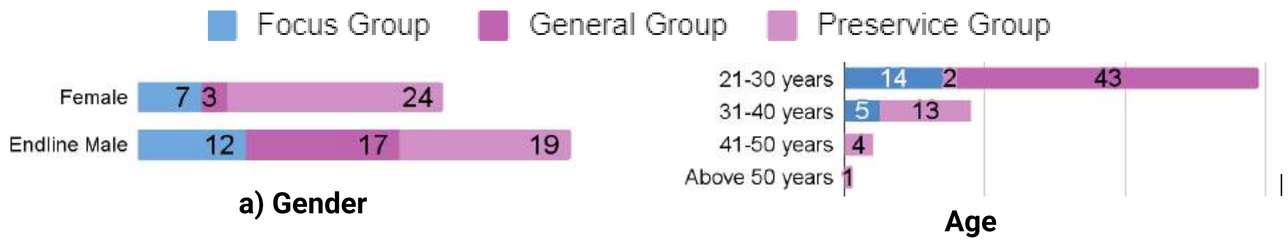


Figure 2.3 Gender Distribution (a) and Age-range (b) of the Participants

2.4.2 Professional Qualifications

As shown in Table 2.6, the qualifications of the teacher participants included B.Ed. (Bachelor of Education), B.Sc. (Bachelor of Science), PGDE, M.Sc. (Master of Science), and M.Ed. (Master of Education).

Table 2.6 Professional Qualifications of Teacher Participants

Sample Type	B.Ed.	B.Sc.	PGDE	M.Sc.	M.Ed.
Inservice Group (Focus)	12	1	6	-	-
Inservice Group (Others)	8	-	2	4	6
Pre-Service Group	-	-	43	-	-
Total	20	1	51	4	6

2.4.3 Subject Specialization in Teacher Education Training

Participants in different categories were enrolled based on their subject of specialization during teacher education training: physics, chemistry, biology, and mathematics. Some inservice teachers, particularly those with a B.Ed. qualification, had expertise in teaching two subjects. However, they were enrolled in the respective subject groups based on their teaching schedule for the academic year 2022.

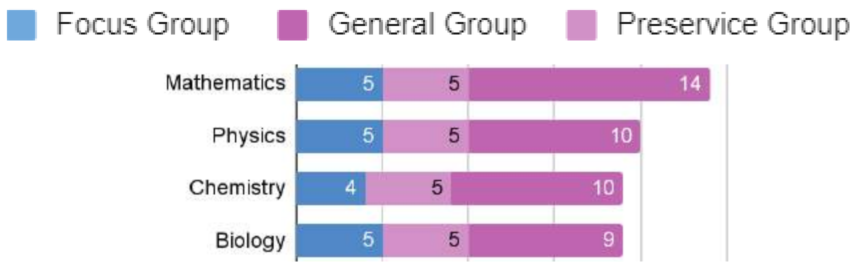


Figure 2.4 Subject of Specialization during Teacher Education Training

2.4.4 Years of Experience

The teaching experience of a teacher can have a significant impact on the effectiveness of teaching and learning because experienced teachers often have a deeper understanding of their subject matter and their student's learning needs, which can help them foster more engaging learning for the students. The table 2.7 below shows different categories of in-service teacher participants' total number of years of experience as a school teacher and years of experience as a school teacher in the current school where they teach.

Table 2.7 Teaching Experiences as a School Teacher and in the Current School

Number of years	Total Teaching Experience in Years			Total Teaching Experience in the Current School		
	Focus Group	General Group	Preservice Group	Focus Group	General Group	Preservice Group
0-5	12	1	NA	15	7	NA
6-10	7	6	NA	4	9	NA
11-15	-	7	NA	-	3	NA
16-20	-	6	NA	-	1	NA
Total	**19**	**20**	NA	**19**	**20**	NA

2.4.5 ICT Devices and Usage

In this technological era, having an ICT device such as a laptop, smartphone, tablet, smart TV, and so on can provide numerous benefits to teachers. Such devices can support them with lesson planning, teaching, professional development, student communication, and administrative tasks.

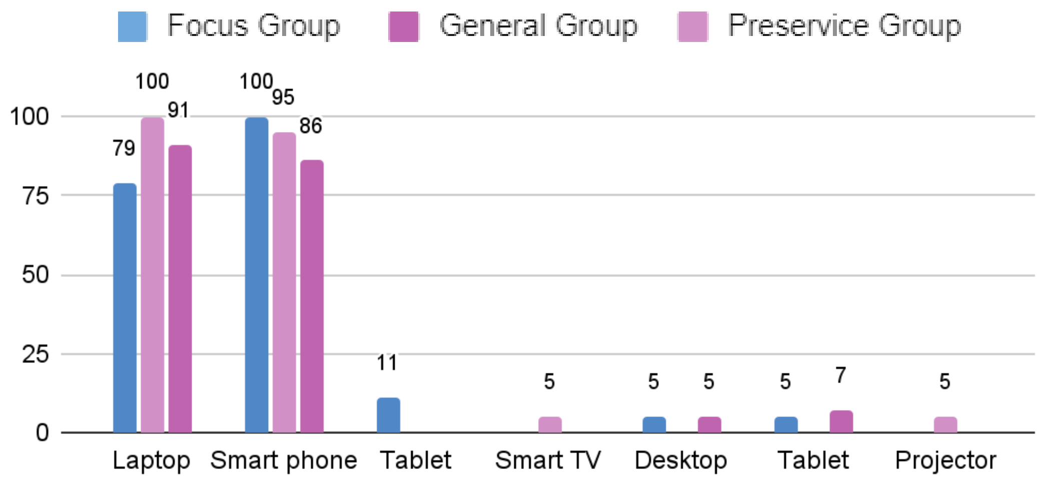


Figure 2.5 ICT Devices Owned

The most common devices owned by the participants were laptops and smartphones, with 79% of the focus group, 100% of the general group, and 91% of the pre-service participants owning personal laptops. Although it would be unusual to find anyone without a smartphone, data show that approximately 5% of in-service participants and 14% of pre-service participants did not have one.

The data showed that all participants (100%) used personal data packs to access the CL4STEM modules and Telegram groups, while a smaller percentage (23%) used institutional internet networks in addition to personal data packs. In Bhutan, personal data packs tend to be quite costly, whereas institutional network access is typically free. Unfortunately, the majority of the participants did not have the opportunity to access the modules and the Telegram communities of practice during class hours and had to spend their own personal data to explore and complete module activities and tasks after school hours.

According to the survey, the most commonly used ICT device for CL4STEM lesson plan implementation was a laptop (96%), followed by a smartphone (87%), a projector (59%), a smart TV (28%), and a smart board (9%). The findings revealed that the participants primarily used personal devices like laptops and smartphones to implement the lesson plans. However, the findings also revealed that schools lacked an adequate number of government-supplied ICT devices such as projectors, Smart TVs, and smart boards. As a result, it is recommended for the schools to be equipped with the necessary ICT devices to enable teachers to use emerging technologies while teaching STEM subjects.

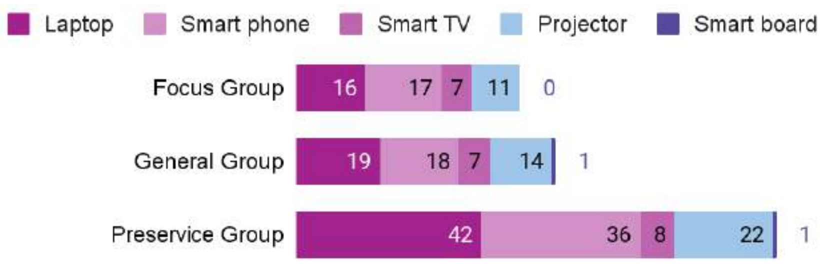
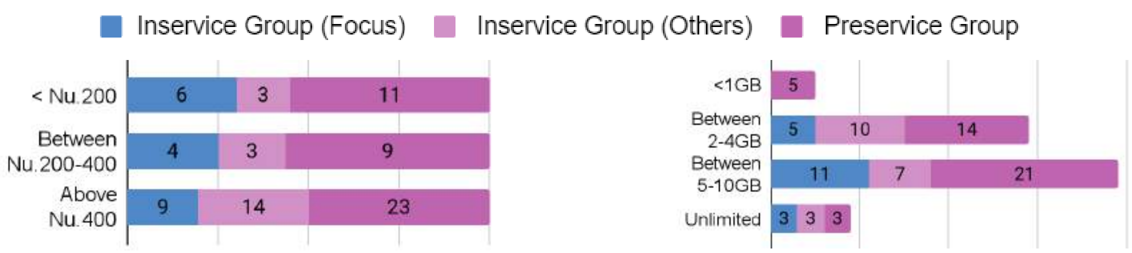


Figure 2.6 Distribution of ICT Devices Used to Implement CL4STEM Lesson Plans

According to the section above, all of the participants utilized their personal data plan to access the internet for CL4STEM modules and Telegram CoPs. The graph below shows that the monthly expenses incurred by participants for internet access varied depending on the sample type or background. Among the focus group, approximately 58% used a data package between 5-10 GB, while 26% used between 2-4 GB and 16% used an unlimited package. In the general group, 50% of the participants used between 2-4 GB, followed by 35% using 5-10 GB and 15% with an unlimited package. The preservice group participants raised concerns about the expensive cost of the data package and the findings validate their concern as 49% of them had to use between 5-10 GB for the CL4STEM modules and CoP participation.



(a) Monthly Expense **(b) Weekly Data Usage**

Figure 2.7 Approximate (a) Monthly Expenses on Internet and (b) Weekly Data Usage

For each module, participants were given six weeks to complete the assigned tasks and implementation of the module. The focus group (58%) and the pre-service group (49%) had a similar pattern of data usage, with a significant proportion of participants utilizing between 5-10 GB of data per week. The general group had a lower average data usage, with around 50% of participants using between 2-4 GB of data per week.

Unit 3: Teacher Knowledge, Attitudes and Practice

This section is subdivided into ten themes based on the conceptual framework of Higher Order Thinking with Inclusion & Equity (HOTIE) for Science and Mathematics teachers. The conceptual framework consists of Subject Matter Knowledge (SMK), Pedagogical Content Knowledge (PCK) and the General Pedagogical Knowledge (GPK) aspects. Each theme will present analysis of the data gathered from the teacher Knowledge Attitudes and Practice (KAP) surveys shared on Google Form during the Baseline (prior to module implementation) and Endline (after module implementation) data collection periods, interviews taken during Baseline, Midline, and Endline data collection periods, and classroom observations as part of the Midline data.

3.1 Subject Matter Knowledge (SMK)

Sound knowledge about the subject matter is of paramount importance in the teaching profession. In this study, SMK has been divided into two sub themes viz. knowledge of science/mathematics subject matter and nature of science/mathematics.

3.1.1 Knowledge of Science/Mathematics Subject Matter

- The knowledge possessed by the teacher in one or more disciplines of either science or mathematics.
  - 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

The knowledge of science/mathematics subject matter refers to the in-depth understanding of topics possessed by the teacher. It focuses on the teachers' ability to articulate big ideas/key concepts of the subject and the interconnections between the concepts/topics within the subject itself. The knowledge of science or mathematics subject matter would also be reflected in the teachers' ability to justify what counts as knowledge within the subject domain.

The survey asked around 4-6 questions per subject to assess the teachers' SMK. The changes from Baseline to Endline showed that a slightly greater percentage of teachers were able to correctly answer questions in Baseline as compared to Endline for biology (Baseline= 56%, Endline= 53%), chemistry (Baseline= 54%, Endline= 53%) and mathematics (Baseline= 93%, Endline= 78%). In physics, desired changes were observed, where a slightly greater percentage of teachers answered questions correctly in the Endline (68%), as compared to the Baseline (64%). The minor changes in teacher performance could potentially be attributed to the nature of the tool, or the timing of its implementation, but a more conclusive assessment would require further exploration.

The interview data was organized into two sub-themes: teacher's knowledge of the big ideas in their subject and knowledge of interconnections between topics and disciplines (Table 3.1.1).

Table 3.1.1 Changes in Knowledge of Subject Matter

Knowledge of Science and Mathematics Subject Matter (Sub-themes)	Baseline	Endline
Knowledge of the big ideas in their subject	5	9
Interconnection between topics and disciplines	2	6

1) **Knowledge of the Big Ideas in their Subject:** The teachers' understanding changed from general awareness of the knowledge of science and mathematics to articulation of big ideas from the

subject matter. There were more examples in mathematics than in other subjects. Some quotes on the change in teachers' understanding are shared below:

Baseline	Endline
"Well, we can relate mathematics to many things. If we look at our NNC (New Normal Curriculum), that new curriculum, now, we are focusing on the real-life implementation of the content in the class." - 1100	*"Mathematics deals with problem-solving and quantitative reasoning skills, which are very important to learning mathematics."- 1100*

2) **Interconnections between Topics and Disciplines:** When asked about interconnections between topics and disciplines, teachers shared the importance of teaching and learning of science and mathematics. They were able to give more specific responses regarding interconnections in the Endline.

Baseline	Endline
"I really think that learning physics should be one of the main subjects of all those sciences because physics deals with mathematics. It deals with many other things…actually our world right now is actually ruled by physics only." - 1304	*"I think that learning specially like physics is very important because it strengthens the quantitative reasoning and problem solving skills that are valuable in the area beyond physics." - 1304*

From the classroom observations, it became evident that many of them demonstrated a good knowledge of subject matter and the knowledge of the interconnectedness of topics and disciplines. Not surprisingly, all experienced teachers (>6 years of experience) demonstrated a deeper understanding, as compared to the focus group or the preservice teachers. Following are some examples of the teachers demonstrating a good SMK knowledge during classroom observations:

1. They were able to identify special cases of symmetry that students were coming up with, e.g., the plane of symmetry of the cone as infinity when the base is considered as a circle (1109).
2. During an experiment on Faraday's laws of electromagnetism in class, the teacher 1312 was able to identify where students were making mistakes. He then used different approaches to build their understanding of foundational concepts before conducting the experiment. He conducted the experiment in a virtual lab, while also using the physical apparatus. This led to students asking multiple questions, which too were handled properly (1312).

In summary, the survey did not show trends of knowledge enhancement for the subject matter from Baseline to Endline. The interview exhibited some progression across the timeline. The existing knowledge of subject matter as depicted in the observation data revealed that the teachers were able to not only share connections between topics but also demonstrate an understanding of subject matter on the topics that they taught.

3.1.2 Nature of Science/Mathematics

- Teachers' knowledge of the nature of science, such as its empiricism; that it is situated in a particular historical, social, economic context; it requires creativity and imagination; that modern science is 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 the ability to represent something mathematically
- Ability to communicate the nature and structure of science/mathematics to students

Under the theme of ‘Nature of Science/Mathematics’ all the participants were administered a survey item which said: “Many things in Science/Mathematics are accepted as true with no explanation” The participants' understanding of the nature of science and mathematics is presented in Figure 3.1.2 (a). With more participants (Baseline=61%; Endline=66%) disagreeing with the statement, it suggests that the majority of participants believe that scientific and mathematical theories are not simply accepted as true, but are based on evidence and reasoning.

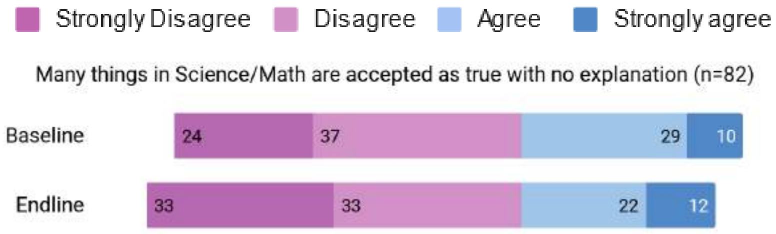


Figure 3.1.2 (a) The Participants' Understanding of the Nature of Science and Mathematics

Further, subject-wise data analysis revealed that, except for chemistry, the majority of participants in all the subjects gave the desired response during the Baseline (Chem 26%; Math 67%; Phy 65%; Bio 84%). However, the percentage of participants who disagreed with the statement in chemistry increased from 26% to 58% at the Endline.

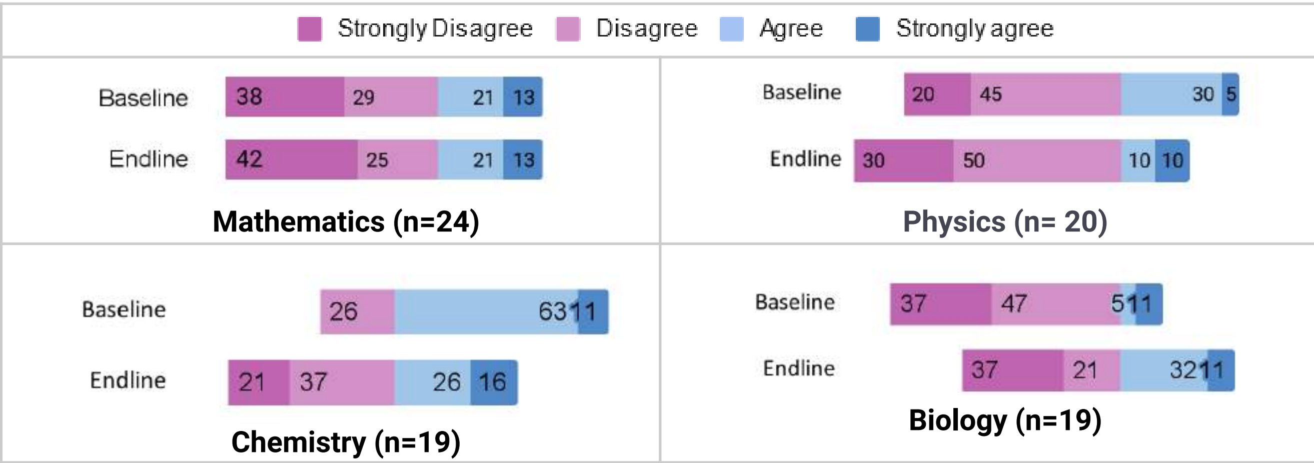


Figure 3.1.2 (b) Subject-wise Understanding of the Nature of Science and Mathematics

Gender wise, the disagreement levels of both male and female participants increased slightly in the Endline, thus showing no major difference.

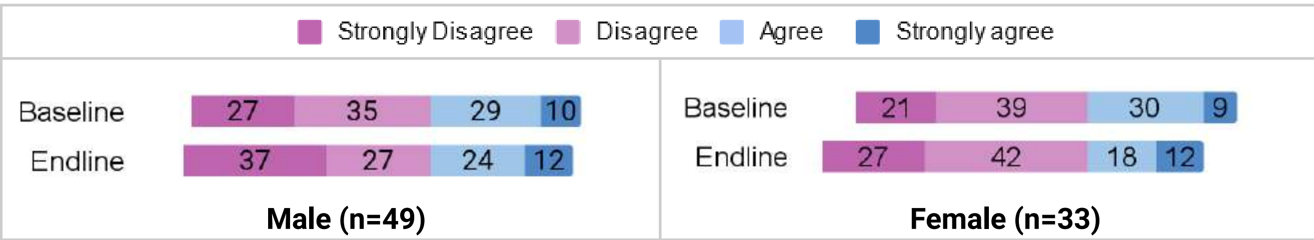


Figure 3.1.2(c) Gender-wise Understanding of the Nature of Science and Mathematics

The percentage of preservice participants who disagreed with the statement is lowest at both the Baseline (56%) and the Endline (56%). This suggests that participants with less experience may have a less developed understanding of the nature of science. Therefore, it is also a reminder to teacher education institutions that, in order to improve teachers’ understanding of the nature of science, we must teach science in a way that emphasizes the importance of evidence and reasoning, while providing opportunities for teachers to engage in scientific inquiry.

Interviews were not able to capture the teachers' understanding of the nature of the subject as defined in the beginning, as the participants shared their knowledge about the importance and real life applications of the subject. The overall changes observed in interview data are shown in Table 3.1.2 below:

Table 3.1.2 Observed Changes in Interview Data for Nature of Science

Nature of Science and Mathematics (Sub-themes)	Baseline	Endline
Importance in developing scientific skills (problem solving, reasoning, critical thinking skills)	5	6
Application of science and mathematics knowledge	5	8

There is no change in teachers' knowledge about the nature of science and mathematics from the Baseline to Endline. Unlike the survey results, there are no differences shown either between subjects or gender.

Importance in Developing Scientific Skills (Problem Solving, Reasoning, and Critical Thinking skills: The following selected quotes are an illustration of the understanding of the participants with regard to the nature of science/mathematics and their importance. According to 1100 [Midline]: "Science and math give the student a platform where they can develop their reasoning and problem-solving skills, which are very important in our life". Likewise, 1300 [Midline] shared that: "Learning physics in high school is very important. It develops our critical thinking when you learn science. There is brain development. It can unlock the mysteries of the universe". Another participant,1502 [Endline] said that: "Science and math actually teach us to be a critical thinker. Science and technology are the backbone of the economy".

Application of Science and Mathematics Knowledge: Similarly, participants shared the significance of science and mathematics with regards to their application. For example, 1500 [Baseline] shared that: "The world is governed by science and technology. For instance, studying science creates self-awareness in oneself and helps one know the surroundings around us and that governs the world". 1101[Midline] stated: "Because in daily life we know that we use mathematics everywhere, even when we go to shops, we need to do some calculations, simple basic calculations and when in engineering we use mathematics".

During the classroom observation, the teacher's knowledge about the nature of science/mathematics is mainly inferred from the kind of pedagogical approach they use to connect their concepts to the big ideas. It was noticed that teachers used practicals (n=2), generalisation (n=2), real-life examples (n=2), connecting to the big picture, communication, observation, prediction, reasoning etc. indicating that the teachers employed many pedagogical practices to share details about the subjects.

This study indicates that secondary school teachers and pre-service teachers have a reasonably good understanding of science and mathematics subject content, as measured by the survey. Experienced teachers have a better understanding of the nature of science and mathematics when compared to pre-service teachers. In the case of interviews and classroom observations, there has been no reportable change or difference between genders or subjects.

3.2 Pedagogical Content Knowledge (PCK)

The theme of PCK focuses on five subsections: teacher's knowledge about instructional strategies, students' misconceptions and conceptual difficulties, representation of content, context for learning, and curriculum knowledge. The teacher needs to acquire mastery over instructional strategy and resources required for delivering the content to meet the diverse needs of learners, including students' misconceptions around topics that are difficult to understand. The teacher also should have a fair knowledge of multiple forms of representation of content. The teacher should have the ability to use locally available resources in his or her teaching and be able to relate the content taught in the classroom with the everyday experiences of the students. This section will present the data and findings from the subject surveys (n=82), interviews (n=20) and classroom observations (n= 14).

3.2.1 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, mathematization, 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 students' misconceptions and learning difficulties

The survey questions on instructional strategy were subject and topic-specific. For chemistry, physics, and mathematics,a positive change was reported in the overall performance of teachers. In physics, improvement in instructional strategies was seen across all three items, with improved performance in laws of motion (+25%) and electromagnetic induction teaching strategies (+25%). In the third category for physics, on handling student misconceptions, teachers reported being quite adept at the Baseline (90%) and at the Endline (95%). For biology, one question was noted with a positive change, and another had a negative change. Given that most of the survey items for both science and mathematics (8 items out of 10) reported some positive change in Endline, it suggests that the CL4STEM modules have had an overall positive impact on the teachers' knowledge of different instructional strategies and abilities to use them.

