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

CL4STEM Nigeria Endline Report

Bhutan | Nigeria | Tanzania | India

Connected Learning for STEM (CL4STEM)

The Connected Learning for Science, Technology, Engineering, and Mathematics (CL4STEM) project aims to pilot Connected Learning Initiative (CLIx, https://clix.tiss.edu) TPD innovation and research its effectiveness and potential scaling. It is designed to build capacities of secondary school teachers in Science and Maths to help foster higher-order thinking with inclusion and equity in their classrooms. The CL4STEM pilot engages teachers in curated Open Educational Resources-based modules in Science and Maths and encourages participation in online Communities of Practice. 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 generated from this project would be disseminated to stakeholders in the federal/provincial ministries of education and relevant regulatory and professional bodies 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.

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Authors: Emaya Kannamma, Yaki Akawo Angwal, Tanushree Rawat & Mustapha Tajordeen Mohammed

Report is available for download at https://www.connectedlearningforstem.org/
Any questions, suggestions or queries may be sent to us at : info@connectedlearningforstem.org

Team

Governance team

Ibrahim Babangida Badamasi University, Lapai (IBBUL), Nigeria
Nuhu George Obaje, IBBUL, *Principal Investigator*
Abdullahi Abubakar Kawu, *Nodal Officer*

Open University of Tanzania (OUT), Tanzania
Edephonce Nfuka, *Lead Investigator, Tanzania*

Samtse College of Education (SCE), Bhutan
Rinchen Dorji, *Lead Investigator, Bhutan*

Tata Institute of Social Sciences (TISS), India
Padma Sarangapani, *Principal Technical Consultant*
Mythili Ramchand, *Lead Technical Consultant, Knowledge Transfer*
Vikas Maniar, *Lead Technical Consultant, Innovation Diffusion Study*

Steve Nwokeocha, *Advisor*

Project team, IBBUL, Nigeria

Research: Mustapha Tajordeen Mohammed (Lead), Aliyu Zakariyya, Aminu Aliyu, James Omonu
Research fellows: Emaya Kannamma, Yaki Akawo Angwal
Adaptation: Abdulwaheed Adelabu Salihu (Lead), Naomi Dadi-mamud, Ibrahim Abdullahi
*Dissemination:*Mohammed Aliyu Paiko (Lead) Dickson Musa Achimugu, Hussaini Majiya

Teacher Educators:
IBBUL: Abdullahi Abubakar, Aliyu Ibrahim, Aliyu Alhaji Zakariyya, Ibrahim Abdullahi, James Omonu, Jibrin Yabagi, Naomi Dadi-Mamud, Samira Muhammad Abdullahi, Yusuf Abdullahi
Bayero University, Kano: Garba Shuaibu, Mutawakkilu Muhammad, Mufida Bello Hussaini
Kaduna State University: Aliyu Umar Abubakar, Fatima Shehu Kabir, Halliru Ibrahim, Samira Dahiru Hunkuyi, Sarah Victor Usman
Secretariat Staff: Aisha Isa, Musa Salihu Ewugi, Steven Ibrahim
Financial Officers: Alhaji Abdul Garba, Alhaji Alhassan Aliyu, Alhaji Muhammad Daniya
Technical Support Team: Said Abdulsalam, Abdulnazif Abdulqadir, Tassalla Ibrahim, Hauwa Ibrahim

Knowledge Partner Team, CETE, TISS, India

Research Coordinator: Tanushree Rawat
Mathematics: Ruchi Kumar (Lead), Jeenath Rahaman (Until Apr 2023), Anirudh Agarwal (Until Apr 2021), Arushi Bansal (Until Dec 2021),
Physics and Chemistry: Shamin Padalkar (Lead), Deepika Bansal (Until Mar 2022), Geetha M (Until Mar 2022)
Biology: Rafikh Shaikh (Lead), Sarika Bansode (Until Feb 2022)
Design Thinking: Bindu Thirumalai, Jennifer Thomas
Universal Design for Learning: Apoorva Panshikar, Sujata Bhan, *SNDT, Mumbai*
Knowledge Transfer Coordinator: Emaya Kannamma
Technical support: Sadaqat Faqih Mulla, Satej Shinde
Administrative Support: Gayathri Moily, Vijay Jathore, Tushar Vaity, Kailash Panvalkar, Rohan Kamble, Shruti Patil, Swati Kamble, Vijay Arsud