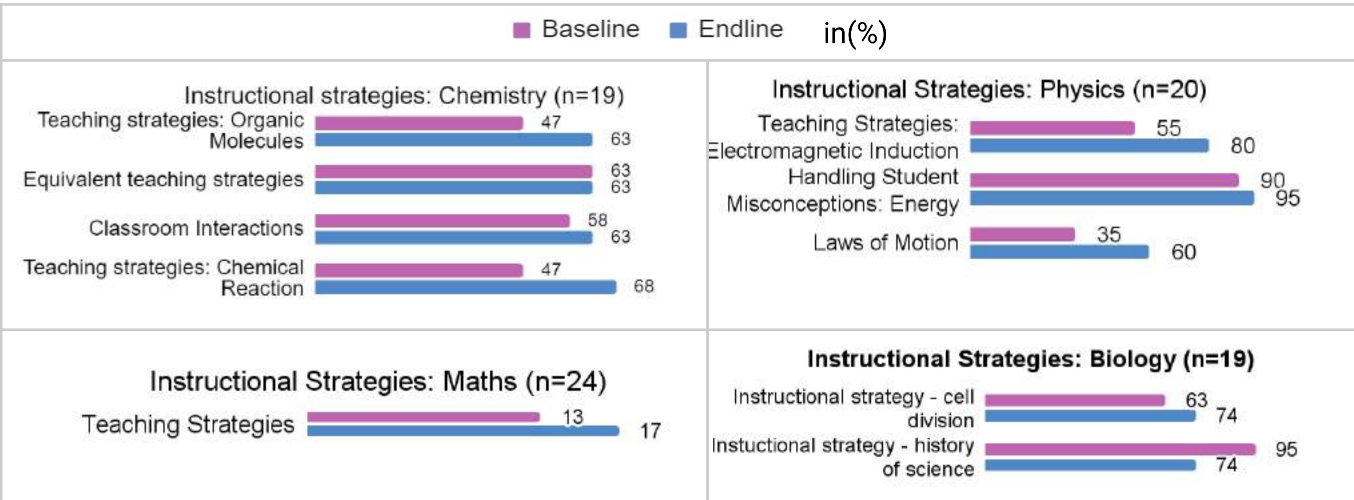


Figure 3.2.1(a) Subject-specific Instructional Strategies

The survey also included items on general instructional strategy in science surveys. For a particular item, the participants were expected to choose the type of teacher who would be most successful in teaching science to the students. The four categories were: a teacher who would guide with pointed questions, a teacher who worked as a facilitator, a teacher who usually explained the concept and gave practice, and lastly a teacher who would teach using group discussions. Figure 3.2.1(b) below depicts the changes in teacher performance. Looking at the consolidated data, a majority of science teachers selected the group discussion strategy for teaching (45% in Baseline; 41% in Endline). A similar decrease in the number of teachers who chose teaching by giving explanations and practice (31% in Baseline; 19% in Endline) has been reported. On the positive side, there is an increase in the number of teachers who chose facilitator as their preferred teaching strategy (19% in Baseline; 33% in Endline). The number of teachers using the facilitator strategy to teach science to students has increased across all three science subjects.

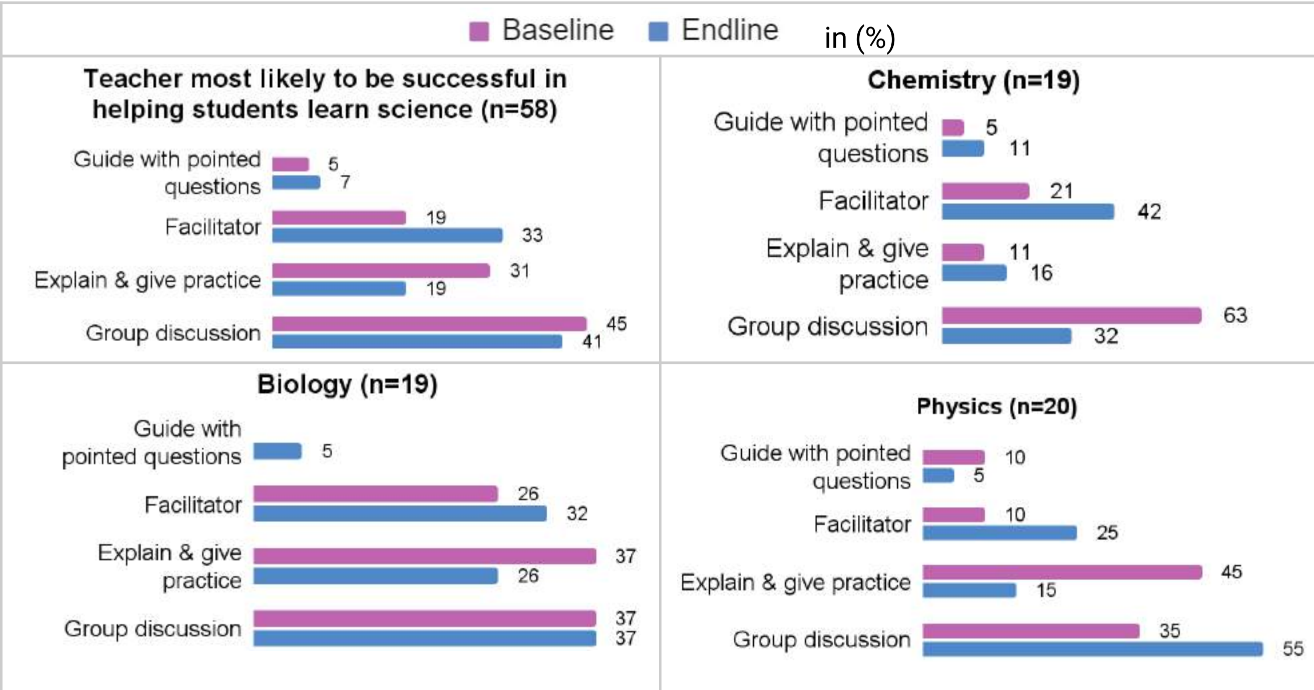


Figure 3.2.1(b) General Instructional Strategy

Another question posed to the participants was to rate their agreement with regard to various instructional practices (Figure 3.2.3). For science teachers (n = 58), an overall positive change was seen regarding teachers' attitudes towards various instructional strategies. For instance, regarding the demonstration of experiments with passive involvement of students in the teaching of science ,we see that an increasing percentage of teachers disagree (34% in Baseline vs. 50% in Endline). Overall, in science, 6 out of 7 items on instructional strategy demonstrated a small positive change in teachers' attitudes.

Similarly, there is a positive change in the attitude of mathematics teachers with regard to all but one survey item. Changes of more than 20% were observed in “Discourage student arguments about ideas and procedures”, “Students should remember formula and facts”, “Encouraging students to come up with solutions", and "Teachers should strictly follow the textbook.” Minor positive changes were observed in categories of “Discourage students from sharing misconceptions” (+9% desirable change in Endline vs Baseline) and “Student explanation more important than correct answer” (+8% desirable change in Endline vs Baseline). In the final category, "Students shouldn't leave the class feeling confused", a minor negative change (8%) was observed.

Overall, these findings suggest that there was a general positive change in the teachers' attitudes towards using higher-order thinking strategies for teaching science and mathematics to students.

Figure 3.2.1(c) The Response of Participants to Various Instructional Practices

The following themes emerged from the interview data:

Table 3.2.1 Changes in Interview Data for Instructional Strategies (sub-themes)

Instructional Strategies - Sub themes	Baseline	Endline
Collaborative learning through group work	4	5
Awareness about Universal Design for Learning (UDL)/ differentiated instructional strategies	1	7
Using technology	5	8

Collaborative Learning through Group Work: Collaborative learning through group work was the most common instructional strategy used by almost all teachers, as evidenced in the interviews as well as in the classroom observations. Interviews showed that the teachers were aware of the various instructional strategies such as differentiated instruction, peer discussion, problem-solving, creativity and critical thinking, design thinking and project-based learning in the Baseline itself. Some examples of teachers' knowledge about group work are shared below:

Baseline	Endline
"I just demonstrate the steps. I make sure that they are clear about the steps and I assign them the individual work but in class nine, I have ample time. So what I do is I go for group activities. I go for videos, I go for their participation, and I give them projects like that kind of thing was." - 1100	*"I try to create a mixed group whereby there will be some low achievers and some high achievers. High achievers will be helping the low achievers and there will be a teacher to guide them. I also applied Universal Design for Learning."* - 1100
"Actually, they learn what actually happens. And sometimes I also do an experiment. For example, in oscillation when we talk about time periods and all those things. So I actually conduct a real experiment where student actually knows how to actually use that formula that is there in the template equation in oscillation." - 1304	*"I usually take classes in labs where we are more accessible to all those equipment and all those materials that are required for the physics class to be conducted.* *Like this, using that UDL principle and the Lesson plan. So especially like group activities and the use of simulations and all those things are some of the teaching ways that I have actually used here. Moreover what I have used is in that thing where the high performing student helps the low performer."* - 1304

During Midline classroom observations, group work, which involved students working in groups, was a common strategy (71% of the teachers) (Figure 3.2.4), with the seats arranged either beforehand or during class to allow for increased interaction between students. Almost all (93%) teachers used questioning and classroom discussion in the class, with students responding and the teachers conducting the lesson by building on the students' responses. Figure 3.2.1(d) shows examples of group work from classroom observations.


Figure 3.2.1(d) Implementation of Group Work across Classrooms

While speaking with the teachers, it also became apparent that there was some alignment between MoESD's priorities (Kagan Structure)[31] and CL4STEM suggested collaborative teaching strategies. The next quote from 1307PM highlights the same: "We are implementing Kagan's structure, so my classroom is more of a group-wise." (1307PM, Endline).

Awareness about Universal Design for Learning (UDL)/Differentiated Instructional Strategies: Universal Design for Learning (UDL) as a concept was introduced by the CL4STEM modules to the participating teachers. Through interviews it was evident that in the Endline more number of teachers (Baseline=1, Endline=7) were aware of using differentiated instructional strategies to support diverse groups of students. Three teachers specifically mention that they used the principles of UDL to design instructional strategies for mixed-ability student groups. Some quotes are shared below:

Baseline	Endline
"When I give a lecture session, they [students] just listen and don't think and just rely on us and do not explore. When I engage them in group activity, there is so much interaction, research and exploration. They get motivated and there is learning taking place."-1501	*"I use many instructional strategies to accommodate students of diverse learning abilities. Some of the instructional strategies include group work, pair work and use of digital tools such as Mentimeter, Google form, PPT, Youtube, quizzes etc."* - 1501
"And sometimes I also do an experiment. For example, in oscillation when we talk about time periods and all those things. So I actually conduct a real experiment where the student actually knows how to actually use that formula that is there in the template equation in oscillation." - 1304	*I usually take classes in labs where we are more accessible to all those equipment and all those materials that are required for the physics class to be conducted.* *I follow the UDL principle and the Lesson plan. I have also made the high performing student help the low performer."* - 1304

Use of Technology: The use of technology to support lessons is the final subtheme in instructional strategies. In the Endline study, teachers integrated various ICT technologies along with the instructional strategy. The integration of technology tools helped teachers make their teaching engaging, motivating

[31] The Kagan structure, a transformative pedagogy framework developed by American educational psychologist Dr. Spencer Kagan, has been implemented in Bhutan since 2016. It includes a number of cooperative learning structures that promote active learning, collaboration, and critical thinking.

and interactive. The ICT used by the teachers were Padlet, quizzes, discussion forums, Google Form, slideshow etc.

Baseline	Endline
"My class is more student centered because I do more group work most of the time. And I take them to the lab specially to conduct experiments and all." - 1301	*"I have used simulation videos especially when our scientific apparatus for carrying out experiments is not working in the laboratory."* - 1301
"I could feel some difference in the sense, when I give a lecture session, they just listen and don't think and just rely on us and do not explore. When I engage them in group activity, there is so much interaction, research and exploration. They get motivated and there is learning taking place." - 1501	*"I use many instructional strategies to accommodate students of diverse learning abilities. Some of the instructional strategies include group work, pair work and use of digital tools such as mentimeter, google form, PPT, youtube, quizzes etc."* - 1501

The classroom observations found that 79% of the teachers used different types of ICT tools, e.g., slides, presentations, YouTube videos, interactive tools, etc, in their lessons during the implementation, thus supporting the trends from the interviews.

In summary, the three data sources exhibited the teacher's competency and ability to use a range of instructional strategies to deliver meaningful learning experiences for the students. The survey results showed that overall, there was a positive impact on the teacher's knowledge of instructional strategies and the teacher's attitudes towards student-centered instructional strategies. These findings were also supported by the classroom observations and the interviews.

3.2.2 Students' Misconceptions & Conceptual Difficulties

- Knowledge of students' prior-conceptions, errors, misconceptions/alternative conceptions, ways of students' thinking, and concepts students find difficult to learn
- Knowledge of areas that students find difficulty in understanding
- Ability to use students' errors to understand their ways of thinking and design learning experiences to support students' STEM learning

A misconception is a mistaken belief about a concept or idea that can impede students' learning and even result in poor performance in science and mathematics. Teachers must be aware of the common misconceptions which students have in order to address them in their instruction. They can design lessons that address misconceptions to provide students with opportunities to correct them.

The surveys administered to the participating teachers included questions about students' misconceptions (Figure 3.2.2(a)). For example, in biology, teachers were asked to identify common misconceptions about ecology, genes, genetics, and cell biology. In both the Baseline and Endline surveys, teachers were able to correctly identify misconceptions related to ecology and the concept of genes.

The percentage of teachers answering questions on student misconceptions correctly increased in all subjects in the Endline data for all but 2 topics. For example, in biology, the percentage of teachers answering favourably to questions related to genetics and cell biology increased by 5% and 32% respectively. In mathematics, the percentage of teachers answering positively to questions on geometric properties and area increased by 21% and 4% respectively. In physics, the percentage of teachers correctly answering positively to questions on force and energy increased by 5% and 20% respectively.

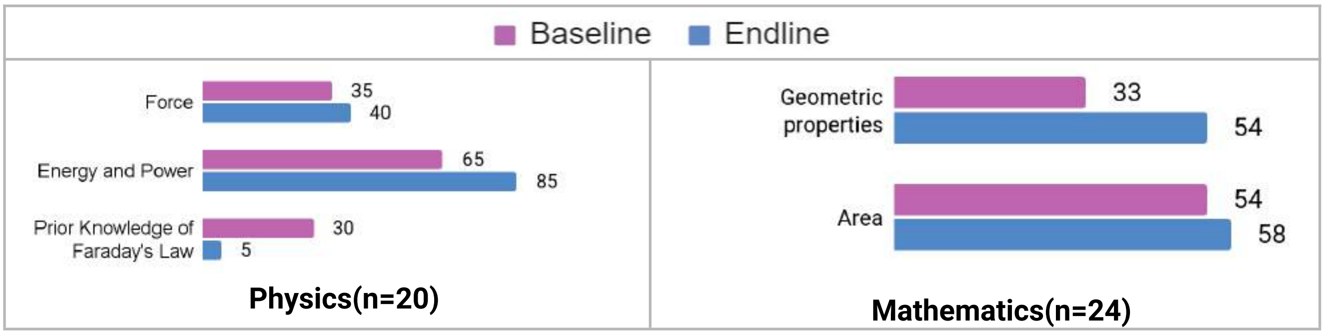


Figure 3.2.2 Responses to Subject-wise Misconceptions of Students

Overall, the above results suggest that teachers have a mixed understanding of the conceptual difficulties that students face in different subjects. The CL4STEM modules appear to have helped teachers better understand students' misconceptions and how to address them.

Likewise, the efficacy of the CL4STEM modules in helping teachers better understand students' misconceptions and develop strategies for addressing them is further supported by the interview data shown in Table 3.2.2. The trend in interview data from Baseline to Endline shows that the teachers' understanding of students' misconceptions in their subject, recognition of sources of misconceptions, and strategies for addressing the same have all increased.

Table 3.2.2 Change in the Participants Regarding Student Misconceptions

Students' Misconceptions & Conceptual Difficulties (Sub-themes)	Baseline	Endline
Teachers' understanding of students' misconceptions	13	19
Identifying sources of students conceptual difficulties	13	19
Strategies for addressing conceptual learning difficulties	0	4

This section will present the teachers' discussions on some of the most common misconceptions that they have encountered, potential factors that may have caused these misconceptions, and some strategies that the teachers have used to address the same. These discussions are based on the sub-themes that emerged from the interview analysis.

i) Teachers' Understanding of Student Misconceptions

As shown in Table 3.2.2, the number of teachers who could identify and understand students' misconceptions increased from 13 at the Baseline to 19 at the Endline. Four mathematics teachers during Baseline reported students' difficulties in understanding, disintegrating, solving, and relating word problems to real life situations. During the Baseline interview, 1100 further expressed concern about students' difficulty relating word problems to real life, saying, "When I give them an equation, they can solve it, but when I turn the same question into a word problem, they struggle to solve it. This means students are unable to relate the mathematics problem to real-life situations." This is a serious misconception because it may prevent students from experiencing the relevance of mathematics in their everyday lives. Likewise, other misconceptions reported by 1101 at Baseline included students' difficulty understanding and working with fractions. Teacher 1103 explained the process of clarifying students' misconceptions as shared in table below:

Baseline	Endline
“...there there's a few students who really interested in mathematics as I mentioned earlier one thing is they are not able to communicate in English and they are not a very good reader, therefore they face challenges in solving word problems.” 1103	*“I try to make math concepts simple to learn for them. I use different strategies to solve a problem, like I simply conduct a class for 15 to 20 minutes and then provide them 35 to 40 minutes for their group discussion. They discuss among themselves and if they face any problems, then I intervene rendering help. I try to conduct my classes in a learner centred manner.” 1103*

At Baseline, four physics teachers reported that the students face a lot of difficulty solving numerical problems. According to 1303 Baseline, "Most students say that physics is very difficult because there is calculation. From top to bottom, they say that there is a calculation. They are poor in mathematics." This implies that the teacher believes the students need to be proficient in mathematics, and good at calculations to succeed in physics. This is a misunderstanding, as physics is about understanding the physical world, and calculations are just a tool that can be used to solve problems. Similarly in Endline, all participants reported that students find Physics difficult due to lack of resources and ability to conduct experiments, interact with the field, and lack of foundational knowledge of Physics. The following quotes exemplify this: “Most of the time since the materials are not available or the place is not the right place.” (1303); “Actually, they don't come into the field, practice and learn.” (1301).

Prominent misconceptions encountered by biology teachers were regarding the students' inability to understand the concepts that they are learning and comprehend the applications of theory in the real world. For example, 1700 Baseline said, “We teach about photosynthesis, we are not able to show the real-life applications.” This concern highlights the challenge that biology teachers face in helping students understand all the complex scientific concepts practically.

ii) Identifying Sources of Conceptual Difficulties

Identifying students' misconceptions is an essential part of the teaching process that can help teachers enable their students to learn more effectively and develop a deeper understanding of the concepts being taught.

The participants reported that students' misconceptions can be attributed to factors on the part of both the students and the teachers. From the students' perspective, factors included the inability to understand the relevance of mathematics in everyday life, language barriers, lack of proficiency in mathematics, lack of understanding of the physical principles involved, a perception of science subjects as hard, lack of interest and motivation, and their social background. From the teachers' perspective, the factors included a lack of understanding of students' prior knowledge, a lack of required resources, a focus on syllabus-driven classes, and not adequately challenging students practically and through problem-solving.

Participants who reported language barriers and the lack of mathematical proficiency for doing well in science and mathematics subjects appear to be very serious, as stated by 1103 (Baseline), "Students have difficulty communicating in English and reading. This makes it difficult for them to comprehend word problems and express mathematical ideas." The official language of Bhutan is Dzongkha, but there are many local dialects. However, English is used as a medium of instruction in schools and in the workplace, making it difficult for a student to succeed in school without mastery of English. However, the participating teacher 1103 reported at the endline that a combination of direct instruction, group discussions, and personalized assistance facilitated a learner-centered environment and supported student understanding of mathematics concepts without language barriers. According to 1704 (Baseline), "Students lack reading comprehension skills and are not able to understand the concepts and terminologies given in textbooks and follow the teacher's instructions in biology lessons." When a language barrier makes it difficult for students to understand teacher instructions, it can become especially problematic during examinations and when comprehending and communicating mathematical and scientific concepts and terminologies. However, teachers do their best to overcome the language barrier and make the students understand concepts as during the endline 1704 has recommended using technological devices to support students' understanding and motivating them. Participant 1503 (Baseline) shared that students' prior knowledge is essential for understanding the new concept, and the lack of it can lead to misconceptions: "I believe when they don't have a fundamental understanding, they fail to understand actual concepts such as what a proton, electron, or neutron are, even though they're fast learners." During the endline the teacher participant 1503 has further reiterated the importance of recollecting students' prior knowledge stating "students' difficulty with the STEM subject topics can be eased if it is connected with students' prior knowledge and if the lessons are made interactive by designing activities."

Another reason for misconceptions mentioned by the teachers is the lengthy syllabus, which causes them to focus more on completing the syllabus, preventing them from conducting classes in more practical ways which enable hands-on learning. 1702 stated during the endline that "I observed in classes 11 & 12 the syllabus is very vast and students are not exposed to hands-on experience. Since they do not have a good foundation from the lower classes, they lack practical skills."

iii) Strategies for Addressing Conceptual Difficulties

Overcoming students' conceptual difficulties caused by misconceptions can be challenging for both students and teachers. However, there are a number of strategies that can be used to address these difficulties and help students succeed. This section presents some of the effective strategies used by teacher participants to overcome students' conceptual learning difficulties and how those strategies improved their ability to correct students' misconceptions as they progressed with the CL4STEM module implementation.

Baseline	Endline
"...they can solve questions but cannot relate that to the real-life situation. So, if I give them an equation, they can solve it, but if I turn the same question into word problem students are facing problems to solve that word problem. That means we students are not able to relate the problem to real life because word problems this tries to relate mathematics to real life." *-1100*	*"…mostly I try to make the class interactive through group activities, not only me, their high achiever friends, and those who are interested in mathematics, they can also help them and when the friends teach them they understand it better."* *" …the universal design for learning actually tries to involve everyone in the classroom. And when we try involving everyone in the classroom, it really helps the poor achievers, and low achievers, in the use of ICT."* *"I have tried using that design thinking whereby I've related the lesson to a real-life situation I have introduced them in such a way that they will be interested."* *-1100*
"I have observed that students are unable to connect the concept with practical. Moreover, they can understand the theory but they cannot	*"I consider things such as checking prior knowledge of the students with examples and connecting with the present lesson. I ensure that my lesson objectives are SMART and time management has also been considered from my side.*

link theory with the practical. I mean they are not able to critically analyze the questions. They can only solve direct questions. They are weak in numerical parts." *-1500*	*Moreover, I engage my students in hands-on activities, learning followed by assessment"* *"...try to make a checklist in order to check the understanding of students. And this is something that I picked up from CL4STEM."-1500*

In addition to the above quotes, the participant 1500 was employing a variety of strategies, including cold calling, whole class worksheets, exit slips, and quizzes, paying attention to student body language and facial expressions, asking open-ended questions that require students to think critically, and providing students with opportunities to explain their thinking as noted in the participant's classroom observation. From other classroom observations, two examples of student misconceptions being addressed by teachers can be shared:

1. While observing a chemistry teacher, it was noticed that the whole class had a conceptual misunderstanding of the definition of organic and inorganic compounds. The teacher (1506) tackled this by relating students to the concept of organic and inorganic compounds present in the world around us through everyday items they are familiar with, thus rectifying the misconception before progressing to the actual lesson on the nomenclature of organic compounds.
2. Similarly, in a coordinate geometry class, the teacher (1104) wrote the coordinates of a point using the wrong notation– (y-axis value, x-axis value) instead of the correct notation (x-axis value, y-axis value). He asked the students to explain the difference between the two notations and cleared their misunderstanding about using the correct coordinate notation system, before proceeding to the lesson on reflection.

This section suggests that teachers became more proficient in identifying and addressing students' misconceptions. Interview analysis stated that student misconceptions can be attributed to both student and teacher factors. However, as suggested and implemented by the participants, there are a number of strategies that can be used to address these difficulties and help students succeed.

3.2.3 Representation of Content

- Knowledge of multiple forms of representation of content - e.g., analogies, equations, gestures, graph 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 diverse needs of students

Representation of content refers to the knowledge regarding the presentation of information in different ways. This can be done through a variety of media, such as text, images, videos, simulations, and audio. This section reports the findings of surveys, interviews and classroom observations on representation of content. The first survey item about the representation of content evaluated the participants' knowledge of different options that teachers have for representing content.

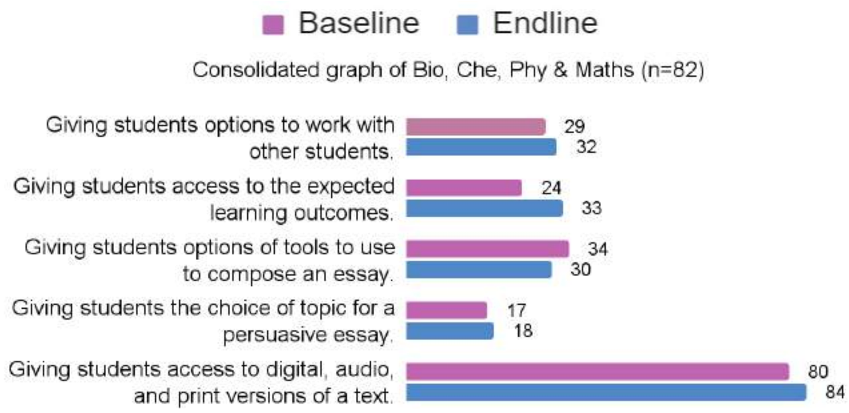


Figure 3.2.3 (a) Participants' Knowledge of Multiple Forms of Representation of Content

The most popular way of representing content was “Giving students access to digital, audio, and print versions of a text”, with 80% of teachers selecting this option during the Baseline and 84% in the Endline. It is encouraging to find that teachers are using this option to make the content more accessible to students with different learning styles. “Giving students access to the expected learning outcomes”, on the other hand, was the least popular. Sharing the learning outcomes at the start of the lesson will help students understand what they are expected to learn and track their progress toward those learning outcomes.

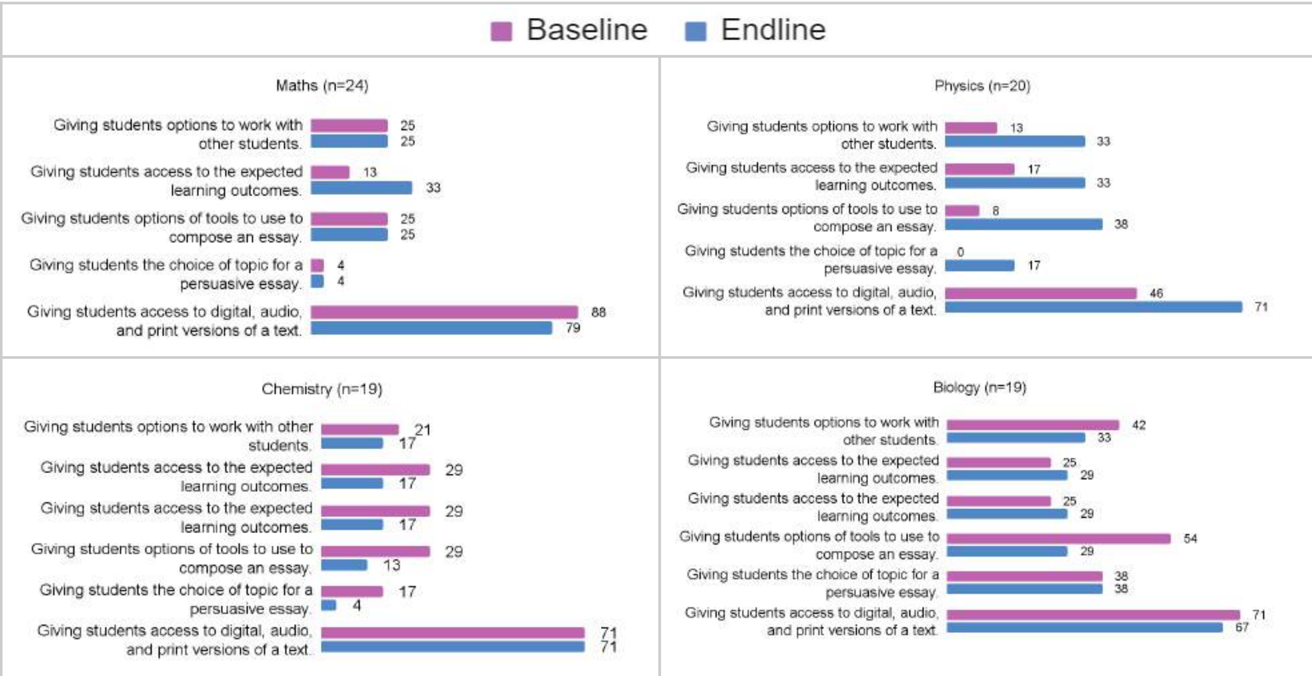


Figure 3.2.3 (b) Subject-wise Segregation of Multiple Forms of Representation of Content

When the data was segregated subject-wise, it was observed that physics had the largest growth in teachers who selected providing content material in various forms to students (+24%). In all other subjects, most teachers (>60%) had selected providing access to multiple forms of content in both Baseline and Endline (Figure 3.2.3(b)). "Giving students the option to work with other students" was zero in Baseline. However, teachers’ response increased by 21% for male teachers, and 11 % by female teachers in Endline. This suggests that more teachers became aware of the benefits of group work and started to incorporate it into their teaching practices.

Available Resources for Representing the Content

All four subject surveys had listed seven resources: Personal education; Textbooks and curriculum materials; Supplementary science books and magazines; Charts, models, worksheets, and activities; Integration of real-life situations, objects, and experiences; Utilization of digital/ICT-based resources; Participation in popular talks and lectures.The teachers were asked to select the resource they used the most.

As can be seen from Figure 3.2.3(c) most teachers (>70%) reported using all resources except popular talks and lectures in both Baseline and Endline. For popular talks and lectures, there was an 18% positive change observed in the Endline. Teachers relied heavily on their own education, textbooks, charts, models, etc., and ICT as the major resources for teaching. Popular talks and lectures, and other magazines, or books were the prominent minor resources used by the teachers.

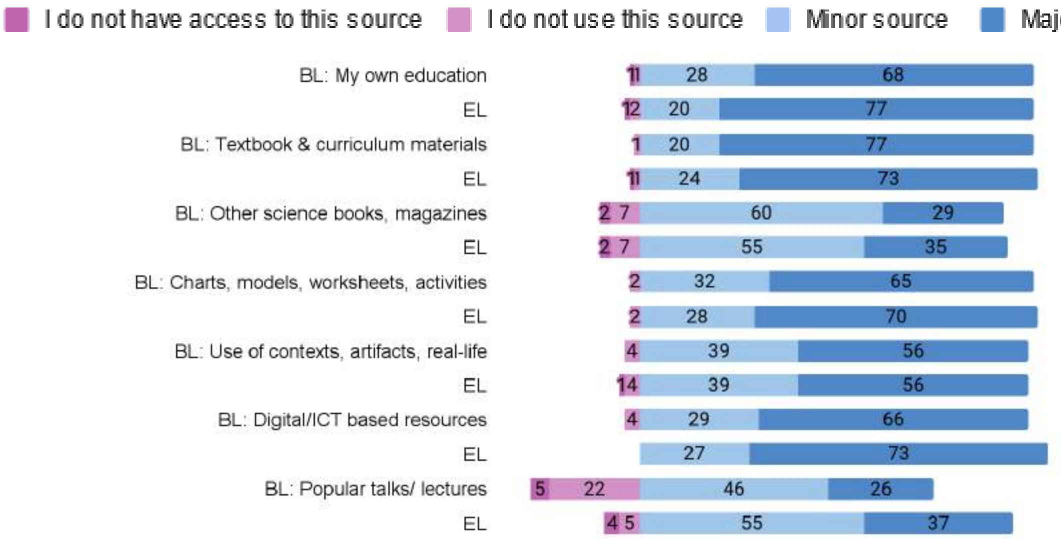


Figure 3.2.3(c) Use of Listed Resources by the Participants (n=82)

Among the subject groups, in addition to “My own education, Textbook & curriculum materials, Other science books, and magazines” as the major resources, “Digital/ICT-based resources” have also been selected as a major resource. Comparatively, physics teachers have used Digital and ICT resources as a major resource (Baseline 75% and Endline 80%). This is supported by findings in the other sections. Digital/ICT-based resources are becoming more popular in the classroom and these resources can provide teachers with a variety of tools and resources to help them engage students and make their teaching more interactive. There was a 25% increase seen in the number of mathematics teachers, who shared that in Baseline they did not use “Popular talks” as a resource while teaching, but in Endline they listed it as a minor resource.

Another survey question inquired about the most useful representation for developing proportional reasoning in students in mathematics classes (Figure 3.2.3(d)). There is an increase (+21%) in the number of participants who responded correctly to the question asked, suggesting that there has been an increase in the understanding of useful representations while teaching proportional reasoning. Likewise, the number of chemistry participants who correctly answered the question about the most appropriate way to use an analogy to teach about atomic structure decreased by 16%. This suggests that fewer teachers were comfortable using analogies and metaphors to teach abstract scientific concepts, potentially because they can lead to further misconceptions.

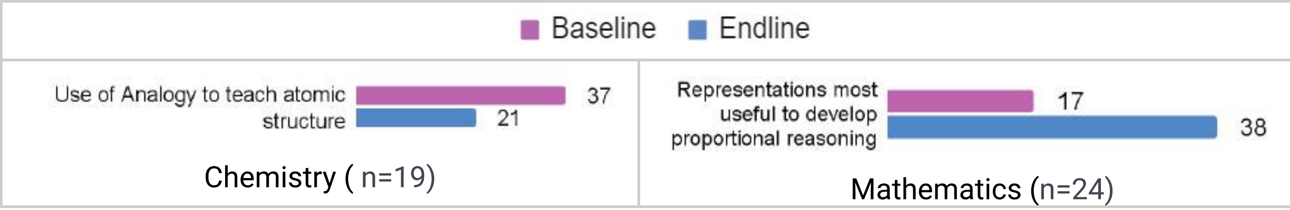


Figure 3.2.3 (d) Most Useful Representations for Teaching Certain Topics

The following findings shown in Table 3.2.3 were observed from the qualitative interview data:

Table 3.2.3 Change in Representation of Content Sub-themes as Observed in Qualitative Data

Representation of Content - Sub-themes	Baseline	Endline
Use of analogies	1	0
Use of models, textbook, lab experiments and illustrations	3	0
Use of technology (videos, ppt, internet, OERs and ICT tools)	17	19

The interview analysis looked into the teacher's understanding and use of varied media such as analogies, equations, gestures, graphs, diagrams and illustrations, models, tables, texts, videos, simulations, and photographs to represent content to meet the diverse needs of students and for effective teaching.

ICT was the resource predominantly used by teachers. Some of the ICT tools commonly used are Mentimeter, Google Classroom, videos, Phet simulations, Messenger, Kahoot app, mobile phone, LCD, Telegram, and PowerPoint presentations. A few teachers have also acknowledged using chart paper and flash cards. While there is variation in the use of teaching aids among subjects due to the nature of the domain and the topic at hand,no significant progression is observed from Baseline to Endline.

Regarding the use of models, textbooks, lab experiments, and illustrations, here is an example of participant 1701 sharing the usage of varied representations at different phases. An interesting shift has been observed where the participant mentioned using ICT as a source of information during the Baseline, and reported attempting interactive ICT in the classroom during the Endline.

Baseline	Endline
"Usually, like I go for the old textbooks(ICSC), I see old textbooks as a good reference. And I also googled online resources and used them for my lessons." - 1701	*"Most of my lessons were planned considering inclusiveness. Video lessons, simulation diagrams and handouts were used." - 1701*

Most participants have shared the use of technology to represent content; for example, participant 1524 expressed her usage of different ICT tools in the two stages of the interview.

Baseline	Endline
"I also use digital tools such as Phet, smartphone, and then other digital tools, especially online tools."- 1502	"I employed various means of representation namely open educational resources, used PHET simulation, power point, apps, google classroom, molecular models etc."- 1502

Greater use of ICT tools was reflected in the classroom observations as well, as 79% of teachers used different types of ICT means to represent content while their classes were being observed, e.g., slides, presentations, YouTube videos, interactive tools, etc. Among the interactive tools, teachers used Geogebra, PHeT simulations, Mentimeter, digital bells, edPuzzle, Slido, Word Clouds, etc. Further, the ICT tools were complemented with many non-digital resources as well, such as the use of worksheets (among 36% of teachers), charts, 3D models, and experimental apparatus. Thus, most of the teachers were using multiple means of representation of the content in their classroom.

In summary, teachers were aware of multiple means of representation of content for students. ICT-based resources and group work strategy were the most preferred way of representation, as seen from both surveys and interviews.

3.2.4 Context for Learning

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

The survey questionnaire included a question on whether mathematics should start with everyday skills. The exact statement was: "Students should start with mathematics skills that relate to everyday life, such as percentages, multiplication, and other basic computational skills." Analysis has revealed that 13% more teachers disagreed with this statement in the Endline data as compared to the Baseline (Figure 3.2.4). This discrepancy indicates that certain teachers may hold reservations regarding the suitability of these topics as a starting point for mathematics teaching, or they may perceive a misalignment with the existing curriculum. Further inquiry is required to gain a deeper understanding of the underlying reasons behind this slight shift in perspective.

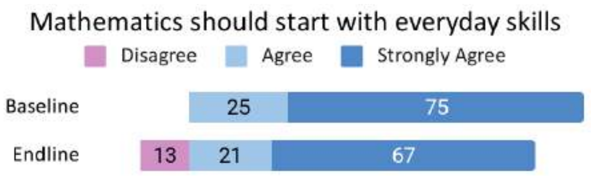


Figure 3.2.4 Context for Learning in Mathematics

Looking at the qualitative interview data, key findings have been presented in Table 3.2.4:

Table 3.2.4 Changes in Qualitative Data for Context for Learning

Context for Learning - Sub-themes	Baseline	Endline
Improvisation of locally available resources and school laboratory	9	7
Mediation with Technology	6	8
Real life application and experience	2	8

In the context for learning, the interview made an attempt to understand teachers' knowledge on the significance of space and resources to promote STEM learning. Further, the ability of participants to adapt resources/use locally available materials to meet the needs of learners and their capability to connect different topics in science/mathematics to everyday experiences were also considered in the analysis. There was a general understanding and acceptance that to promote science and mathematics learning, appropriate space and resources are critical. The analysis revealed that there was no significant or obvious progression from Baseline to Endline, nor was there any obvious variation between genders or subjects. However, teachers attempted to use local resources, mediate technology to make learning easier for students, and contextually execute lessons through real-life applications.

Of the 14 teachers observed, 11 used some or all of the examples of local contexts and local names, and two others used models and available materials in their classrooms. Some of the examples are shared below.

1104, while teaching data interpretation, connected the same with local contexts by showing graphs and tables of various languages spoken locally. The teacher quoted the national report which discussed students' poor performance in Dzongkha (national language) and mathematics and asked students to check if that was true for their class 8. Students entered their data and found that it was science where their class had performed poorly instead of what was reported in the national report. Even for the reflection activity, the teacher brought in more relatable examples of cute emojis, etc., for students to appreciate the reflection. 1301 discussed the different examples for Potential Energy and Kinetic Energy that students had contributed. When one of her students suggested an elastic band, the teacher appreciated that example, drew it on the board, and shared that such catapults were used by village people to hunt birds or chase monkeys but are no longer used now. 1506 incorporated the local context by asking the students to look around and write down the names of ten items that they saw around them. She would later use these examples to classify materials as organic or inorganic. 1704 made use of the local environment to bring examples of ecology into the lesson. Further, in his genetics lesson, the teacher asked students to look at themselves and their benchmates to identify similarities and differences between themselves. Students came up with answers such as big eyes, thin ears, thick ears, etc., to engage with genetics. 1705 pulled out examples from students' local contexts and also asked students for local examples in the food chain and food web. 1708 used the context of two ecosystems, pond and tree ecosystems, for students to observe different organisms engage in different types of ecological interactions and to discuss different adaptive features in the class. 1718 brought in the local context in the form of activity; he asked the students which animals they would like to clone and which part of the animal they would make donor cells from. This allowed students to talk about their preferences for animals - cows, goats, etc., and engage with the activity.

Though the survey results did not provide much information on the progression of the context for learning, the observation data provided examples and scenarios of teachers' applications to address the context for learning. Likewise, the interview analysis demonstrated that there is a general understanding and acceptance that to promote science and mathematics learning, appropriate space and resources are critical. The analysis revealed no significant or obvious differences from Baseline to Endline, nor obvious variation between genders or subjects.

3.2.5 Curriculum Knowledge

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

The survey question was negatively coded and read as follows: "It is not necessary for a teacher to know the different topics/concepts that are taught in other grades/forms/classes in their subject".

The majority of the science teachers (34% strongly disagree & 38% disagree) disagreed with the statement at the Baseline. It becomes sharper in the Endline with 53% strongly disagreeing and 22% disagreeing with the statement, indicating a positive shift towards curricular knowledge among science teachers. Furthermore, the same pattern was noticed across subjects of physics, chemistry, and biology, with more teachers strongly disagreeing with the negative statement with regard to curricular knowledge.

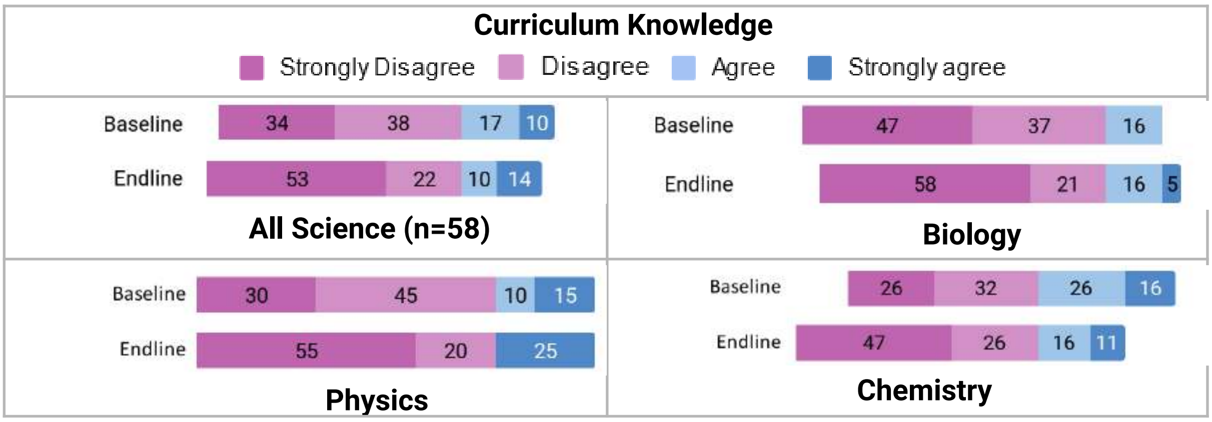


Figure 3.2.5 Subject-wise Agreement Scale on Curricular Knowledge

There is no visible and significant transition in the teachers' understanding of curriculum knowledge of science/mathematics from the Baseline to the Endline nor is there a difference between subjects or genders.

The interview analysis highlighted that the goal of teaching science/mathematics was to develop problem-solving and critical thinking skills in students, and to promote the significance of STEM subjects for the economic development of a nation. This shows that there is some variance between the teachers' understanding of curricular knowledge and the definition of curricular knowledge in the KAP framework which needs to be studied further. Teachers (across subjects) attributed nation-building as one of the goals of teaching STEM subjects, along with developing critical thinking, scientific reasoning, and problem-solving skills, as evidenced in the following quotes:

> "Because now with the changing world STEM has become one of the priority subjects, where the world actually leads with all those concepts. So, I think that science plays a vital role in changing and all those transformations." (1304)

> "It's very important to learn mathematics as it deals with problem-solving skills and quantitative reasoning skills." (1100)

> "Science and math actually teach us to be a critical thinker. Science and technology is the backbone of the economy and then the economy of the world". (1501)

> "Science knowledge is very important to develop scientific knowledge and skills that are required in the world." (1702)

> "Knowledge of biology is important to understand about our own body and health. Also for career it is important." (1704)

During the classroom observations, the teachers demonstrated a good grasp of the curriculum knowledge in many ways. For example, 1104 mentioned that for certain topics they don't necessarily follow textbooks, instead they abide by the prescribed curriculum document (National School Curriculum). Further, when the same teacher was requested to teach a new class, the teacher planned the activity after taking into consideration the syllabus that the students had already learnt in their previous standard. 1109 mentioned that the students faced difficulty with 3D objects and not so much with 2D objects, which were present till class 9. In class 10, however, when they encounter 3D objects they find it very difficult to understand the plane of symmetry, indicating the increasing levels of difficulty in a hierarchical curriculum. 1118 created activities and topics that were aligned with the curriculum and the CL4STEM modules, thus being able to recognise the connections. 1301 displayed curriculum knowledge by focusing on the textbook problems and the textbook topics. 1302 and 1312 mentioned that the topic they had taught was relevant to the curriculum but was not exactly aligned to the CL4STEM modules, indicating the teachers' awareness about the curriculum. 1309 made students perform practical experiments in the class to calculate heat loss between multiple media. In order to make the experiment feasible for implementation in his class, 1309 used two liquid media instead of one solid and one liquid media. Once the students had conducted the practical experiment, the teacher also taught them to calculate heat lost/gained, demonstrating high curricular knowledge. 1501 displayed her understanding of curriculum knowledge when she was teaching the topic of hydrocarbons to her 9th standard students by explaining how the same topics were connected to the 11th grade curriculum.

In conclusion, the findings related to curriculum knowledge indicate a positive shift among science teachers, with a majority disagreeing with the statement that it is not necessary for a teacher to know the different topics/concepts taught in other grades in their subject. This shift is more pronounced in the Endline, with a higher percentage of teachers strongly disagreeing with the statement. This positive shift is consistent across the subjects of physics, chemistry, and biology. Classroom observations showed that all the observed teachers had a good understanding of curricular knowledge.