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iii. Abbreviations

B.Ed.	Bachelor of Education
BL	Baseline
BSc.Ed.	Bachelor of Science Education
CAST	Center for Applied Special Technology
CBAM	Concerns Based Adoption Model
CETE	Centre of Excellence in Teacher Education
CL4STEM	Connected Learning for STEM
CLIx	Connected Learning Initiative
CoP	Community of Practice
EL	Endline
FG	Federal Government
FGN	Federal Government of Nigeria
FMOE	Federal Ministry of Education
GB	GigaByte
GPK	General Pedagogical Knowledge
HOTIE	Higher Order Thinking with Inclusion and Equity
ICT	Information and Communications Technology
IDS	Innovation Diffusion Study
KAP	Knowledge, Attitudes and Practice
M.Ed.	Master of Education
MAN	Mathematical Association of Nigeria
MSc.Ed.	Master of Science Education
NCE	Nigerian Certificate of Education
NERDC	Nigerian Educational Research and Development Council
NUT	National Union of Teachers
OER	Open Educational Resources
PCK	Pedagogical Content Knowledge
PGD	Post Graduate Diploma
SMK	Subject Matter Knowledge
SNA	Social Network Analysis
STAN	Science Teachers Association of Nigeria
STEM	Science, Technology, Engineering and Maths
TE	Teacher Educator
TISS	Tata Institute of Social Sciences
TPD	Teacher Professional Development
TV	Television
UDL	Universal Design for Learning
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPS	Uninterruptible Power Supply
VP	Vice Principal

1. Introduction

The Connected Learning for STEM (CL4STEM) seeks to strengthen the capacities of middle and secondary school science and mathematics teachers in Bhutan, Nigeria and Tanzania to foster inclusive higher-order learning in their classrooms. It aims to pilot the Connected Learning Initiative (CLIx)[1] innovation, developed and scaled in India, in the new contexts of Bhutan, Nigeria, and Tanzania, through a South-South collaboration.

Successive Nigerian governments at national and state levels have recognized the significance of science and technology in the overall national development and have therefore developed policies and programs in this regard[2]. The provisions of the National Policy on Education[3] support the scientific development and the utilization of science and technology-based programs at all levels of the Nigerian education system. In Nigeria, STEM is taught in every school from the basic level to the university. The quality and standard of the national STM curricula being used in schools are locally relevant, globally accepted, and among the best in the world[4]. However, the teaching of STM in Nigerian schools has been generally described as ineffective and the students' achievements in terms of knowledge and skills are yet to meet expectations[5,6]. The current teaching competencies of science teachers and the manner in which science is taught are identified as part of the problems[7,8].

The methods and strategies employed by Science Technology Engineering Mathematics (STEM) teachers in most of the Nigerian schools have hitherto remained teacher-centered and textbook-oriented[2,7]. This is contrary to the teaching strategies recommended by the national STEM curriculum that emphasizes learner-centered and inquiry-based teaching strategies and methods which involve hands-on and minds-on learning activities. Most of the STEM teachers are not familiar with effective teaching strategies and they do not possess the knowledge and competencies required for using inquiry-based teaching in implementing the Nigeria STEM curriculum[8,9]. Therefore, STEM teachers need to acquire the required levels of knowledge, skills, and competencies for teaching STEM subjects efficiently.[7&9]

Furthermore, a good number of teachers and support staff in the school system are far from being computer literate and are incapable of applying technology in teaching science (Shittu, Kareem &

[1]The CLIx initiative was seeded by Tata Trusts, Mumbai, and is led by Tata Institute of Social Sciences, Mumbai and Massachusetts Institute of Technology, Cambridge, MA, USA. In March 2018, the initiative won the prestigious King Hamad Bin Isa Al-Khalifa Prize for the Use of Information and Communication Technology (ICT) in the field of Education. For more details, see https://clix.tiss.edu

[2] Mustapha, M.T. (2009). The Imperative of STM Education for Attainment of Niger State Vision 3:2020. Niger State College of Education Lecture Series, 5.