3.3 General Pedagogical Knowledge (GPK)

The theme of GPK deals with teachers' classroom practices (evaluation strategies, catering to individual differences, and managing the classroom during teaching and learning). These practices have been classified into predetermined sub-themes that include Equity and Inclusion, Classroom Management, and Assessment to foster HOTIE.

3.3.1 Equity and Inclusion

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

Inclusion and equity in teaching and learning refer to an environment in which every student feels welcomed, respected, and supported in their educational journey. Equity in education refers to the principles of fairness and justice. It entails recognizing and addressing the systemic barriers that prevent some students from having equal access to opportunities and resources. Equity in teaching and learning entails providing students with the assistance they require to succeed, regardless of their background. Inclusion is the practice of ensuring that all students, regardless of background, identity, or ability, participate fully and actively in the learning process. This includes making accommodations, modifications, and support systems available to ensure that all students have access to the curriculum, engage with the learning material, and contribute to the classroom community.

The GPK on equity and inclusion of 58 science teacher participants was analyzed for only the three science subjects and not math, due to implementation constraints.

Table 3.3.1 Teaching Challenges Posed by Different Student Groups

Which group of students pose a challenge for you to teach effectively?	Frequency of teachers' responses (n= 58)											
	Baseline (%)				Endline (%)				Change (%)			
	B	C	P	Mean	B	C	P	Mean	B	C	P	Mean
Students with different academic abilities	53	53	45	50	42	47	55	48	-11	-6	10	-2
Students who come from a wide range of social, ethnic or religious backgrounds	11	26	55	31	47	42	40	43	36	16	-15	12
Students with special needs, such as physical or psychological impairments	53	58	65	59	79	42	55	59	26	-16	-10	0
Students who are disinterested	63	74	65	67	68	68	65	67	5	-6	0	0
Students with poor motivation	37	53	45	45	47	42	55	48	10	-11	10	3
Students with disruptive behaviour	42	32	30	35	47	26	55	43	5	-6	25	8

The percentage of teachers considering the factor “students with different academic abilities” as a challenge for effective teaching have slightly dropped overall. However, the drop is higher in biology and chemistry but not in physics, indicating that the modules enabled biology and chemistry teachers but not physics teachers to accommodate all the students with different abilities. The biology (36%) and chemistry (16%) teachers perceived “students from different social, ethnic, or religious backgrounds” as a challenge, whereas the physics (-15%) teachers did not.

The category of “students who are disinterested”, was found to be posing challenges to 67% of teachers in both Baseline and Endline when it comes to effective teaching. The teachers' perceptions regarding students with poor motivation as posing challenges in the classroom has increased slightly (+3%). The categories such as “students who come from a wide range of social, ethnic or religious backgrounds” (+12%), “students with disruptive behaviour” (+8%), and “students with special needs, such as physical or psychological impairments” (no change) are reported to pose challenges to teachers with regard to effective teaching. Hence, it can be concluded that teachers still need support in managing disruptive students, students with special needs, and students from different social statuses. While comparing the Baseline and Endline reports, however, one can see that the teachers have developed a greater awareness of the students' social backgrounds.

The science teachers' perceptions of groups of students who posed challenges for them to teach were analyzed gender-wise. The analysis indicated that female science teachers do not find the following groups of students as challenging to effective teaching: “Students with different academic abilities” (-9%); “Students with special needs, such as psychological” (-35%); “Students who are disinterested” (-16%); “Students with poor motivation” (-12%) and “Students with disruptive behavior” (-6%). The male science teachers, however, have reported the following groups of students as challenging to teach effectively: “Students from a wide range of social, ethnic, or religious backgrounds” (+12%); “Students with special needs, such as psychological" (+15%); "Students with poor motivation" (+3%) and "Students with disruptive behavior" (+6%). This suggests that male and female science teachers view student challenges differently.

Except for "Students with different academic abilities" (-7%), the focus reported that all of the above-mentioned student groups pose challenges for them to teach. This implies that the focus group may need more experience as well as additional knowledge and skills to accommodate students with different needs. Similarly, the general group reported having difficulty teaching students with different needs, with the exception of "Students with disruptive behavior" (-6%). Overall, the findings indicate that the challenges of teaching students with different needs can be difficult to overcome, even for experienced teachers. However, there are strategies that can be used to manage these challenges. It is also important to remember that the students' needs may change over time, so teachers need to be flexible and adaptable. Surprisingly, the data for the preservice group suggests that they are less likely to find "Students with special needs, such as physical or psychological impairments" (-10%); "Students who are disinterested" (-17%) and "Students with poor motivation" (-11%) challenging to teach. Since they were on field practicum, the general pedagogical modules that were offered to them may have raised their awareness of the challenges of teaching students with different learning needs. These modules may have provided them with information about different types of learning disabilities, as well as strategies for differentiating instruction and meeting the needs of all students.

The survey further examined the participants' agreement on equity and inclusion, and Figure 3.3.1 shows the responses of all the teacher participants (n = 82).

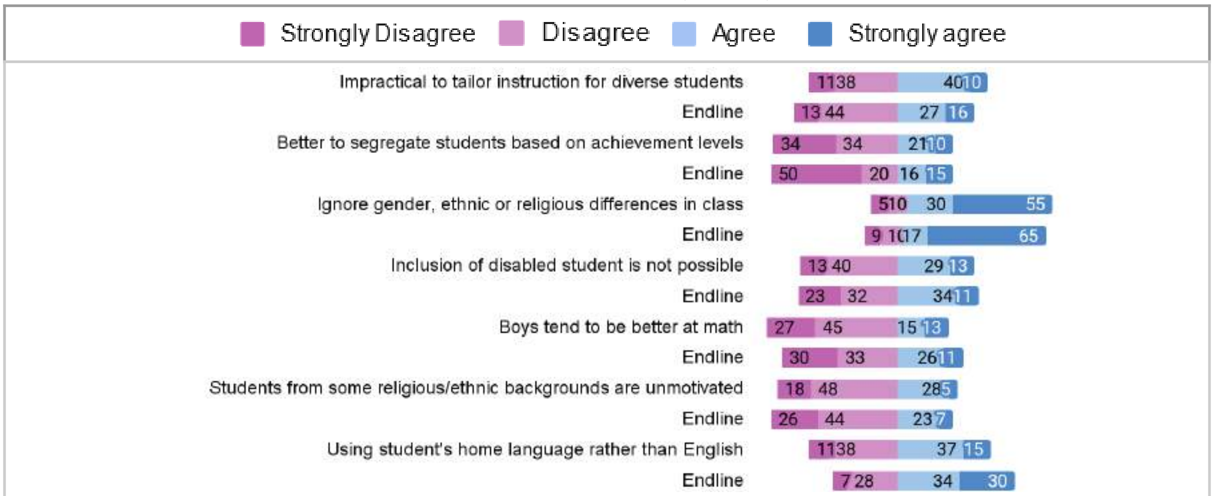


Figure 3.3.1 Teacher Attitudes on Equity and Inclusion (n=82)

The results of the Baseline survey showed that almost an equal proportion of teachers agreed and disagreed with the statement: "It is impractical for teachers to tailor instruction to the different abilities of different students". However, more teachers disagreed with the statement in the Endline survey, indicating that more teachers gained the confidence to work with mixed-ability students. Likewise, teachers (Baseline= 53% & Endline= 55%) believe that students with disabilities could be included in mainstream classes. Furthermore, the percentage of teachers who agree that students should not be separated based on their achievement levels has increased slightly.

Culturally, Bhutanese students are not differentiated based on gender, ethnic, or religious differences; this is also evident from the statement by teachers (Baseline= 85% and Endline= 82%) . This is interesting because in the earlier question, there was a 36% increase in biology teachers, who believed it was challenging to teach students of different backgrounds. The majority of teachers (Baseline= 72% and Endline= 62%) disagreed with the statement that boys tend to be naturally better than girls in science and math. The percentage of teachers who agreed to use their home language rather than only English for science and math learning was 52% at the beginning and 64% at the end. This indicates that more teachers recognized the importance of using their home language to promote equity and inclusion as per the Endline survey.

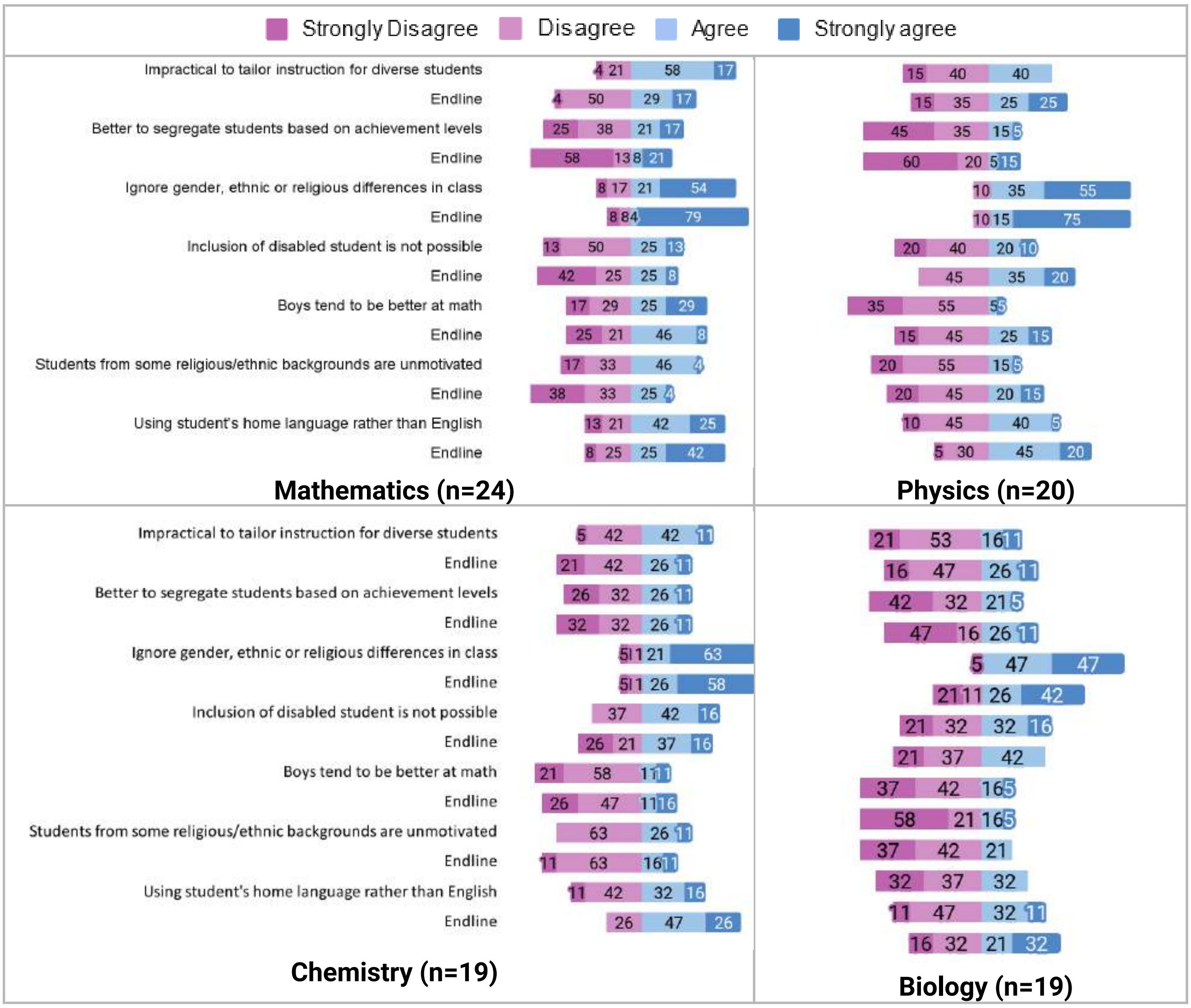


Figure 3.3.2 Subject-wise Distribution of Teacher Attitudes towards Equity and Inclusion

The percentage of teachers who believe “It is impractical to tailor instruction for diverse students” has decreased from Baseline to Endline. This was the case for mathematics (-29%) and chemistry (-16%) teachers only, as physics (+5%) and biology (+10%) teachers continue to believe that such steps are impractical. It indicates that physics and biology teachers may require additional training and support to understand the benefits of inclusive education and how to effectively tailor instruction. Respondents across subject groups also disagreed with the statement that “it is better to separate students based on achievement levels”. This suggests that teachers believe that students can learn from one another and that they should be given the opportunity to interact with students from diverse backgrounds.

Mathematics (Baseline= 63% and Endline= 67%) and biology (Baseline: 53%, Endline: 58%) respondents agreed that including students with disabilities in regular classes is possible, whereas physics respondents agreed only in the Baseline survey (Baseline: 60%, Endline: 45%). Chemistry respondents (Baseline= 58% and Endline= 53%) have stated that it is not possible. The difference in opinion between chemistry respondents and respondents from the other three subjects could potentially be attributed to the nature of chemistry classes. Chemistry classes often involve risky practical lessons, which may cause some teachers to feel that it is not safe to include disabled students in these classes. It is surprising that 54% of mathematics teachers agreed to the statement that “only boys perform better in math” in both the Baseline and Endline surveys (Baseline: 54% and Endline: 54%). This suggests that there is a need for professional development opportunities for teachers that focus on equity and inclusion in math education. These opportunities should help teachers understand the impact of gender stereotypes on math achievement and create a more equitable learning environment for all students.

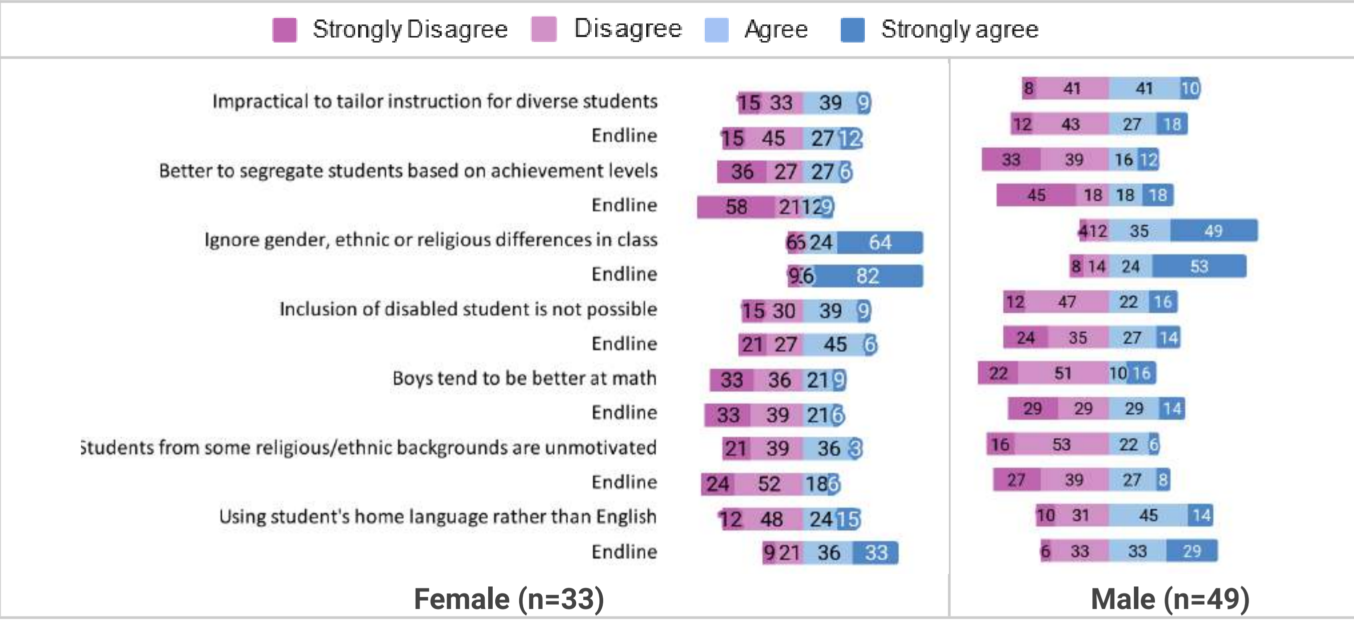


Figure 3.3.3 Gender-wise Distribution of Teacher Attitudes towards Equity and Inclusion

According to the findings from Figure 3.3.3, both male and female teachers are very supportive of inclusive education, except for the statement that “Boys tend to be better at Math”. More male teachers disagreed with this statement compared to female teachers at the Endline.

Further, the perceptions of mathematics teachers on students' natural abilities and learners' interest in learning mathematics were investigated, and the results are shown in Figure 3.3.4.

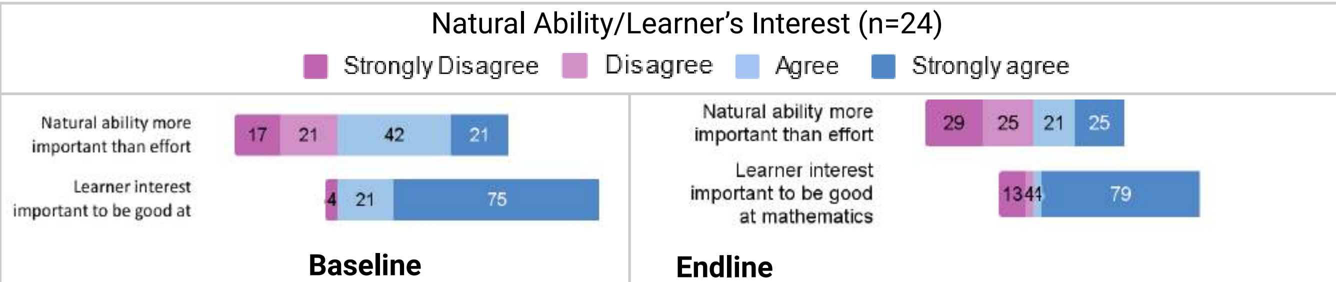


Figure 3.3.4 Teachers’ Perception of Students’ Natural Ability and Learners’ Interest

Initially, 63% of teachers believed that natural ability was more important than effort for success in mathematics. By the end of the study, 46% of teachers agreed with this statement. This suggests that there has been a small positive shift towards inclusion and equity in math education, with slightly more than half of the teachers believing that effort is more important than natural ability for all students.

Initially, 96% (Baseline) of teachers believed that interest in mathematics was a prerequisite for success in the subject. However, after the implementation of OERs focused on promoting equity and inclusion, this belief decreased to 83% (Endline). This suggests that teachers still have persistent beliefs about inborn math abilities and that more research and intervention are needed to support math learning and address teachers' beliefs.

Similarly, the perceptions of science teachers regarding equal opportunities for students to speak and the use of cultural diversity in teaching were investigated, and the results are shown in Figure 3.3.5.

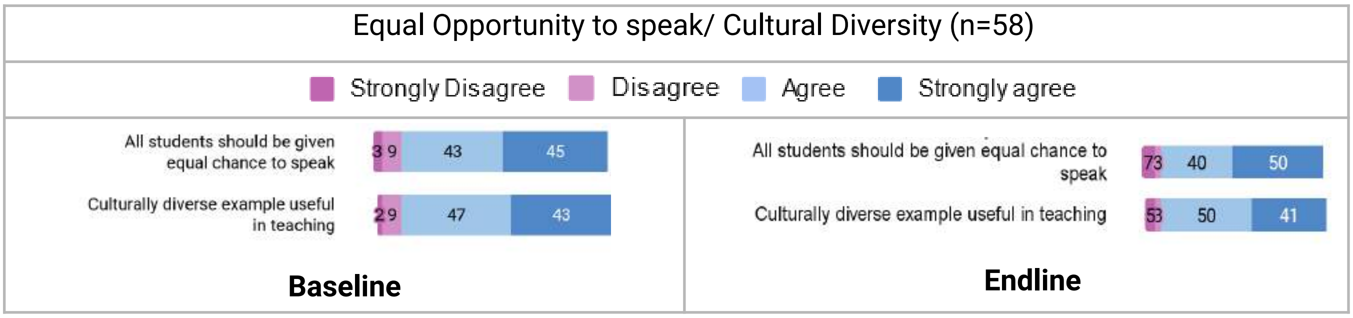


Figure 3.3.5 The Response of Science Teachers' to Equal Opportunity to Speak/ Cultural Diversity

The science teachers' beliefs on promoting equity and inclusion can be seen by their emphasis on giving all students an equal opportunity to speak. This was further supported by 88% of teachers in the Baseline and 90% of teachers in the Endline. This indicates that science teachers generally allow all students to participate in class and make them feel included in classroom activities. Bringing examples relevant to students with different cultural experiences matters a lot in teaching science. This is supported by the fact that 90% of teachers in the Baseline and 91% of teachers in the Endline agreed with the statement. This shows that teachers are culturally sensitive and support students' learning through the available cultural resources in their local contexts.

The following change was observed when the overall interview data was considered:

Equity and Inclusion - Sub-themes	Baseline	Endline
Understanding of Equity and Inclusion	19	19
Planning and practice for Equity and Inclusion	5	14

Consistently from the Baseline to the Endline, the interview data revealed all teachers' awareness of the existence of students from diverse backgrounds, such as urban and rural, boarder and day scholars, older and younger, male and female, underprivileged and affluent, and repeating students. They are also cognizant of the different learning categories, such as high/average/low achiever, fast/slow learner, and those with good/poor English communication skills. Therefore, a general consideration of inclusion of learners with diverse backgrounds and different learning needs is visible in the thoughts and practices of the teachers. The interview data revealed that besides ensuring the use of various teaching aids, the teachers also organized various activities such as group work, pair work, independent work, peer tutoring, and remedial classes that ensured maximum participation, thus eventually catering to diverse learners. Few even indicated that they were mindful of student's socioeconomic status and religious background while teaching or organizing activities.

For the purpose of the interpretation, equity and inclusion are classified into two sub-categories: Understanding Equity and Inclusion and Planning and Practice for Equity and Inclusion. The terms equity and inclusion may mean different things to different people. Individual differences and diversity include, but are not limited to, age, disability, ethnicity, gender, gender identity, language, national origin, race, religion, culture, sexual orientation, and socioeconomic status (APA, 2015). In the context of this study, it refers to gender, disability, language, settlement (urban or rural) and socioeconomic status, and type of school (boarding/day-scholar). The data did not show any difference between genders or between subjects in the change in understanding or practice in relation to equity and inclusion.

During Baseline interviews, teachers expressed the existence of a diversity of learners in the classroom; however, during the Endline interviews, teachers were able to elaborate on strategies that they either use in their teaching and learning process or make recommendations for use in education to ensure equity and inclusion. Interestingly, a few even shared practices to address equity and inclusion during the Baseline. The following table shows examples of progressive change from the Baseline to the Endline with regard to the teachers' understanding of equity and inclusion. It can be seen that the teachers' responses moved from discussing ideas of equity and inclusion to planning and practicing for equity and inclusion.

Baseline	Endline
Change in teachers' understanding of equity and inclusion	
"The high ability students will understand the concept within no time and they become restless."- 1100M	*"Because the universal design for learning actually tries to involve everyone in the classroom. And when we try involving everyone in the classroom, it really helps the low achievers.*"- 1100
"We are dealing with different kinds of children. Our school is identified as an inclusive school where we also have some children with disabilities."- 1304	*"We cannot make one Lesson plan that actually fits only for a few people, but we have to make a Lesson plan for all, so that was inclusiveness. It was one of the things that I always kept in mind when I planned the lesson."*- 1304
Change in teachers' planning and practice towards equity and inclusion	
"Only few students from rural people are able to perform well but students from urban areas will do better as they are open minded, they are more exposed in terms of modernization but they take it lightly."- 1104	*"I did activities through groups, group activities, but I made sure that everybody was involved in that activity."*- 1104
"I cannot make every student learn within 45 minutes. So what I do is, poor students I select and give them a remedial class."- 1300	*"There are some students who don't understand when the teachers are explaining. Some students learn from their peers. So what I do is I let the low achiever students group with the high achiever, mixed and I made the high achiever student to explain to the low achiever."*- 1300
"In my classroom, usually when we have diverse students, I feel this is because some high achievers have educated parents back at home and are guided well."- 1701	*"Mostly organised the group activities in classroom teaching and lessons were planned considering inclusiveness. Most of my lessons were planned considering inclusiveness. Practice multiple means of representation for learners."*- 1701
"Especially as per my observation it is quite difficult to score well in science subjects for the students, maybe they do not have proper foundation. Some students are doing well but some students find it difficult."- 1704	*"I have student groups based on their mixed abilities. I provide them group activities where they can actively and productively engage in discussion and learning. Sometimes I used to take them outside to experience the real life situation."*- 1704

The study revealed that many teachers found students who are disinterested to be a significant challenge in terms of effective teaching. Although the intervention supported the teachers in dealing with students of different academic abilities, it did not provide much support in arousing students' interest. Teachers reported that students with poor motivation, disruptive behavior, and special needs posed challenges in the classroom. There was a greater awareness of students' social backgrounds among the teachers when comparing the Baseline and Endline reports. The analysis of Likert scale items revealed some positive shifts in the teachers' perceptions regarding mixed ability grouping and using students' home language for teaching mathematics and science.

Interestingly, there were some results that stood out when data was sliced for the gender of the teacher: male teachers reported students with different academic abilities and students from different social backgrounds as more challenging compared to female teachers. Female teachers showed more concern and awareness about students with special needs and physical or psychological impairments. The analysis based on teachers' experience levels (focus, general, and preservice) revealed that the challenges of teaching students with different needs can be difficult to overcome, even for experienced teachers. The interview data revealed that there was an increase in the teachers' understanding of equity and inclusion and the practices that they used, such as using mixed ability groups, further supporting the findings from the surveys.

3.3.2 Classroom management

- Knowledge of multiple modes of classroom interaction - Ex: organising inquiry learning/project-based learning/problem-solving to promote students' agency, a variety of grouping practices to support collaborative learning, use of activities for multiple ways of 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

With regards to classroom management, the survey asked participants if it was a good strategy to have mixed ability groups of students during group work. As can be seen in the figure below, there was a minor positive change (5%) where the teachers reported an increase in the preference of mixed-ability student grouping.

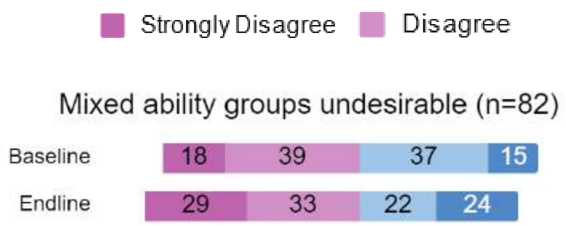


Figure 3.3.2 (a) Teachers' Perspectives on Mixed Ability Grouping

As was also reported in the section on instructional strategies, the most common classroom management strategy was using groups. Through qualitative data (interviews and observations), it became evident that few teachers were able to articulate the various strategies of classroom interaction other than group work and collaborative learning. Some of the participants mentioned the Kagan strategy as an effective classroom management strategy. By utilizing Kagan's strategy within the

CL4STEM framework, teachers could create a conducive learning environment that enhances student engagement and facilitates a deeper understanding of STEM subjects. Classroom observations revealed that 71% of teachers engaged students in group work and activities, while 93% used questioning to keep the students motivated and engaged.

The following are examples of evidence that exhibits a progressive change in the practice of classroom management (using hands-on activities for addressing disciplinary issues) from Baseline to Endline:

Baseline	**Endline**
"There are some students, even after telling or reminding them several times, they don't listen. Whenever I have students with disciplinary issues, first I try to advise them. After advising also if they don't listen then I inform the class teacher and then they follow up on it." - 1501	*"I make sure to include hands-on activities wherever possible. There are few students who don't cooperate with us in the class. They don't listen to us, or maybe they are not interested in the subject. The concept of inclusion from the CL4STEM was helpful in addressing disciplinary issues in my class."* - 1501
"In terms of disciplines so no issues but sometimes few students are not able to concentrate and get distracted and am managing it by gaining students' attention." -1104	*"I did activities through groups, group activities, but I made sure that everybody was involved in that activity."* -1104

In the examples below, it is demonstrated that in Baseline interviews, the teachers did not mention explicit strategies for classroom management. In Endline, however, the teachers mentioned explicit strategies such as using more ICT to engage students, as a classroom management strategy, thus showing more awareness.

Baseline	**Endline**
"I face difficulties when dealing with low performing students because they do not open up. Some of them don't even come to clear their doubts despite repeated reminders." - 1100	*"My class mostly will be very interactive trying to create that environment. I try to make my class very interactive and very engaging through the use of ICT. Nowadays when we use ICT, th*ere will be more participation in class." - 1100
"If a student comes up with some behavioral issues, the first thing is I talk with the students and understand their problem and then try to solve at my level. I put it to the class teacher only if it doesn't go well then." - 1124	*"I focused on infusion of ICT during the content delivery and sometimes in assessment parts. So in that case students were engaged."* - 1124

The second qualitative finding was that the teachers relied on using ICT to make the class interactive and introduce new content as a strategy for building student engagement. This finding was validated in the classroom observation as well, where 71% of the teachers used ICT in their lessons, either for group work or for sharing new content (Figure 3.3.2 (b), (c),(d)).

Figure 3.3.2 (b): The Use of Slides & Physical Setup to Teach Electromagnetism

Figure 3.3.2 (c): Students Using Headphones in Class

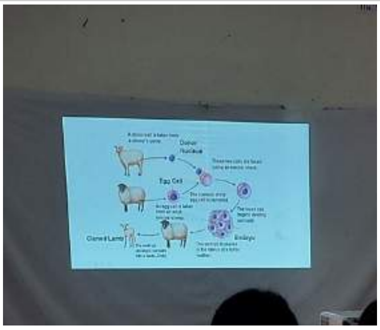


Figure 3.3.2 (d): The Teacher Making Use of Slides to Share New Content with Students

In summary, through the survey, interviews and classroom observations, we can conclude that there was a minor positive impact of CL4STEM on teacher knowledge and practice of managing classroom interactions.

3.3.3. 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

Different types of assessment tools used by the teachers included standardized tests, reasoning based questions, projects and practicals, and observation of students' progress. It was found that teachers use all of the indicated assessment methods, and the percentage of teachers who prefer standardized tests has increased by 27% in the Endline. With regard to the gender of the teacher, it was observed that 76% of female teachers used observation of students as the main assessment method in Endline as compared to 58% in Baseline. There was no other reportable change in the survey data when sliced on gender, subject or the teachers' experience.

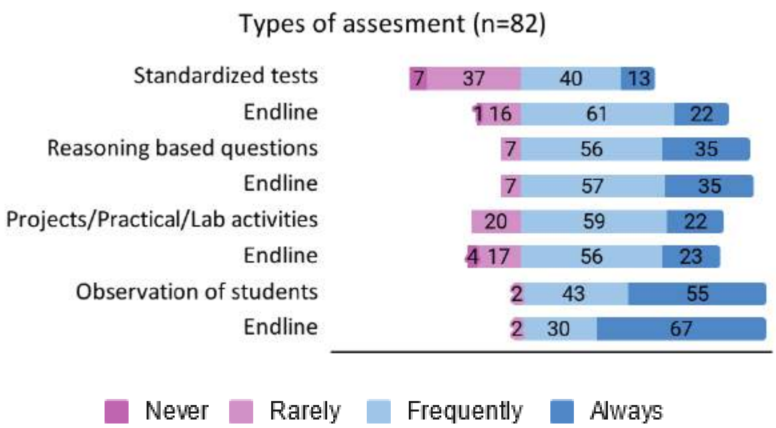


Figure 3.3.3 Perspective of Teachers over Questions of Assessment

From a qualitative point of view, both formative and summative assessments were carried out to assess students' learning across STEM subjects by the teachers. The teachers mentioned the use of formative assessment methods such as asking students to demonstrate their understanding during the lesson, checking random notebooks, etc. in Baseline. However, in the Endline, teachers were more aware of the meaning of formative and summative assessments and therefore used strategies such as pretest and post-test for assessing student understanding.

Baseline	Endline
"I make students do presentations in groups, I ask them to submit their presentation, write up and assess using rubrics." - 1503	*"I use formative and summative assessment and also provide support to individual student's learning. Learned to use quiz and true & false from the modules."* - 1503
"Once I deliver the lesson, I take the last 4 to 5 minutes to correct the notebook of students randomly. I also give them a project and test and then a notebook correction as one of the means of assessment." - 1103	*"By the end of the unit, we conduct unit tests and then some other class tests to assess their learning before I was involved in CL4STEM, we only had class test, units tests and all. However with the help of this CL4STEM, I have used pre-test and post-test to assess and plan students' learning."* - 1103

Similarly, teachers also reported using online quizzes as a strategy for formative assessment in the Endline interviews.

Baseline	Endline
"I actually do a test at the end of the chapter. I also ask them questions. I assign one period for a question and answer session. After teaching I also let them do group work and make them present." - 1703	*"Used both formative and summative form of assessment, so in formative assessment I used online quizzes."* - 1703
"Usually I assess their learning by assigning them class works and even I gave them homework." -1101	*"Before I would just provide them classwork and homework for assessing them. OK, after the CL4STEM, I have used Kahoot and Mentimeter. I would give them a quiz."* - 1101

Classroom observations also validated that the teachers used multiple formative assessments, such as giving quick worksheets at the beginning of the lesson, asking questions to individual or groups of students, giving opportunities for students to demonstrate their understanding in front of the class, posting questions on the Telegram groups of the class for students to work on as homework, open book activities and so on.

The participants have used a variety of assessment tools, including standardized tests, reasoning-based questions, projects and practicals, and the observation of students' progress. All things considered, the teachers could gain a clear understanding of formative and summative assessments and regularly implement formative assessments for students.

Unit 4: Perceptions of CL4STEM

The teachers' perceptions of CL4STEM innovation implementation were studied using three tools: the Concerns Based Adoption Model's Levels of Use and Stages of Concern framework (Hall & Hord, 1974), and Moore and Benbasat's (1991) seven characteristics of innovation framework. This chapter first presents the teachers' stages of concerns and levels of usage of CL4STEM and then proceeds to explain the change in teacher perceptions of CL4STEM from Baseline to Endline.

4.1 Stages of Concern (SoC)

The SoC survey consisted of seven statements, to gauge the varying concerns of participants with regard to CL4STEM implementation. Data from the Endline survey is presented in the table below.

Table 4.1 Data from the Endline Survey

Overall Stages of Concern		Focus	General	Preservice	Total
0. Unconcerned	Not interested in participating CL4STEM	0	0	1	1
1. Informational	Know about CL4STEM, and interested in making use of it at some point in time	1	3	6	10
2. Personal	Concerned about the demands of CL4STEM vis-a-vis existing workload and how it fits in the existing working conditions	4	3	8	15
3. Management	Grappling with how to effectively navigate the online modules and participate in the Telegram groups of CL4STEM	1	0	3	4
4.Consequence	Evaluating how CL4STEM teaching strategies impact/help in student learning	8	4	7	19
5.Collaboration	Exploring ways of collaboration with other teachers and educators to help impact student learning using CL4STEM teaching strategies	4	4	9	17
6.Refocusing	Exploring ways of improving CL4STEM teaching strategies through further refinement of the modules and CoP participation and/or alternative ways of achieving better results	1	6	9	16
	Total	**19**	**20**	**43**	**82**

Concerns about the demands of CL4STEM in relation to existing workload and how it fits into existing working conditions have been expressed by participants (21% Focus, 15% General, and 19% Preservice). Similarly, participants (42% Focus, 20% General, and 16% Preservice) expressed concern about determining how CL4STEM teaching strategies impact/help student learning. The participants (21% Focus, 20% General, and 21% Preservice) also expressed concerns regarding collaboration with other teachers and educators to improve student learning through the use of CL4STEM teaching strategies. The other concerns of the participants (5% Focus, 30% General and 21% Preservice) were about exploring ways to improve CL4STEM teaching strategies through further refinement of the modules and CoP participation and/or alternative ways of achieving better results.

During the interview, participants were asked to choose one statement from the seven options for CL4STEM that best indicated their overall SoC. There was a good spread of choices wherein no specificity to subjects or gender was observed. Five participants had marked the fourth stage of Consequence – “Evaluating how CL4STEM teaching strategies impact/help in student learning”. Some of the reasons expressed were as follows: “I'm in that process of evaluating how CL4STEM teaching, strategy impact or helping student learning. Because we have finished implementing that, but I think I'm still like analyzing teaching strategies in CL4STEM are effective on the teaching and learning how the students are benefited" (1303); "because I am implementing the strategies in my class" (1503); "I am trying to evaluate whether it works or not" (1704); "I cannot conclude that my students are performing better but I am interested to find out"(1701); "because I am curious about the impact" (1700).

Four of the participants chose Collaboration – "Exploring ways of collaboration with other teachers and educators to help impact student learning using CL4STEM teaching strategies". One of the reasons was as follows: "the reason could be basically similar to what I have shared, just a moment so. They've been working together since. We have to actually learn together so that the teaching becomes more interesting." (1304).

There were three participants who chose the statement Refocusing – "Exploring ways of improving CL4STEM teaching strategies through further refinement of the modules and CoP participation and/or alternative ways of achieving better results". Only one participant, 1104, was able to provide a reason for the choice: "since it is a new knowledge, especially technology and higher level pedagogy we need to make it more applicable and easy to use."

Three participants chose Personal – "Concerned about the demands of CL4STEM vis-a-vis existing workload and how it fits in the existing working conditions". Some of the reasons stated for the concern were as follows: "because although this project helps in our classroom teaching. However, looking at the workloads and the syllabus coverage of our curriculum, so I think it will be overburden for the teachers" (1124); "the reason that I found is that the concern about the demand of CL4STEM in relation to our existing workload. We all know that we are so much busy. On top of that CL4STEM demand a lot of students centered teaching and more of a practical and experiments. We teachers already burdened with a lot of work, and on top of that when you do a CL4STEM lesson, it is very demanding and challenging" (1300); "I think we require extra effort to do that because it demands our extra time. Since I had my share of workload at school, I faced time pressure having to attend to school work and CL4STEM project. So for me time management was quite challenging for me. So that's why I'm concerned about that" (1501).

Two participants chose Informational – "Know about CL4STEM, and would like to use at some point in time". The participants gave the following reasons: "we didn't get much time to actually, you know, practice, we were actually I mean already bogged down with so many you know lessons" (1502); "so it helped me in content as long as it helped me in the strategies. It helped me in integrating the ICT tools more than anything engaging in hands-on practice, and I am interested to learn more" (1703).

From the survey analysis of the SoC, there seems to be an even spread on the concerns such as: "Evaluating how CL4STEM teaching strategies impact/help in student learning"; "Exploring ways of collaboration with other teachers and educators to help impact student learning using CL4STEM teaching strategies"; "Exploring ways of improving CL4STEM teaching strategies through further refinement of the modules and CoP participation and/or alternative ways of achieving better results" and "Concerned about the demands of CL4STEM vis-a-vis existing workload and how it fits in the existing working conditions". Though the choices are quite similar in the interview, however, there seems to be some level of variation in the popularity. In the interview, evaluating impact in student learning was a popular choice followed by collaboration with other teachers and educators. Likewise, the concern about workload and improving the modules was also shared by the participants.

4.2 Levels of Use (LoU)

The Levels of Use survey was adapted from the LoU interview from CBAM. This survey focused on statements with increasing use of the CL4STEM model (modules and CoPs). The table below shows the distribution of the different LoU of the participants.

Table 4.2 The Distribution of Participants' Different Levels of Use

Levels of Use	Statements	Focus	General	Preservice	Total
0. Non- Use	Little or no knowledge of CL4STEM, No involvement and/or no intention to be involved	0	0	2	2
1.Orientation	Trying to know more about CL4STEM	1	2	8	11
2.Preparation	Not yet assessed CL4STEM modules and Telegram groups (CoPs) but plan to do so soon	0	0	0	0
3.Mechanical use	Still learning how to effectively navigate CL4STEM modules and Telegram groups (CoPs)	3	1	8	12
4.a. Routine	Comfortable with CL4STEM online module and Telegram groups (CoPs) /Able to implement the teaching strategies in my class as per instructions given in the modules and discussions in Telegram groups (CoPs)	9	8	13	30
4.b. Refinement	Have adopted CL4STEM teaching strategies to meet the different needs of my students (without diluting the core objectives of CL4STEM- PCK+UDL/Higher order teaching with inclusion and equity)	3	8	7	18
5. Integration	Having internalized the CL4STEM teaching strategies, able to collaborate with other teachers around CL4STEM teaching strategies to meet the different needs of students	2	1	2	5
6. Renewal	Having internalized the CL4STEM teaching strategies, now in a position to suggest well thought out modifications and alternatives to the present innovation	1	0	3	4
	Total	**19**	**20**	**43**	**82**

Among the participants, 19% expressed a desire to learn more about CL4STEM and were also learning how to navigate CL4STEM modules and Telegram groups (CoPs). The majority of the focus group (47%), general (40%), and preservice (30%) were found to be comfortable with the CL4STEM online module and Telegram CoPs and were able to implement the teaching strategies in the classes as per the instructions given in the modules and discussions in Telegram CoPs. It was also encouraging to see that participants used the teaching strategies recommended in the modules to meet the various needs of the students.

Focus group participants were asked to mark one category out of nine choices that best indicated their LoU of CL4STEM during their Endline interviews. The choices were evenly spread across subjects and genders. Most participants (n= 10) chose the level 4a: "Comfortable with CL4STEM online module and Telegram groups (CoPs)". Following were some of the reasons for their selection: "I was able to implement the teaching strategy in my class as per the instruction given in the modules and discussions in the Telegram group. Besides, I'm using the telegram group very often to know the way forward since the online modules are very user-friendly. It has helped me a lot to gain the knowledge of the module that we were provided with" (1100); 1124 added she was able to implement the teaching strategies as per instructions given in the modules and discussions in CoPs. Some of the other reasons included: "The use of OER proved to be incredibly convenient. It allowed me to seamlessly integrate CL4STEM into my lesson plan, as it provided clear directions and guidance on the dos and don'ts. This support made me feel at ease throughout the process" (1501); "I thoroughly enjoyed the structured lessons in the CL4STEM project” (1502); and "Learning from peers in Telegram chat was enriching, and the provided strategies in the forum and module were informative for implementation." (1704). Most teachers had chosen Routine Use (level 4a) as their preference in surveys and interviews.

The second popular choice in interviews was the level 5 (Integration): “Having internalized the CL4STEM teaching strategies, able to collaborate with other teachers around CL4STEM teaching strategies to meet the different needs of students''. The reasons for the choice, as shared by the participants, are as follows: “I was able to collaborate with other teachers around, see, and most of the time use strategies to meet the differences of students" (1301); “I was able to help some of the teachers who were not part of this project, and that's why I was actually working together with them. So, I was guiding them as well as learning from them” (1304); “I was able to collaborate with other teachers around, see and most of the time apply teaching strategies to meet the differences of students. I believe that every student has the ability to learn something new and can be made possible by applying a new teaching strategy” (1700). In surveys, however, the second popular choice was Refinement (level 4b)

Other Levels of Use chosen by participants are described next: Participant 1104 from Mathematics selected Refinement (level 4b): “Have adopted CL4STEM teaching strategies to meet the different needs of my students (without diluting the core objectives of CL4STEM- using Pedagogical Content Knowledge (PCK) and Universal Design of Learning (UDL)/Higher order teaching with inclusion and equity).” He shared, “In same class same period [I] have used different methods of teaching like, traditional methods is one [method] and then group activities… a kind of a… not really simulation, but I used the mathematical apps sir. So, this might have… might have helped the different abilities [students] to cope with concepts.” Further, a participant from Physics 1300 chose Mechanical Use: Still learning how to effectively navigate CL4STEM modules and Telegram groups (CoPs) and the reason for the choice was “by going through this CL4STEM module, there are a lot of things we have to learn and navigate. We have to implement it. So still, there is room for improvement, because of this, I chose that.”

With regards to Levels of Use (LoU), it was evident from both survey and interview analysis that the majority of the participants were comfortable with the CL4STEM online module and the Telegram groups (CoPs), leading to effective implementation of strategies in their classes. Collaboration among teachers to apply the strategies learnt from the modules was also highlighted in these interactions. There is also mention of an attempt to plan and deliver lessons to ensure meeting the needs of diverse learners. Some participants were still learning how to navigate the CL4STEM modules and CoPs aiming to improve their usage of the CL4STEM resources.

4.3 Teacher Perceptions around CL4STEM

Teacher perceptions of CL4STEM were evaluated using Moore and Benbasat’s (1991) framework on innovation perceptions. The perceptions survey filled out by the teacher participants contained seven themes: (i) voluntariness, (ii) relative advantage, (iii) compatibility, (iv) image, (v) ease of use, (vi) results demonstrability, and (vii) visibility. The participant responses to each of these themes are explained below.

4.3.1 Voluntariness

The study defined voluntariness as whether the teachers participated in the project by their own choice or if they were compelled to participate by their school authorities. The measurement of voluntariness was based on two 7-point Likert statements.

The majority of teacher participants in the schools did not agree with the statement: "My school principal does not require me to participate in the CL4STEM", indicating that the majority of teachers were compelled to participate by their school authorities. When asked about the level of their perception regarding the voluntariness of their enrollment in the CL4STEM project, the quantitative data showed negative results (Figure 4.3.1). Some of the participants perceived that their participation in CL4STEM was mandatory, while others felt that their participation was not enforced.

Overall, the findings of the quantitative data related to voluntariness suggest that there was no observable change in voluntariness of participation. The majority of teachers felt compelled to participate in the CL4STEM project by their school authorities, however, there were some teacher participants who may have felt that their participation was voluntary.

Qualitatively, it was found that a majority of participants mentioned being identified by their management or school to take part in the CL4STEM project, indicating that it was not initially a personal choice for them. However, they acknowledged that as they engaged with the project through their participation in OERs and CoPs, they began to recognize its significance for their professional growth. From their statements, it is evident that using the knowledge and skills in their professional practice is voluntary as they have seen the benefits.

For example, 1100 shared, “Well, to be very frank, in the very beginning, I didn't have any reason to join the project. It was put to me by the school mathematics department. But later on, when we got the orientation program from the Samtse College of Education, I started taking things more seriously. And today, I feel very, very lucky to be a part of this project because I have learned a lot from this project”.

Similarly, 1103 stated, “Nobody forced or compelled me to join. The only thing is that the college administration asked me whether I was interested in joining the CL4STEM project, so I consented to it, and it’s purely based on my volunteerism. Transformation is happening in our education system, and this is an opportunity for us to learn about technology, design thinking and universal designs for learning. I feel it is very important for us”.