[3] Federal Ministry of Education (2004). Senior secondary school curriculum Biology. NERDC, Press, Yaba, Lagos

[4] Nigerian Educational Research and Development Council (NERDC) (2009). Senior Secondary School Curriculum: Fishery for SSS1-3. Sheda, Abuja: University Press Plc

[5] Maduabum, M.A. (1990). Crisis in integrated science classroom. Reflections on integrated science teacher education in Nigeria. Journal of the Science Teachers' Association of Nigeria, 26 (2), 19 – 24.

[6] Ayeni, A (2021) The Impact of Parental Involvement on Adolescents' Academic Achievement in Nigeria" (2021). Theses and Dissertations. 175. https://scholar.stjohns.edu/theses_dissertations/175

[7] Olawuwo, A. F. (2015). Issues and trends in science education: Teacher as a factor in student performance. Journal of Arts and Education, 7, (2), 114-154

[8] Mustapha, M.T. (2012). Reforming the knowledge base of pre-service science teacher education program for contemporary relevance, effectiveness and professionalism in Nigeria. 1st. AFTRA Teaching and Learning in Africa Conference proceedings, 2, 26-35

[9] Badmus, O. T. & Omosewo, E. O. (2018). Improving Science Education in Nigeria: The Role of Key Stakeholders. European Journal of Health and Biology Education, 7(1), 11-15. https://doi.org/10.29333/ejhbe/87086

Tukura, 2019)[10,11]. Researchers have reported that most teacher education courses do not provide meaningful contexts for applying ICT to enhance teaching and learning. Even though ICT is included in the teacher education program, teachers are not sufficiently trained to use ICT in the instructional setting[12] (Richard, 2021)[12]. To resolve this gap, the STEM teachers require further ICT-compliant education and training to enable them to function in the technology-driven classroom in the 21st century. In addition to ICT competence, the science teachers are also in need of continuous training to enhance their knowledge of the subject matter,and pedagogy.[10,7,13] The CL4STEM project addresses these concerns and specifically focuses on developing the capabilities of science and mathematics teachers, along with an emphasis on the pedagogical content knowledge requirements of teachers in Nigeria. It is also in tune with the strategic plans of national and state governments for addressing the challenges regarding the continuous professional development of teachers (FGN, 2013). CL4STEM aims at building capacities of middle and secondary school teachers in science and mathematics to foster higher-order learning in classrooms and enable their ICT competencies.

Teacher Educators (TEs)/faculty of teacher education are the key agents responsible for adapting the innovation and implementing it in Bhutan, Nigeria and Tanzania. They have employed the CLIx approach to Teacher Professional Development (TPD) which includes specially designed Open Educational Resources (OERs) to enhance the teachers' Pedagogical Content Knowledge (PCK) and the mobile-based Community of Practice (CoP) to promote peer group professional learning. In the context of each country, this involved:

1. Offering a course comprising a set of 13 CL4STEM modules to enhance the teachers' PCK using OERs and blended learning.
2. Supporting the teachers in their capacity-building exercise and translating the learning experience into practice by enrolling them into a mobile-based CoP to promote peer group professional learning.

The implementation of the innovation took place in 3 stages:
Stage 1: knowledge transfer of the CLIx approach to TPD.
Stage 2: adaptation and development of contextually relevant design 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 of the three collaborating universities participated in virtual workshops and created 13 modules for Teacher Professional Development (TPD) based on the programme's 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

[10]Federal Ministry of Education (2013). National Policy on Information and Communication Technologies (ICT) in Education. https://education.gov.ng.
[11] Shittu, A.T., Kareem W. B.& S.C. Tukura (2019). Science lecturers' perceptions and self-efficacy towards use of computer mediated technologies. Journal of Research in Science and Vocational Education, 1 (1), 222-233
[12] Bello, G. (2018). Technological pedagogical and content knowledge: The missing link in Nigeria teacher education programme. In G. Bello; M.T. Mustapha & M.M. Osokoya eds. Contemporary issues in STEAM Education in Nigeria, 18-25
[13] Oyelekan, S.O. (2018). ICT competency standards for teachers from global perspective.In G. Bello; M.T. Mustapha & M.M. Osokoya eds. Contemporary issues in STEAM Education in Nigeria, 304-313