1304 had the following to say, “there was no such reason for me and why I joined this CL4STEM. But I'm happy that I'm part of it. So, this program is really helping me learn what is unknown to me. So that's why I don't have any regrets about joining this one because, frankly saying I don't have any idea what CL4STEM means. But now I have some ideas and I know how to use all those resources that are available in this program”.

Another participant, 1702 shared, “it was not my plan to join this project, but when there was a proposal from the college of education, the school gave the name list, and we were selected from the school to join this project, and now I find it quite enriching and fruitful one. It's not a forceful one, because I was quite interested with the motive that this project is based on 21st century learning pedagogy. So, I was always interested in learning and getting involved in professional development for my career”.

The joy of being a part of the project was also highlighted by some participants. For instance, 1502 said, "Samtse College of Education has shared about CL4STEM project with this school and we were informed of it. And then we were invited to join this wonderful project and then some of our colleagues who are from the science department joined CL4STEM. And actually, you know, a STEM project is an aspiration that comes from the highest authority in the government. So it was a very wonderful, you know, journey joining the CL4STEM, to be part of the national goal".

In summary, the quantitative findings suggest varying perceptions of participation in the CL4STEM project among teachers, with the majority of participants feeling compelled by their school authorities and colleagues who participated voluntarily. The qualitative findings, however, highlight the participants' recognition of the value of voluntary engagement, their gratitude for being involved, and the positive emotions associated with contributing to a national goal.

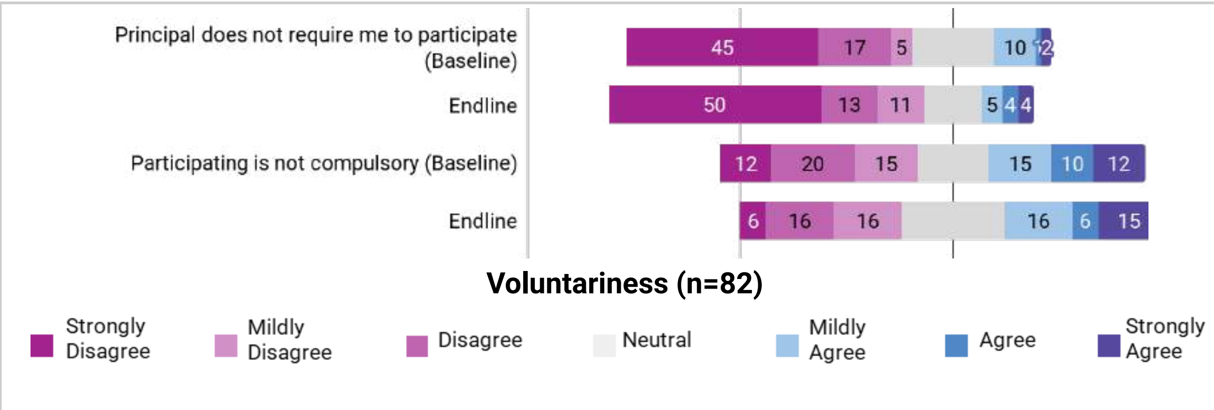


Figure 4.3.1 The Participants' Response on Voluntariness

4.3.2 Relative Advantage

Relative advantage in this study refers to the degree to which an innovation is perceived as being better than its precursor. This parameter contains the following statements: "Participating in the CL4STEM will allow me to teach science and mathematics topics faster"; "Participating in the CL4STEM will improve the quality of my teaching"; "Participating in the CL4STEM will make it easier for me to teach"; "Participating in the CL4STEM will enhance the effectiveness of my teaching" and "Participating in the CL4STEM pilot gives me greater control over my teaching".

Both quantitative and qualitative data provided a comprehensive picture of the teachers' perception of the CL4STEM practices in the area of relative advantage. For example, based on the quantitative data collected, a significant majority of the participating teachers perceived the relative advantage of the CL4STEM practices as superior (Figure 4.1.2). However, the quantitative data further revealed a slightly diminished trend of relative advantages between the Baseline (85% average) and Endline (80% average) measurements of the CL4STEM project. These relative advantages encompassed faster teaching of science and mathematics topics, improved teaching quality, increased ease of teaching, enhanced teaching effectiveness, and greater control over teaching outcomes for individuals participating in the CL4STEM program.

In addition to the quantitative data, the qualitative data collected from the participating teachers also indicated a positive perception of the CL4STEM practices. For example, participants commented on the learnings they have availed in content, pedagogy, technology and assessment, which enabled innovative practices in their classroom. Interestingly, one of the participants, 1103 remarked, “If I comment on this CL4STEM project, it has been very time-consuming but if you look into this carefully, definitely it helped us because it gave us the strategies and teaching methods of how to look into the student's learning and how to assess their progress in learning. So I should say it definitely helped the teachers and as well as students". Likewise, another participant, 1304, stated how the project had empowered him with technology: “It helped me especially on how to use the digital tools which are hardly known to me, and it makes teaching and learning much easier and more interesting now. Using OER, I am able to explore the topic in different contexts, which makes lessons much better”. Similarly, participant 1501 spells out how she upgraded her use of technology: “Because the OER talks about the technologies and it is ICT oriented. Before I used PPT in my lesson but not menti-meter and all, but after participating in CL4STEM I was able to assess my students through quizzes.com and also was able to use Google Docs and all. So it was quite helpful to me in that regard. Definitely, it added an advantage to my teaching practices”. Participant 1703 acknowledged how the project had helped her with the assessment practices: “There is a huge impact on me, I must say, the first time no ideas using the formative and summative assessments, but now I am fully confident to use assessment throughout my session”.

In terms of relative advantage, both quantitative and qualitative data indicate that participating teachers perceived the CL4STEM practices as beneficial. They have recognized the benefits of CL4STEM such as faster teaching of science and math topics, improved teaching quality, increased ease of teaching, enhanced teaching effectiveness, and greater control over teaching outcomes. These positive perceptions of relative advantage highlight the effectiveness of CL4STEM practices in enhancing STEM education.

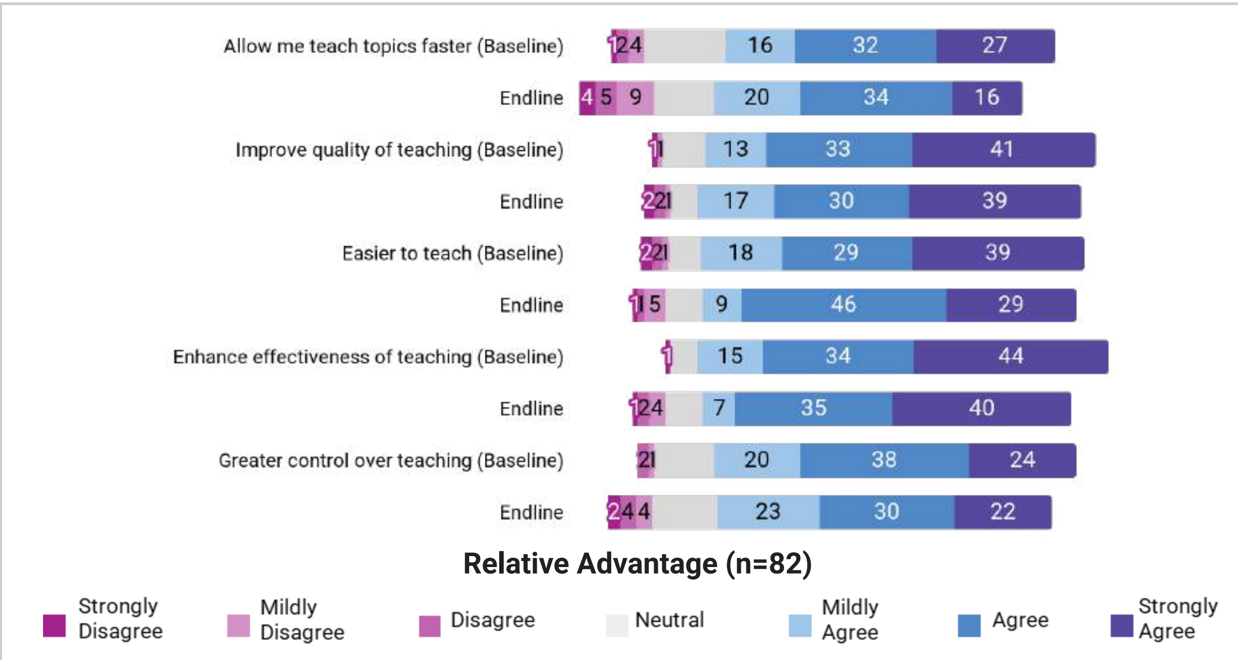


Figure 4.3.2 The Response of Participants on Relative Advantage

4.3.3 Compatibility

Compatibility refers to whether the CL4STEM practices are compatible with the teacher's context. This parameter contained three statements which were aimed to assess the compatibility of the CL4STEM practices with different aspects of teaching: “Participating in CL4STEM is compatible with all aspects of my teaching”,” I think that approaches in CL4STEM fit well with the way I like to teach”, and “Participating in CL4STEM fits into my style of working”.

The survey data revealed that teachers, in general, had a positive perception of the compatibility of CL4STEM practices (76% = Baseline, 79% = Endline), as indicated in Figure 4.1.3. This suggests that the majority of teachers felt that the CL4STEM practices aligned well with their teaching context. Further analysis of the compatibility data was conducted based on gender, participant types, and subject specificity. The detailed graphs presenting these analyses can be found in the appendix. The results of the additional analyses showed that teachers from different genders, participant types, and subject areas generally held positive perceptions of the CL4STEM practices. This implies that teachers across various groups found the CL4STEM practices to be compatible with their teaching contexts.

These findings have significant implications for the adoption and sustainability of CL4STEM practices in the long run. The positive perception of teachers, regardless of their gender, participant type, or subject specializations, suggests widespread acceptance and compatibility of CL4STEM practices. Such acceptance is crucial for the successful implementation and continued use of these practices in STEM education. By being compatible with teachers' existing teaching approaches and contexts, CL4STEM practices are more likely to be adopted by a larger number of educators. This, in turn, enhances the potential for the long-term sustainability of CL4STEM practices within educational settings.

Similarly, the analysis of the qualitative data also revealed that all participants were of the view that the OER’s were very useful, relevant, and blended well with their classroom practices, either in terms of the pedagogy, technology, lesson planning, assessment design, or lesson planning template.

According to 1103, “I teach about algebra, geometries and geometry, and it definitely fits in my situation because the modules are designed for classes VII to X and I teach these grades”. Likewise, 1300 said, “It fits exactly with my style of teaching. As a science teacher, giving a lecture is not enough. So we have to give a concept, then we have to do a practical, and moreover CL4STEM follows learning by doing”. 1501 shared the following comment: “I definitely agree that CL4STEM OERs plus CoP model were very effective for our PD as it is taught through online mode, so it is easy and convenient for teachers to participate. It also focuses more on enhancement of technologies, so as a science teacher, we have to be fully equipped with ICT knowledge”. Participant 1307 also responded positively to the project:“It fits well with my style of teaching. Because, I find this CL4STEM effective. Effective means where I can pick up the strategies or the tools that are prescribed in that module and where I can use them in my daily teaching and learning processes”. Similarly, 1704 stated, “The CL4STEM idea fits very well with my daily teaching practice. The strategies, assessment and ideas of the technology are very useful. The activities were very interesting, and also the design of the modules”. While indicating that it was useful, one participant, 1124, also expressed some apprehension: “Though CL4STEM is very important, especially in mathematics and science, but somehow we could not manage to do it, probably in this classroom learning. We need to look into our school workload, focus on our curriculum and time”.

In general, the teacher perception survey findings demonstrated acceptance and compatibility of CL4STEM practices among teachers indicating their potential for long-term adoption and sustainability in STEM education in Baseline itself. In the Endline, the teacher perception regarding the same increased slightly. The qualitative analysis has revealed that participants found the CL4STEM OER highly useful, relevant, and well-aligned with their classroom practices, highlighting the effectiveness and applicability of CL4STEM in enhancing various aspects of teaching. Such acceptance is crucial for the successful implementation and sustainability of CL4STEM practices in STEM education.

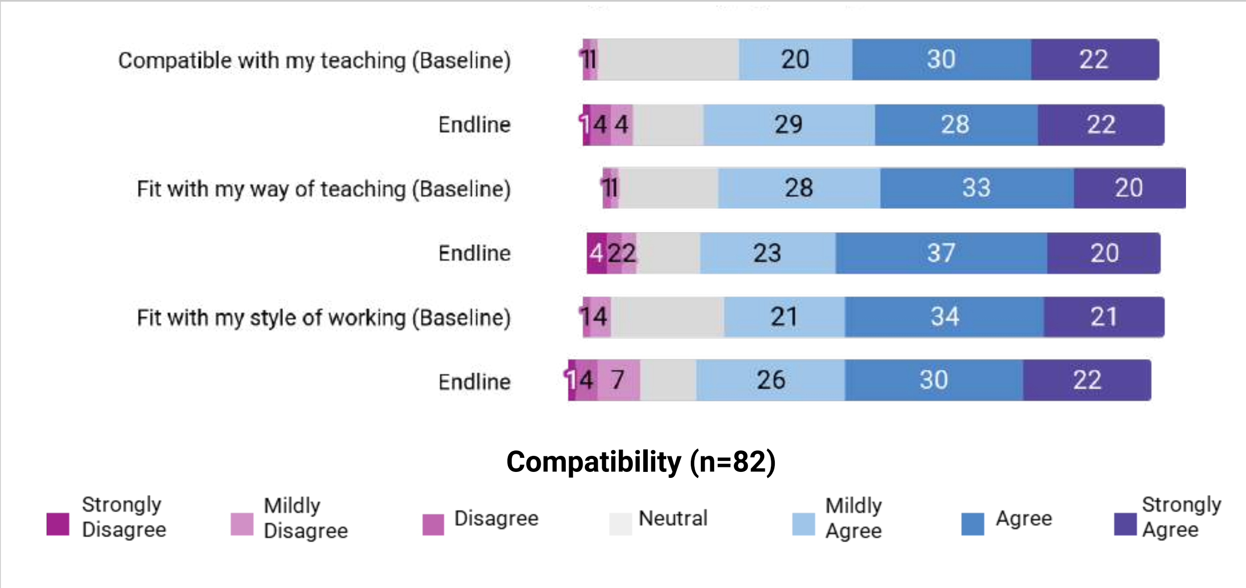


Figure 4.3.3 The Participants' Response on Compatibility

4.3.4 Image

Image refers to the enhancement of the teacher's image after participating in the CL4STEM project. This parameter consists of three questions: "Teachers in my school who are participating in CL4STEM have more prestige than the ones who do not", "Teachers in my school who are participating in CL4STEM have a high profile", "Participating in CL4STEM is a status symbol in my school".

Although the quantitative data showed a greater neutrality in teacher perception as compared to other categories, the overall level of perception was slightly on the positive side (45% in Baseline and 48% in Endline) (Figure 4.1.4). This suggests that participating in CL4STEM may not have a major impact on the teachers' image in terms of prestige, profile, and status symbol in the schools, but there is still a positive perception towards this parameter among the teacher participants.

Similar findings were also observed in the qualitative data, wherein nearly all participants were of the view that they did not develop any special status or recognition in their school during or after their participation in the project since most colleagues in their school were not aware of the project. However, the interview analysis provided some form of recognition at various levels. For example, 1103 said, "Some of the teachers are mentioning that you people are young, energetic so got the opportunity, and we are an outdated generation so we didn't get the opportunity to participate in this CL4STEM". This is a subtle recognition as it indicates that the senior teachers seem to acknowledge that the chosen ones are young and energetic as compared to them. Similarly, 1701 shared that, "to be honest, among the students, I feel that yes, there might have been some change because of the change in the strength of teaching strategies, students may have developed different views about the teaching strategies that I have incorporated, but among the teachers, among their friends, among their colleagues, I feel that it's nothing".

In another extended level, 1501 said, "we are well recognized by school administration and when we talk about this CL4STEM project, they look upon us as resourceful persons. Other teachers were directed to seek our expertise if they have doubts related to STEM subjects". Interestingly, one of the participants, 1301, had a conflicting point to share: “No one appreciates us. A few teachers asked why did you join? You have extra time. They are thinking that we are searching for extra work by joining this CL4STEM”.

In summary, the quantitative data showed a generally neutral perception among teachers regarding the impact of CL4STEM on their image in terms of prestige, profile, and status symbol, although a small number of teachers had a positive perception. The qualitative data revealed that participants did not develop a special status or recognition in their schools, but they recognized subtle forms of recognition and acknowledgement at various levels.

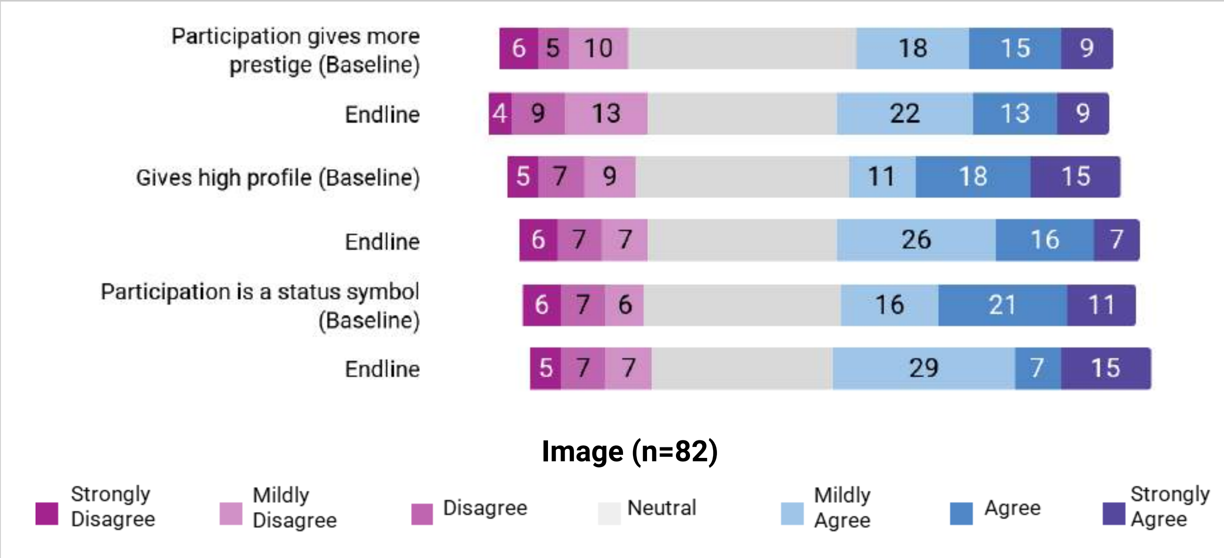


Figure 4.3.4 The Response of Participants on Image

4.3.5 Ease of Use

Ease of use refers to the ease with which CL4STEM practices can be implemented in the classroom with manageable physical and mental effort from the teachers. This parameter consisted of four 7-point Likert questions, and the statements of these questions are as follows: “CL4STEM modules are clear and easy to understand”, “I believe it is easy to learn new approaches to teaching by participating in CL4STEM”, “It is easy to participate in CL4STEM” and “Learning to navigate the CL4STEM modules and community of practice is easy for me”.

The data showed that the overall majority of the teacher participants had a positive perception of the CL4STEM practices regarding ease of use (Figure 4.1.5). An average of 71% teachers responded with high ease of use of CL4STEM in the Baseline, whereas 77% teachers responded that CL4STEM demonstrated a high ease of use in the Endline. This suggests that the CL4STEM program is designed in a way that is accessible and user-friendly for teachers, which may help to promote its adoption and implementation in classrooms.

While the participants were very pleased with the ease of use to a certain extent, a few teachers in the physics group found some of the modules to be slightly difficult. For example, according to 1301, “When it comes to the last module, that is electromagnetism, I found it difficult to learn. Still frankly, I’m not that clear about the module. So many laws, rules. Maybe I'm not in touch with that topic, especially while teaching. I have been teaching class 8 till last year. Recently, I have started teaching Class 9. Maybe because of that I have forgotten the concept now. I faced difficulties while doing that module”. Similarly, 1303 said, “Work and energy was quite easy to understand, and the last unit, electromagnetism, was quite difficult because, although we have learnt in the college only, we were not teaching, since we are not teaching that we totally like and are not familiar with that topic. So, it was quite challenging". Some participants were of the view that time management with regard to the modules could have been done better. For instance, 1100 said, "Well, the module itself was very much easy. It was very user-friendly. Because of time, we were not able to give our 100%. Otherwise, if we were having a comfortable time we would have performed better". Likewise, 1104 also said that, "It was not easy to participate because of time and other things. Around the same time the MoESD also conducted training. The modules were not very easy nor hard, however, there should have been a combination of both face-to-face and online participation for the modules". In general, the majority of the participants found the design of the OER clear and easy to follow. For example, 1500 stated that, "For me the modules were easy and interesting. The OERs and ICT added extra flavor to the modules" . Similarly, 1701 remarked, "It was easy to participate in, as well as an application based on what we are teaching in the class, we could easily correlate the actual learning from modules and incorporate it into our classrooms. So it was quite easy and manageable."

In summary, the data indicates that the majority of teacher participants has perceived the CL4STEM practices to be easy to use (+6% positive change), suggesting that the program is accessible and user-friendly, promoting its adoption and implementation in classrooms. Some participants expressed difficulties with specific modules, time management, and the need for a combination of face-to-face and online participation.

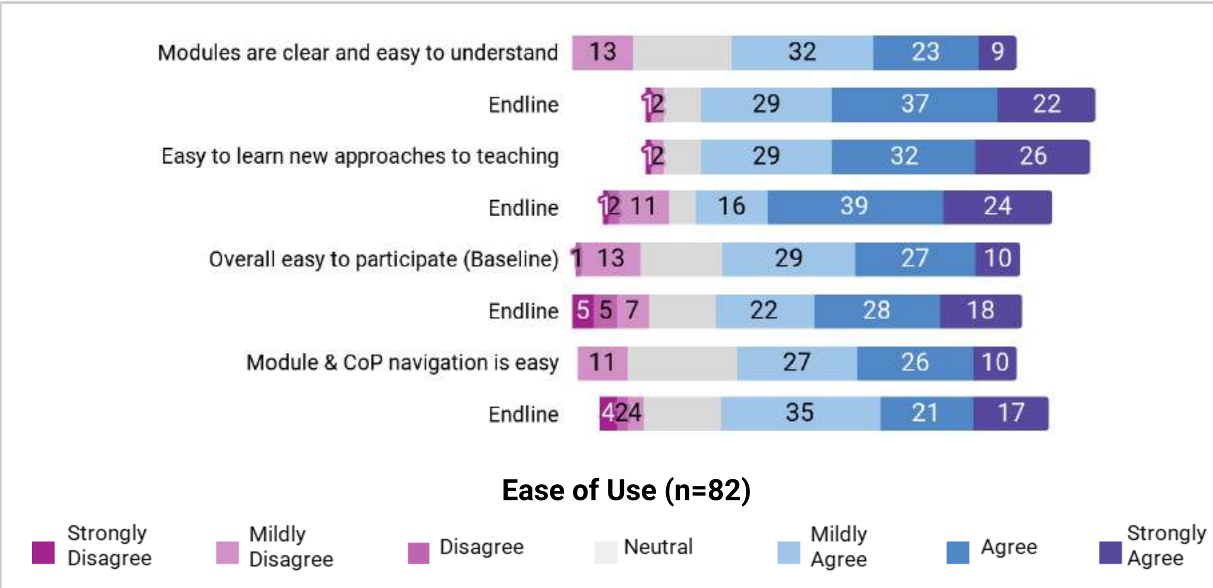


Figure 4.3.5 The Response of Participants on Ease of Use

4.3.6 Results Demonstrability

Results demonstrability in this study refers to the possible demonstration of the advantages and benefits of CL4STEM practices in schools by the participating teachers. This parameter contains the following statements to choose from: "I would have no difficulty telling others about the results of participating in CL4STEM"; "I believe I could communicate to others the consequences of participating in CL4STEM"; "The results of participating in CL4STEM are clear to me" and "I would have difficulty explaining why participating in CL4STEM may or may not be beneficial".