3. Skills to integrate hands-on learning into the classroom; to integrate ICT (where available) into the classroom; to use resources to enhance student talk and the quality of questions asked to develop higher-order thinking and, to adopt inclusive practices
4. Management of a subject-based online CoP to share experiences and build contextual pedagogical content knowledge 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. Timeline of Knowledge Transfer

Phase 1 was designed for TEs to experience an online practice-based reflective teaching course 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. Synchronous sessions were conducted weekly while the TEs were carrying out the course. During the length of the course, they also participated in subject-based mobile CoPs.

Phase 2 focused on Universal Design for Learning 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 the faculty from Shreemati Nathibai Damodar Thackersey Women's University, Mumbai.

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

Phase 4 of the knowledge transfer involved TEs from all the three countries along with the subject teams from TISS, developing 13 contextually relevant modules for teachers of 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[14].

In total, thirteen modules were collaboratively developed, contextualized and implemented in all the three participating countries. Every teacher was enrolled in four modules on the Moodle platform;

[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.

one Common Pedagogy Module and three modules from any 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 the 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 the CL4STEM TPD model as they offer a social learning space for the all 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 led to a greater likelihood of reflective classroom practice. A common Telegram Group was created for all the subject teachers (80) and four separate subject groups. Each participating teacher was a member of two groups; the common CoP and the subject specific CoP. The Teacher Educators were assigned as Course Instructors for each of the twelve subject modules and the common module. This implied that the respective teacher educators were responsible for the teachers' participation in their modules. Adequate access to online modules and an online CoP were ensured for all participating teachers. This implied installing Moodle and Telegram applications on their smartphones and also making them accessible through their laptops/desktops whenever feasible.

The associated research focused on two broad areas. The first was the impact analysis, which focused on the impact of innovation on the teachers' Knowledge, Attitudes, and Practice (KAP) for higher-order teaching and learning of science and maths, both inclusively and equitably. The second area of research was the innovation diffusion research which generates knowledge on the processes of adoption of the innovation for specific local contexts and the conditions that support scaling. The knowledge generated from this project would be disseminated to stakeholders in ministries of education and relevant regulatory and professional bodies to seed it into the policy agenda of these countries. Further, the key insights from this project would be shared with other researchers and opinion leaders in the spirit of creating global public goods.

2. Methodology

This section provides an overview of the implementation of CL4STEM, explaining the research tools, data collection strategies, and the analyses that were conducted. Research shows that the application of teacher professional knowledge is contextual and value-based, where teacher learning is social and situated in nature (Sarangapani, 2011[15]; Winch, 2004[16]; Cochran-Smith & Lytle, 1999[17]). The CL4STEM design focuses on supporting the Teachers' Professional Development by creating modules to gain new professional knowledge and Communities of Practice to engage in social learning.