The perception data showed that the majority of the participating teachers perceived positively in terms of their ability to communicate the advantages and benefits of CL4STEM practices to other teacher colleagues in their schools. The exception was the statement: "I would have difficulty explaining why participating in CL4STEM may or may not be beneficial". The majority of the participating teachers responded to it in the negative, which in this case was the desirable choice. Figure 4.1.6 shows that there is a total of +10% growth from Baseline to Endline in the percentage of teachers who would be able to communicate about CL4STEM.

Although all participants acknowledged that participation in a project like CL4STEM enables building their professional competence and agreed that if such an opportunity is availed of by other teachers, it will be very meaningful, they also cautioned against the challenges due to the teachers' workload, timing, resources, and accessibility. The participants were also able to provide suggestions and even offer precautionary insight with regard to scalability. For instance, 1124 said, "Although this project helps in our classroom teaching and learning process, looking at the workloads, digital competence and the syllabus coverage of our own curriculum, I think it will be a burden for the teachers to engage in such a project." Another participant, 1101, mentioned: "I think it would be better if other teachers also do this because it will help them in enhancing their teaching strategies and remain wiser and more knowledgeable. Teachers are already burdened with a heavy workload. If committing to CL4STEM modules doesn't clash with other workshops and school programs, then I think our teachers should engage in such learning". Yet another participant, 1301, felt that "All teachers should get such opportunities, especially science teachers. We are learning something better for ourselves and our students. But there are some teachers who will not participate, maybe due to time constraints, they neglect the thing or they may not be interested in joining". 1303 stated that, "Time management is a challenge. I think this type of professional development should be in the break time or when they have free time. It should be kind of flexible. So if they have this flexible mode, I think teachers will be happy to participate in that". 1502 is of the opinion that, "If the project is implemented nationwide, I think it would be challenging with the resources, access to the resources, and their workload". According to 1704, "If it is made available for every one of us, all the teachers in Bhutan, then I think they will also benefit from it. So I think it will help them. However, I think one challenge may be just time management, because every teacher should be engaged in their normal activities of the school, and maybe, because they may not get time to attend the module". 1103 suggested that, "So if you are going to provide the same module to the rest of the school, then I'll suggest it to the middle secondary school. If the modules are provided during the winter, it will be convenient for teachers to implement this during the academic sessions".

The perception data on the result demonstrability of CL4STEM practices among participating teachers indicated that teachers generally had a positive perception (+10% increase) of their ability to communicate the benefits of CL4STEM to their colleagues. However, they struggled when it came to explaining the underlying reasons behind these benefits. This suggests that while teachers feel confident in promoting the advantages and benefits, they may face challenges in articulating the rationale behind them. Therefore, addressing these challenges will be crucial in maximizing the impact of CL4STEM and promoting its adoption in schools.

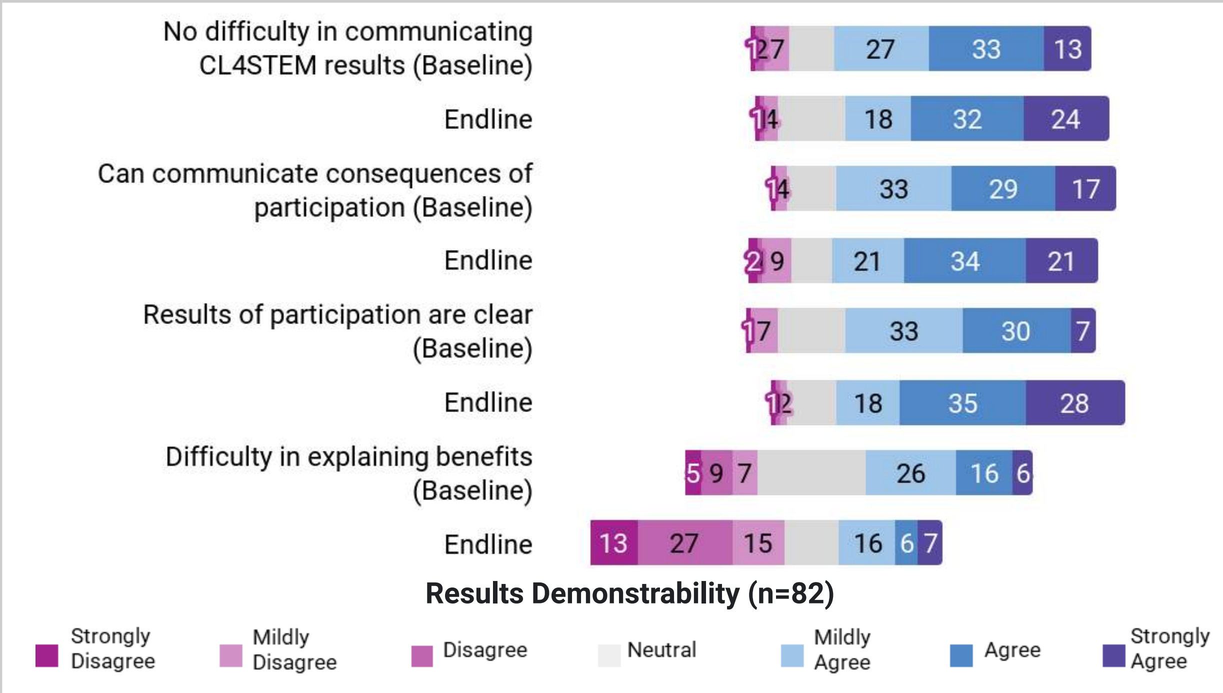


Figure 4.3.6 The Response of Participants on Results Demonstrability

4.3.7 Visibility

The figure 4.1.7 below shows the graphical representation of the observed trend between Baseline and Endline data on the visibility of the implementation of CL4STEM practices. The term visibility in this study refers to the possible implementation of CL4STEM practices by other fellow teachers in their classrooms. This parameter contained two statements: "In my school, one sees many teachers participating in CL4STEM" and "Participation in CL4STEM is not very visible in my school." One positively worded statement and one negatively worded statement ensured that the answers given by teachers were reliable. A desirable change of +6% was seen in both the statements.

The positive trend in the graphs (Figure 4.1.7) suggests that CL4STEM practices are visible and can be observed by other teachers in the school. This visibility can potentially lead to the adoption and implementation of these practices by more teachers, which can have a positive impact on the quality of teaching and learning in Bhutanese secondary schools.

The analysis of the interview data did not demonstrate any significant practices of innovation, either within themselves or amongst their other colleagues. However, some of the views shared by the participants were contextual and showed some level of visibility. For instance, 1100 said, "We are able to use some strategies in the classroom and during the class observation and all of us, the people participating in the CL4STEM seem to do better than others. In the school, we are always discussing with the members who are participating in CL4STEM, we are inviting each other to class, and we are trying to learn from each other. We are trying to share what we have learned from the modules". Likewise, 1300 stated, "I can see that it's visible. Around four to five science teachers from our school are participating in CL4STEM. I can see that all of them are taking their students into the lab and performing experiments". Another participant (1700) remarked: "We gather together and discuss our learning from the modules and then plan lessons together."

In another example, a participant, 1307, commented, "The effect has also influenced the practice of others, especially in our school. Most of the teachers, that is, the teachers that participate in CL4STEM, implement the things they have learned in that module. They also talk about that module with their other colleagues, sharing the concept and the strategies about that module with other colleagues who are not members of CL4STEM. It is also found that the other colleagues are also using some of the strategies." In addition to the science departments, 1502 mentioned that the CL4STEM practice has also spread to other departments in the school.

In summary, the quantitative analysis demonstrates a positive rise in the visibility of CL4STEM practices on average (+8%) among teachers in the partnering secondary schools. Although the qualitative interview data lacked significant instances, participants described contextual visibility through discussions, mutual learning, collaborative lesson planning, and the exchange of concepts and strategies with colleagues from various departments.

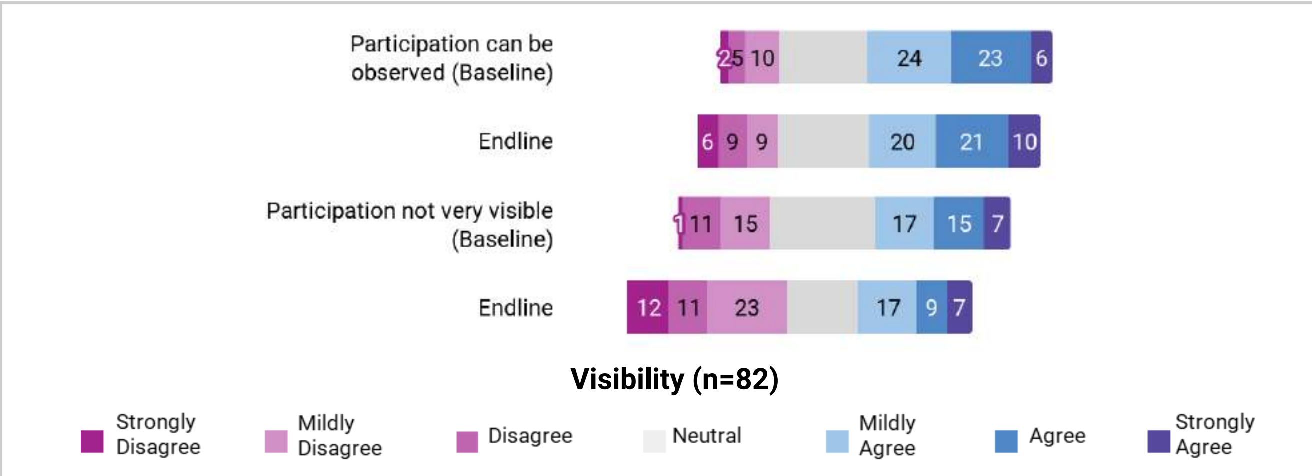


Figure 4.3.7 The Response of the Participants on Visibility

Social learning in CL4STEM refers to the acquisition of knowledge by the participants from interactions with each other, teacher educators, researchers and others. As mentioned in the methodology chapter, all teacher educators and teacher participants were members of online Telegram based groups (one each per subject). This was done to ensure that there was a space for participants to interact with each other as they went along with the modules. In all of these groups, participation ranged from mere observation to actively initiating conversations, sharing practice, and sharing and receiving feedback. The communities of practice (CoPs) served as a critical part of the design for CL4STEM, as they allowed the teachers to have a safe space to seek support, share progress, and celebrate milestones in the project authentically, while also building relationships with their peers and teacher educators for their particular subjects. It was essential for these communities to be online, so that the challenge of not being in the same physical space could be overcome.

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

1. core: those participants who drive the CoP, and are the central actors. This is usually a small group of people.
2. active participants: those participants who are involved actively in the CoP, but are not the core
3. occasional: those participants who interacted in the CoP only when there was something special or specific to contribute, but not all the time
4. peripheral: those participants who are interested in the CoP, but do not participate actively in the CoP

To understand how the nature of participation evolved over time, social network analysis (SNA) was used. The researchers looked at the interaction of all participants within each subject-specific CoP using SNA as well as qualitative thematic analysis. In the rest of this section, first, the SNA parameters were described, and then the qualitative analysis was presented.

Table 5.1 shows the development of the Telegram-based CoPs during the implementation of CL4STEM modules in Bhutan. Three parameters of SNA have been used to showcase the evolution – density, average degree, and maximum degree. Density refers to the number of interactions that happen between the participants of a group at a given point in time. The maximum possible density is 1, indicating that every node in the network is connected to every other node directly. The average degree is the average number of interactions each node is participating in. The maximum degree is the maximum number of connections a node has, or in this case, the participant who has interacted with the most number of people has the maximum degree.

Table 5.1 Evolution of CL4STEM Subject-Specific CoPs

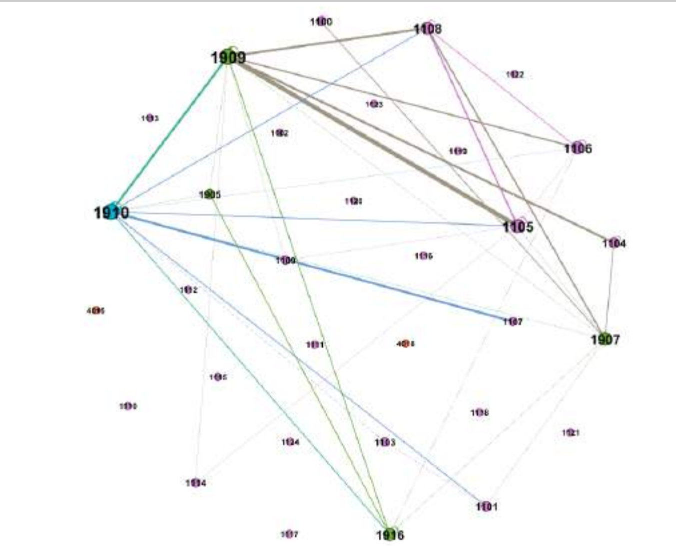
Parameter	Mathematics			Biology			Chemistry			Physics		
	BL	**EL**	**Δ**	**BL**	**EL**	**Δ**	**BL**	**EL**	**Δ**	**BL**	**EL**	**Δ**
Density	0.08	0.20	0.12	0.13	0.32	0.19	0.05	0.23	0.18	0.08	0.31	0.23
Average Degree	2.6	6.3	3.7	3.15	8.08	4.93	1.3	6.07	4.77	1.83	7.08	5.25
Maximum degree	12 (TE)	20 (TE)	8	21 (TE)	25 (TE)	4	12 (TE)	25 (TE)	13	13 (TE)	20 (TE)	7

**BL - Baseline, EL - Endline, Δ - Change*

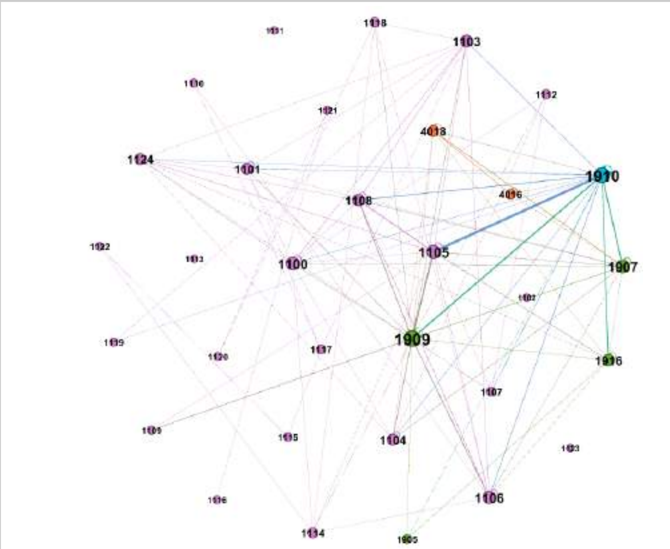
At Baseline, all four subject CoPs had a very low density, ranging between 0.05- 0.13. The Baseline time stamp was taken in June 2022, at the end of the common module and beginning of subject modules, meaning that the teachers were oriented to and familiar with CL4STEM but had not started subject-specific professional development. The endline time stamp is from December 2022 when all the three modules had been closed and the teacher participation was complete. The data from December 2022 includes all interactions from the beginning of the intervention to the end. The density at the end of the intervention period ranged from 0.20 to 0.32. As can be seen from the table above, the density increased somewhat in all four subjects, implying that the number of interactions in each CoP increased over time. This is not surprising, given that not only were the teacher educators explicitly using the CoPs to communicate with teachers but also encouraging teachers to participate in the same. The biggest gain in density is in the physics CoP, where the teacher educators were explicitly following up with individual teachers. More details about the nature of participation are explained in later paragraphs.

At Baseline, the average degree ranged from 1.3 in Chemistry to 3.15 in biology, indicating that the participants in chemistry CoP had interacted with 1 other person on average at the start of the subject modules, whereas participants in biology CoP had interacted with more than 3 people on average at the same time. As time progressed, the average number of interactions between the participants increased across all four subjects, as seen in the table above. The maximum growth in average degree was in physics (5.25), whereas the highest average degree at Endline was reported by biology (8.08). At Endline, each participant in physics was interacting with around 7 other participants, whereas in biology, each participant was interacting with 8 other participants. In mathematics and chemistry, participants interacted on average with 6 other participants.

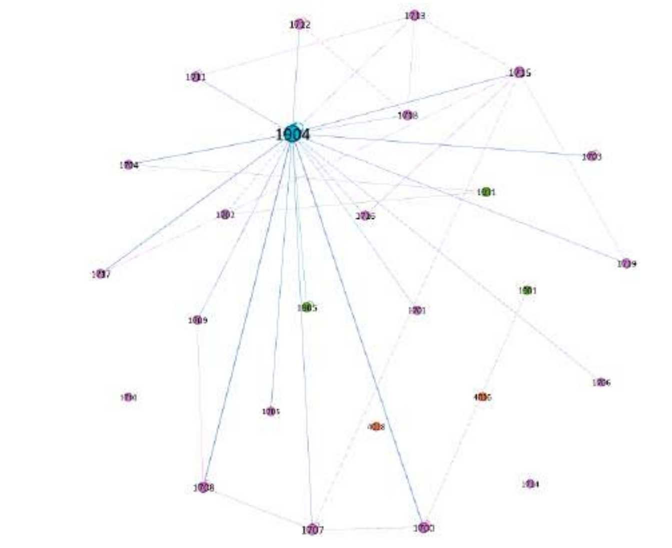
The maximum degree represents the participants who have interacted with the most other participants, meaning that they have the most relationships in the current participant group. The greater the change in maximum degree, the greater the indication that participants have had interactions with more people in Endline as compared to Baseline. It was expected that teacher educators would have high degrees across all four subjects because they were leading the implementation of modules, and hence they would have interacted with the maximum number of participants. This is true in the case of Bhutan, where all participants with the maximum degrees in Baseline and Endline are teacher educators. Images of each subject's network evolution are shared below.



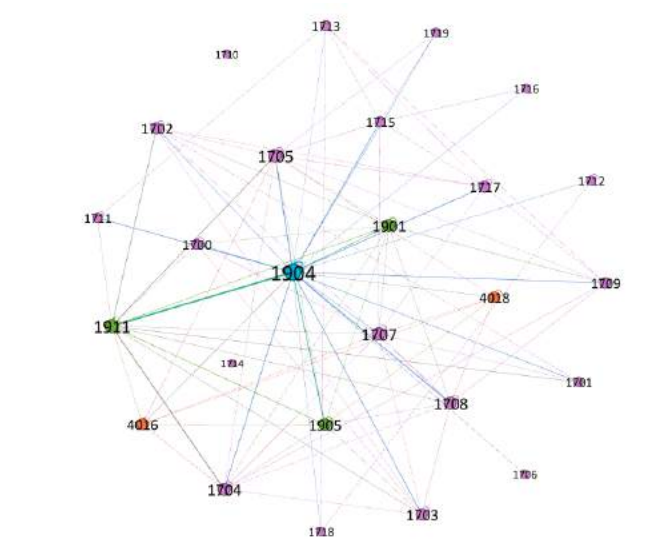
Mathematics Baseline (June 2022)/ Density=0.083



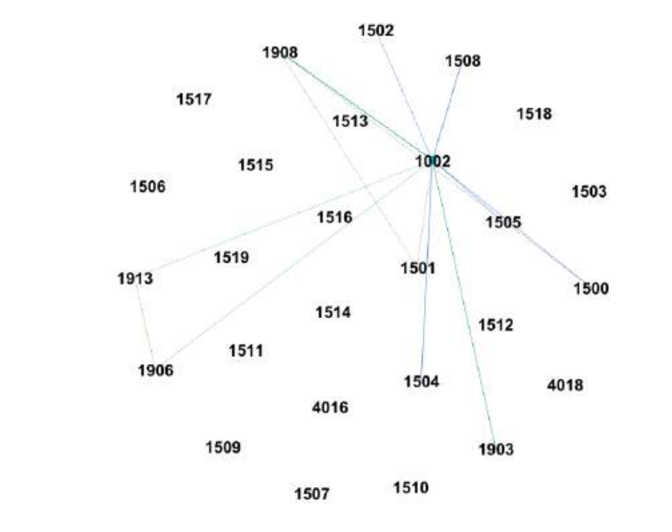
Mathematics Endline (December 2022)/ Density= 0.204



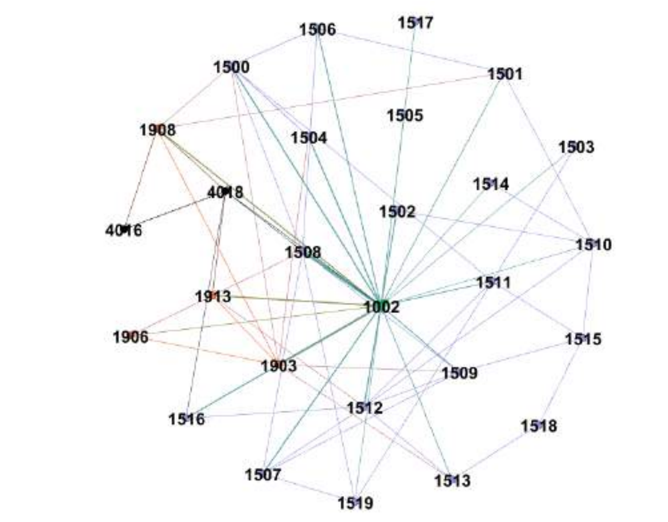
Biology (Baseline= June 2022)/ Density= 0.126



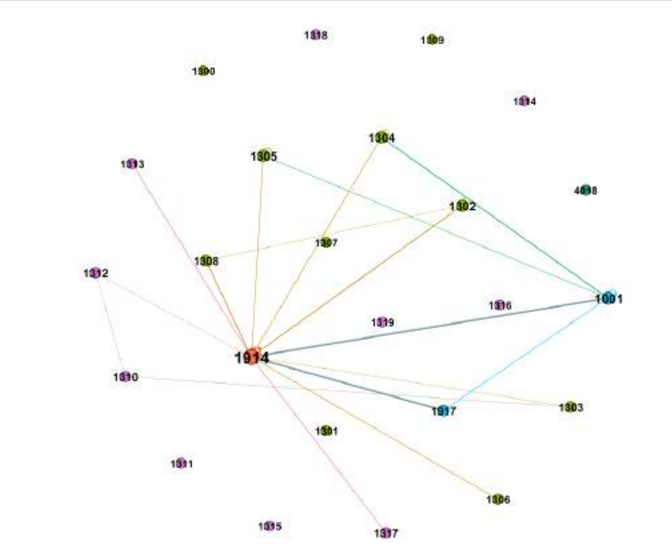
Biology (December 2022)/ Density= 0.323



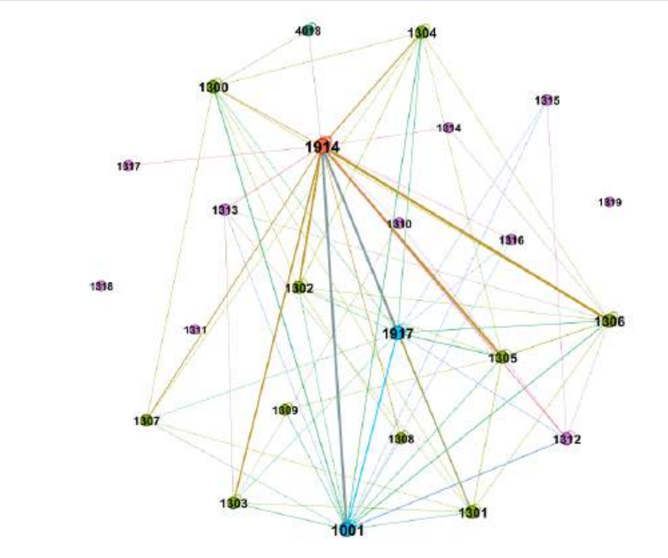
Chemistry Baseline (June 2022)/ Density= 0.051



Chemistry Endline (December 2022)/ Density= 0.234



Physics Baseline (June 2022)/ Density= 0.080



Physics Endline (December 2022)/ Density= 0.308

Figure 5.1: Subject-wise Network Evolution

In Bhutan CoPs, the teacher educators were the core participants across all CoPs who kept the CoP going. Other participants were mostly occasional participants who interacted with others only when there was a specific reason. This is exemplified in the qualitative analysis of the CoP data presented next. Contextually, in Bhutanese culture, asking for help openly, and sharing practice in public forums is a new concept. Thus, while there were examples of teachers reaching out to teacher educators independently on Telegram, teacher participation in the CoPs was limited. Three main types of interactions were seen across all subject CoPs in Bhutan:

1. Teacher educators supporting teachers with technical issues

The most common theme across all Bhutan CoPs was teacher educators supporting teachers to access the CoPs. Most teacher educators shared multiple reminders, either directly tagging the teachers, or by sharing explicit guidance on how to access the modules. Teachers also used the CoPs to discuss the technical issues that they faced while trying to access the modules. The images shared below show some examples of teacher educators supporting teachers with the navigation of technical issues.