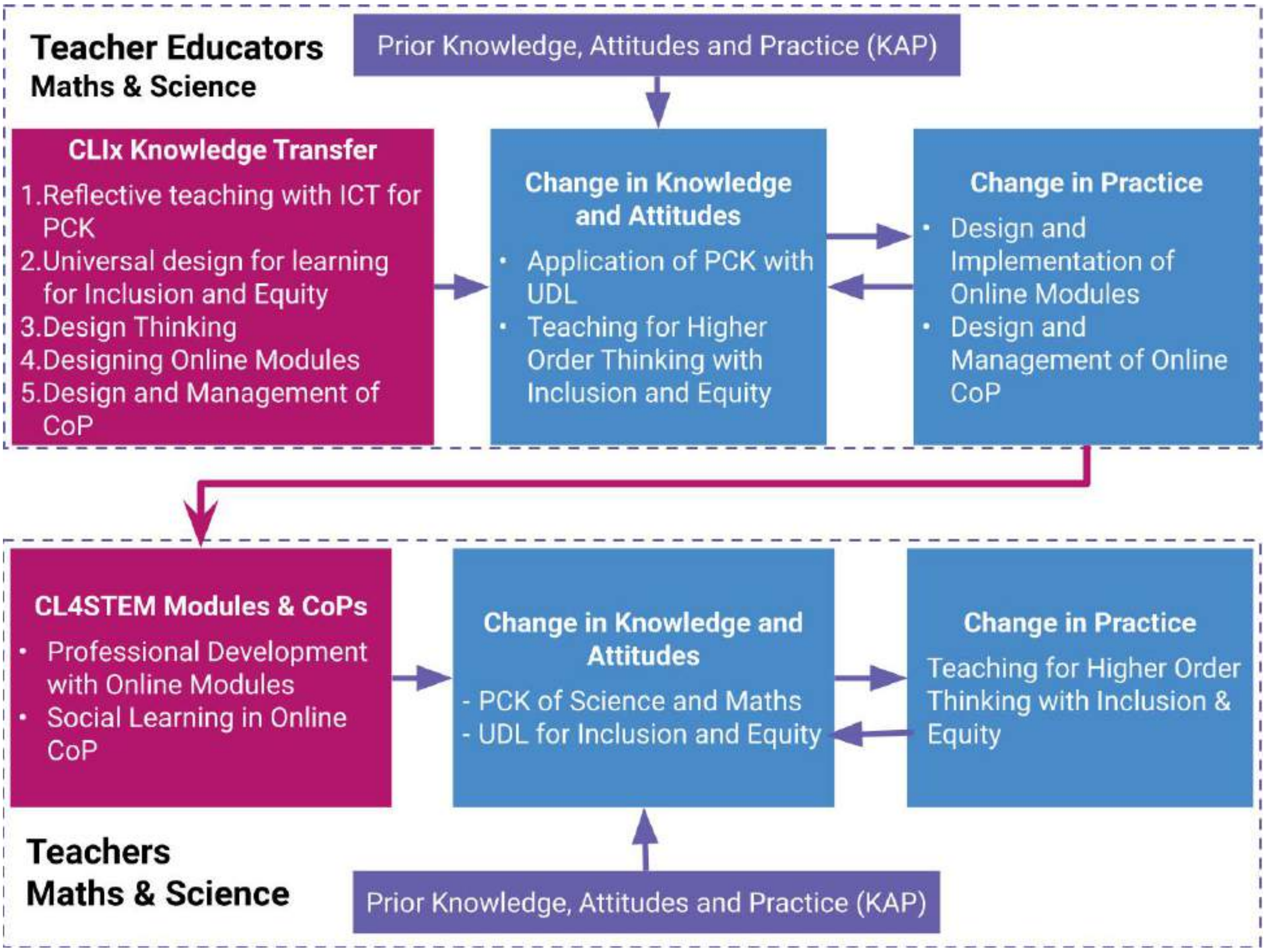

Figure 2.1. CL4STEM Theory of Change

Figure 2.1 presents the CL4STEM theory of change that grounded the implementation and all research activities. The salient features are as follows:

1. The teacher educators' knowledge, attitudes, and practices about higher order teaching with equity and inclusion (HOTIE) improves as they meaningfully engage with the online practice-based reflective professional development through Knowledge Transfer (described

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[15] Sarangapani, P.M. (2011). Soft Disciplines and Hard Battles. Contemporary Education Dialogue 8(1) 67–84.
[16] 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
[17] 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.

earlier) and online Communities of Practices, and engage in the design, implementation and monitoring of the online Teacher Professional Development (TPD) modules.

2. The teachers' knowledge, attitudes, and practices about higher order teaching with equity and inclusion (HOTIE) improves as they meaningfully engage with the online professional development modules (designed by their teacher educators), implement the lesson plans, reflect on their practice, and participate in online Communities of Practice to support their professional development.