Figure 5.2: TE Sending Reminders to Encourage Participation

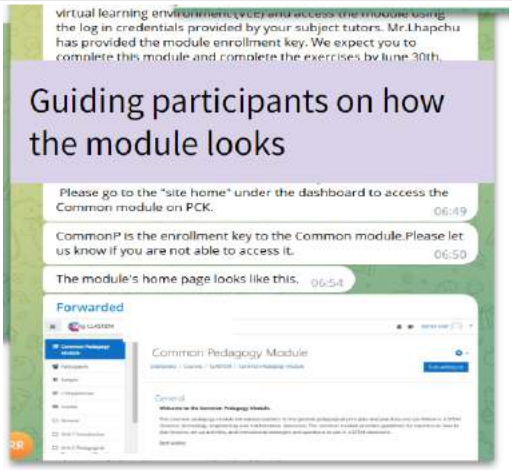


Figure 5.3: TEs Explaining How to Navigate Modules

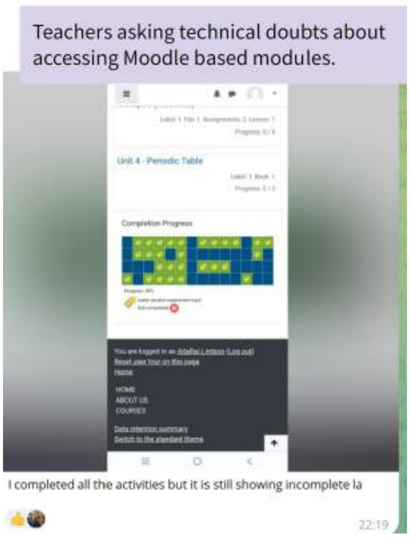


Figure 5.4: Teacher Queries onTechnical Aspects of Moodle

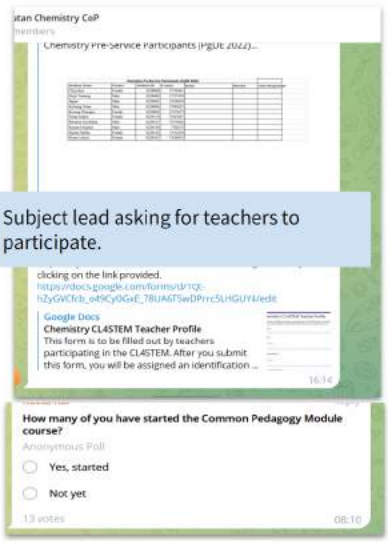


Figure 5.5: TEs Encouraging Teachers to Participate

2. Teachers sharing resources and practice

In Bhutan, teachers' participation in the CoPs was mostly peripheral and occasional, which meant that they would participate in conversation rarely. A mathematics teacher shared,

> "Usually in the telegram groups, I don't send messages, I just go through the messages that other members have sent. I do sometimes ask my friends here for help solving some questions and I also ask them about their progress in the CL4STEM modules. If I face a problem in completing any activity online, I ask them for help by asking them how it should be done." (1101)

The above sentiment was echoed by other teacher participants from physics and chemistry as well. Even though they did not actively participate, they did read the messages and learnt from others' mistakes. A participant shared: "This telegram was really a good one where we learnt from others' mistakes, which was also a part of our mistake" (1304). A physics teacher said, "We used to post that question and some members from that group usually used to post solutions. In that way, it is effective as well as beneficial" (1307).

While teacher participation in the CoPs remained mostly peripheral and occasional, there were some examples of teachers who were active in participation. These teachers shared photos of their practice, examples of resources that other teachers could use, the setups of experiments, and evidence of students' participation in lesson plans. In the figures below, examples of teacher practice, and resources shared by the teachers are presented. The figure shows photos of students using physical and virtual experiments to understand Faraday's laws of electromagnetic induction. The teacher is publicly applauded by the teacher educator in the CoP for this classroom demonstration.

Figure 5.6 CL4STEM Lesson Plan Implementation Pictures

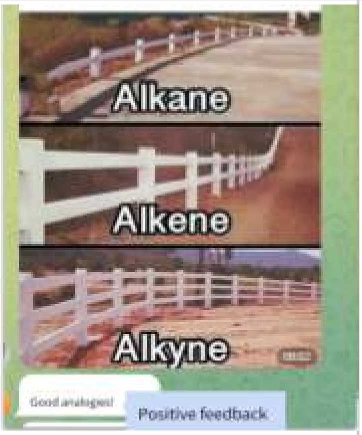


Figure 5.7 Example of Teacher Shared Resource in CoP

Figure 5.8 Teacher Educator Supporting a Teacher's Lesson Plan: Students Learning Faraday's Laws Using Virtual and Physical Resources

3. Teacher educators supporting teachers' practice

Teacher educators would encourage teachers to share their practice. They also shared resources with the participating teachers to be able to better implement the lesson plans that they prepared as participants in CL4STEM. The teachers shared that they benefited from the resources that teacher educators shared in the groups, as seen in the following quote: "[I] Watched videos posted in the Telegram group and used in teaching" (1124). Another teacher shared: "Especially CL4STEM physics group and other groups like mathematics and science groups and others where we can access…We can get any help like on a question paper and ask questions whenever we have doubts. We can post and get help from experts” (1301).

Examples from the physics and chemistry CoPs are shown below. The figure shows the setup shared by the teacher educator for teachers to demonstrate the concept of *d*ipole moment to the students. It also shows the resources sent by the teacher educator to the schools so that the teachers could conduct the experiment on Faraday’s laws of electromagnetic induction.

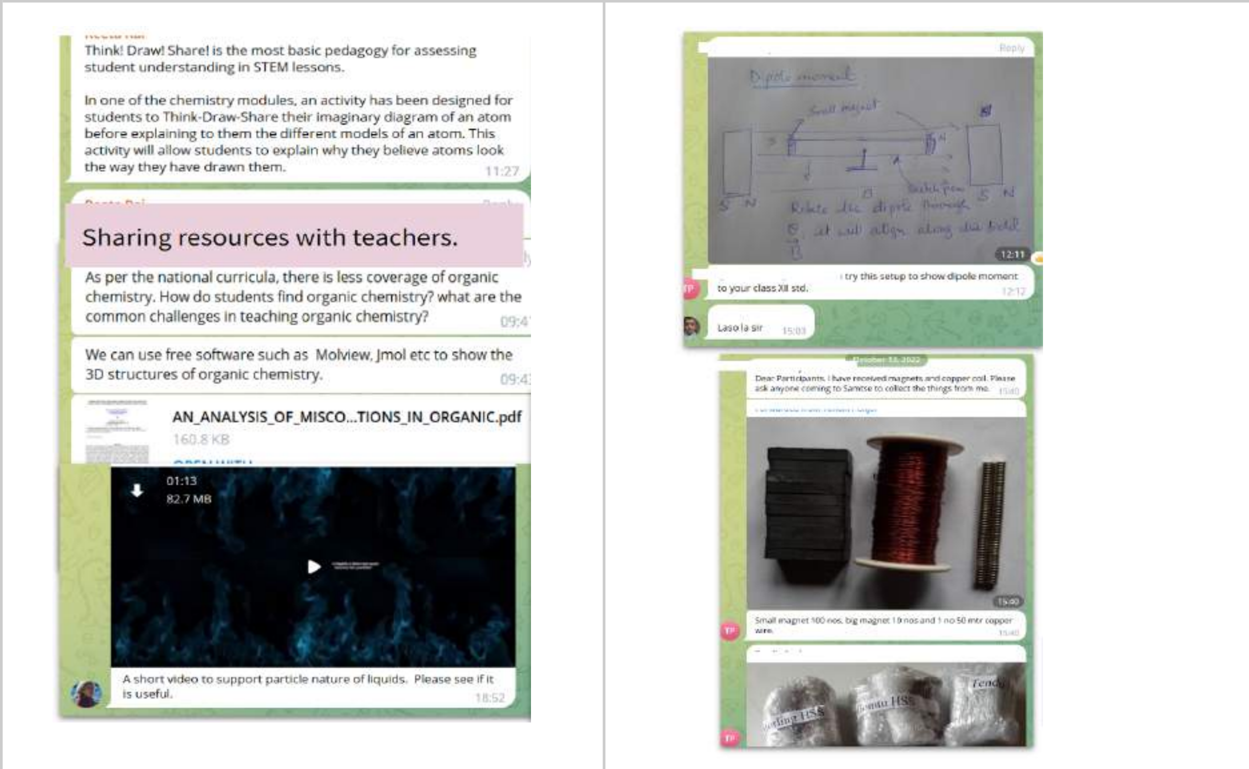


Figure 5.9 Teacher Educators Sharing Resources with the Teachers

Though participants were not able to provide specific examples and were also not in a position to highlight significant impacts, the sharing to some extent indicated that the forum had some positive implications for their personal and professional development. Overall, with regard to social learning in Bhutan, most teachers were occasional participants, with the teacher educators being the core who anchored the CoPs. Both SNA and qualitative analysis supported these findings. Another teacher summed up the role of CoPs in their learning process as follows: “By joining the community of practice group, I got to learn, share and exchange knowledge on topics related to chemistry. Whenever I face difficulty or have doubts, I try to seek help from the mentor and get help through the online platform without any hesitations” (1501).

Unit 6: Conclusion

The CL4STEM project was a Global South-South collaboration between teacher education institutions in Nigeria, Tanzania, and Bhutan to address the global undersupply of quality secondary school STEM teachers. The project began with the capacity building of STEM teacher educators by the teacher educators of TISS, India in developing and contextualizing subject-specific OER for strengthening the capacity of secondary STEM teachers in SMK, PCK, and GPK. The project was implemented in seven secondary schools (5 higher secondary and 2 middle secondary) and 82 (40 inservice and 42 preservice) teacher participants completed the required four OERs, which included the common pedagogy and three subject-specific modules. The impact of OERs on the participants' knowledge, attitudes, and practices of Higher Order Thinking for Equity and Inclusion was assessed using qualitative and quantitative methods. The main findings or changes are summarized below according to the themes. For the survey, all the 82 teacher participants were considered, whereas only the focus group participants were considered for the interview. Only selected participants were, however, considered in the observation. Therefore, while there is good complementarity between the results from the three data sources, it is necessary to understand that complete triangulation should not be expected.

The inception and implementation of this project has derived inspiration from the following change theories. One such is the evidence regarding the global under-supply of STEM teachers and inequitable distribution of teacher qualifications across socio-economic status at the classroom and school level (Qin & Bowen, 2019)[32]. There is also potential for the scalability of robust ICT-based TPD models to make a difference among disadvantaged teachers (Kennedy & Laurillar, 2019)[33]. Participation in professional learning forums and the exchange of meaningful feedback and support increases teacher motivation and makes a difference to their classroom practice (UNESCO 2016)[34]. The CL4STEM theory of change focused on building the capacities of teachers, by using OERs developed by their own local teacher educators. These teacher educators also underwent professional development as part of the CL4STEM project. To support the theory of change, a framework for mapping knowledge, attitudes and practice was developed. It focused on the various essential aspects of teacher practice - SMK, PCK and GPK. This framework was the guiding document for all knowledge, attitudes, and practices data analysis.

In terms of KAP, which consisted of ten themes, the findings indicate mixed results across various aspects of teacher knowledge and practice. While some positive impacts were observed, such as improved understanding of scientific and mathematical theories, competency in instructional strategies, and awareness of equity and inclusion, other areas showed limited change. Further improvements can be made in knowledge enhancement, assessment practices, and context for learning. The findings can be summarized as follows:

1. **Knowledge of Science/Mathematics:** The survey did not show significant trends of knowledge enhancement for the subject matter, but the interviews indicated some progression over time. The teachers were able to articulate concepts from their discipline. From the observation data, it

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[32] Qin, L., & Bowen, D. H. (2019). The distributions of teacher qualification: A cross-national study. *International Journal of Educational Development*, *70*, 102084.https://doi.org/10.1016/j.ijedudev.2019.102084

[33] Kennedy, E., & Laurillard, D. (2019). The potential of MOOCs for large-scale teacher professional development in contexts of mass displacement. *London Review of Education*, *17*(2), 141-158.

[34] UNESCO (2016). Global education monitoring report: Place: Inclusive and Sustainable Cities. https://unesdoc.unesco.org/ark:/48223/pf0000246230

has been revealed that the teachers' were able to not only share connections between topics but also demonstrate an understanding of subject matter on the topic that they taught.

2. **Nature of Science/Mathematics:** Most participants disagreed with the statement that science/math concepts are accepted without explanation, indicating a good understanding of evidence and reasoning. Chemistry participants initially had the lowest understanding, but it improved significantly with the modules. Preservice participants had an overall low understanding of the concepts.

3. **Curriculum Knowledge:** Interviews and observations revealed that teachers had adequate awareness of the subjects and their real-life applications. The teachers showed a positive shift in their understanding of different topics taught in other grades. There was a strong awareness of the importance of science and mathematics in daily life and for national development.

4. **Instructional Strategies:** The three data sources clearly exhibited the teacher's competency and ability to use a range of instructional strategies to deliver meaningful learning experiences for the students. The survey results showed that overall, there was a positive impact on the teacher's knowledge of instructional strategies, as well as on the teacher attitudes towards student-centered instructional strategies. These findings are supported by the classroom observations and the interviews. The observation result clearly provided evidence of the teachers' incorporation of instructional strategies in their classrooms at maximum. Likewise, the interview results supported the optimization of instructional strategies in their classrooms and a positive progression from the Baseline to Endline. Through the interview results, it was evident that the use of technology was very prominent.

5. **Misconceptions and Conceptual Difficulty:** Teachers have increasingly become proficient in identifying and addressing students' misconceptions, as the percentage of teachers correctly answering questions on identifying misconceptions increased across most subjects in the Endline data. The study also discovered that student misconceptions can be attributed to both student and teacher factors.

6. **Representation of Content:** The survey results illustrated the teachers' use of teaching and learning materials to support their teaching to the optimum. There has been no variation in the representation of content among the genders, however, specific resources varied between subjects which is obvious due to the nature of the content. To a certain extent the survey result also indicated progression in the representation of content from Baseline to Endline. The observation analysis showcased the rich usage of a variety of teaching and learning materials illustrating the representation of context. Additionally, the interview analysis revealed progressive change on the representation of content from the Baseline to Endline in general.

7. **Context for Learning:** The survey results did not provide much information on the progression of the context for learning. The observation data provided scenarios of the teachers' understanding and the use of contextually available resources. Likewise, the interview analysis has demonstrated that there is a general understanding and acceptance that to promote science and mathematics learning, appropriate space and resources are critical. The analysis revealed that there are no significant or obvious differences from Baseline to Endline, nor obvious variations between gender or subjects.

8. **Equity and Inclusion:** The teachers were cognizant of the different learning categories, such as high/average/low achiever, fast/slow learner, and students with good/poor English communication skills. Therefore, a general consideration regarding the inclusion of learners from diverse backgrounds and those with different learning needs is visible in the thoughts and practices of the teachers. A few teachers have even indicated that they were mindful of the student's socio-economic status and religious background while teaching or organizing activities. During Baseline interviews, the teachers were only able to comment on the existence of a diversity of learners in the classroom. During the Endline interviews, however, teachers were able to elaborate on strategies that they either use in their teaching and learning process or were able to make recommendations which could be useful in the field of education to ensure equity and inclusion. Overall, the findings suggest that there have been positive shifts in the teachers' perceptions and beliefs regarding inclusion and equity. The findings also call for further research and interventions to address persistent beliefs about inborn math abilities.

9. **Classroom Management:** There was a minor positive change in the teachers' preference of mixed-ability student grouping. Group work and collaborative learning were common classroom management strategies. Some teachers used ICT to enhance student engagement.

10. **Assessment Practices:** There was no significant change in assessment preferences from Baseline to Endline. More teachers opted for standardized tests in the Endline. Formative and summative assessment strategies were used with an increased awareness of assessment language and methods.

The following are specific conclusions drawn from the individual themes:

Table 6.1: Overview of Perceived Changes in Teachers' Knowledge, Attitudes and Practices

	Themes	Change	Nature of change
1	Knowledge of Subject Matter	No	No observable change
2	Nature of Science /Mathematics	No	No observable change
3	Instructional Strategies	Yes	Evidence for more group work, with the use of ICT in teaching and more awareness and reference to equitable practices using UDL
4	Students' Misconceptions & Conceptual Difficulties	Yes	The CL4STEM modules appear to have aided teachers in identifying and addressing the misconceptions in science and mathematics.
5	Representation of the Content	Yes	No singular optimal method for content representation, as it depends on the subject matter, students' needs, and available resources. However, teachers employing diverse representation methods such as text, images, videos, simulations and other media were found more likely to aid student learning effectively.
6	Context for Learning	No	No observable change
7	Curriculum knowledge	Yes	A good understanding of the curriculum was observed.
8	Equity and Inclusion	Yes	Positive shifts in teachers' perceptions and beliefs regarding inclusion and equity

9	Classroom Management	Yes	Positive change in teachers' perception of the preference of mixed ability student grouping and ICT
10	Assessment	No	No observable change

The innovation diffusion research examined seven parameters or themes related to the implementation of CL4STEM practices and their impact on teachers in Bhutanese secondary level schools. The evaluation of teacher perceptions of CL4STEM using Moore and Benbasat's framework revealed several important findings as shown in the table below.

***Table 6.2:* Overview of Changes in Teachers' Perceptions on Participation in CL4STEM**

	Themes	Endline	Nature of Change
1	Voluntariness	Marginally negative	The majority of teachers did not feel compelled to participate in the CL4STEM project by their school authorities, although some participants perceived their participation was mandatory.
2	Relative Advantage	Positive	Teachers' perceptions towards relative advantage of CL4STEM were high in Baseline, and they remained high at the end of the intervention.
3	Compatibility	Marginally Positive	Similar to relative advantage, teachers' perceptions towards compatibility of CL4STEM stayed at similar levels in the Endline.
4	Image	Neutral	There is no change.
5	Ease of Use	Marginally Positive	More teachers reported that CL4STEM resources were easy to use at the Endline as compared to Baseline
6	Results Demonstrability	Marginally Positive	More teachers were able to communicate the CL4STEM results, results of participation in CL4STEM in Endline as compared to Baseline.
7	Visibility	Neutral	There is no change.

With regard to Levels of Use (LoU), it was evident from both survey and interview analysis that the majority of the participants were comfortable with the CL4STEM online module and Telegram groups (CoPs) leading to effective implementation of strategies in their classes. Collaboration among teachers to apply the strategies learnt from the modules was also highlighted. There was also a mention of an attempt to plan and deliver lessons to ensure meeting the needs of diverse learners. Some participants were still learning how to navigate the CL4STEM modules and CoPs aiming to improve their usage of the CL4STEM resources.

In the survey analysis, there seems to be an even spread of the various concerns of SoC such as "Evaluating how CL4STEM teaching strategies impact/help in student learning", "Exploring ways of collaboration with other teachers and educators to help impact student learning using CL4STEM teaching strategies", "Exploring ways of improving CL4STEM teaching strategies through further refinement of the modules and CoP participation and/or alternative ways of achieving better results" and "Concerned about the demands of CL4STEM vis-a-vis existing workload and how it fits in the existing working conditions". Though the choices are very similar in the interview, there seems to be some level of variation in the popularity. In the interview, evaluating the impact in student learning was a popular choice, followed by collaboration with other teachers and educators. Likewise, the concerns about workload and improving the modules were also shared by the participants.

It was evident that teacher educators explicitly used the CoPs to communicate with teachers and also encouraged teachers to participate in the same. There has been some level of variation in the intensity of communication between subjects and the nature and content of communication. Nevertheless, in general, the participants acknowledged the CoP being a useful medium for them as one of the means to professional development.

The implications of teachers' participation have been exhibited across the themes in the Knowledge and Attitude interview as well in the Innovation Diffusion Survey Interview. The following are added statements from the participants on the effect of their professional development after participating in the CL4STEM project.

> "What I have liked the most, I've learned some strategies from it. I've learned to use ICT in much more effective ways. And I have also learned many things from the three modules. Especially through topics like misconceptions of students. I have learned a lot on the team. Both content and strategies were taken care of. So, I have learned a lot from the model. So, I enjoyed that." (1100)

> "Because of this CL4STEM contributes to quality and effectiveness in teaching. So, now I know more about the students and then I focus more on the students rather than simply teaching. My ICT use and assessment practices have also improved." (1103)

> "I really had fun learning many things, especially the topic which I learned when I was student. But right now, in the teaching field I have not been in touch. It was a kind of revision for me. And the new things I have learned the most are about strategies that are given to us while teaching and learning. I really like videos…how to go about some activities, how we can start the lesson.." (1301)

In conclusion, the findings suggest that CL4STEM practices have been well-received by teachers, with positive perceptions regarding their relative advantage, compatibility, and ease of use. While participation may not have significantly impacted the teachers' image, the project has provided valuable professional development opportunities. These findings hold significance for the effective implementation and long-term viability of CL4STEM practices in middle and secondary-level schools in Bhutan, emphasizing the need for continued support and integration into STEM education.