To support this theory of change and to explicitly assess teachers' knowledge, attitudes, and practices towards pedagogical content knowledge and equity & inclusion, a conceptual framework was developed (Table 2.1) . The conceptual framework is aimed towards promoting Higher Order Thinking among learners with Inclusion & Equity (HOTIE). It consists of subject matter knowledge, pedagogical content knowledge and general pedagogical aspects (Shulman, 1986[18]; Ball, Hill, & Bass, 2005[19]; Grossman, 1990[20]; Kind, 2009[21]; Ramchand, 2022[22] and CAST, 2018[23]). This framework guided all the analysis with regard to the impact of CL4STEM on teachers.

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 learning difficulties
4. Students' Misconceptions &	● 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

[18] Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. Educational Researcher, 15(2), 4–14.
[19] 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.
[20] Grossman, P. (1990) The Making of a Teacher, New York: Teachers College Press.
[21] Kind, V. (2009). Pedagogical content knowledge in science education: Perspectives and potential for progress. Studies in Science Education, 45(2), 169-204.
[22] 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.
[23] CAST (2018). Universal Design for Learning Guidelines version 2.2. Retrieved from http://udlguidelines.cast.org

Conceptual Difficulties	• 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 • 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 Communities of Practice (CoPs) are the other significant aspect of CL4STEM design, along with the HOTIE framework. Communities of Practice (CoPs) are a well established concept of social, situated and professional learning through the regular interaction of the community members (Wenger, 1998)[24]. They draw on the idea of situated learning (Lave and Wenger, 1991)[25] that states that professional learning happens by participation in social processes that are situated within specific socio-cultural contexts.

To understand the change in perceptions and learning among participants of CL4STEM over time , research on innovation diffusion was conducted. The widely accepted Concerns Based Adoption

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

Model (CBAM) (Hall, 1974)[26], was used to study the diffusion of the innovation using the HOTIE rubric, Levels of Use (Hall, Dirksen & George, 2006)[27], and Stages of Concerns (George, Hall & Stiegelbauer, 2006)[28] questionnaires and surveys. CBAM focuses on understanding how the various perspectives of teachers with regards to CL4STEM during their participation are addressed. 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

[26] Hall, G. E. (1974). The Concerns-Based Adoption Model: A Developmental Conceptualization of the Adoption Process Within Educational Institutions.
[27] 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
[28] 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 the teachers' KAP to evaluate the impact of the intervention. Stages of Concern and Levels of Use 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)[29] was also used to understand the teachers' perceptions. This framework comprised of 7 characteristics:

1. Voluntariness: the perceived degree to which participants voluntarily participate
2. Relative advantage: the extent to which the teachers perceived CL4STEM suggested better strategies than the existing ways of teaching
3. Compatibility: the degree to which CL4STEM is compatible with the existing context of the teachers
4. Image: how participation in this project affects the teachers' social or professional status.
5. Ease of use: the teachers' ability to successfully participate in CL4STEM modules and CoPs, as well as, implement the lesson plans
6. Results Demonstrability: the degree to which the results from participation in CL4STEM could be tangibly demonstrated and communicated to others
7. Visibility: the 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 for all the data points mentioned in this report. Data was 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 knowledge, attitudes and practice, and to study teachers' perceptions of CL4STEM as they evolved over time.

A total of 80 teachers (20 each from Physics, Chemistry, Maths, and Biology) who participated in the pilot intervention became part of the implementation. Out of these 80, 20 teachers (5 each from Physics, Chemistry, Math, and Biology) were in the focus group. The only difference between the focus group and the rest was that focus group teachers were interviewed at every stage of data collection (Baseline, Midline, and Endline).

Table 2.2. Overview of Baseline Data

Baseline Tools	Teacher Profile	Teacher Perceptions Survey	Subject Impact Survey	Interviews
Focus Group	5	5	5	5
Others	15	15	15	0
Total per subject	20	20	20	5
Total (all subjects)	**80**	**80**	**80**	**20**

Table 2.2 shows the number of participants who responded to each research instrument. Baseline tools consisted of:

1. Teacher & school profile surveys to collect the demographic data about the participants and understand the context in which teachers would be working in.
2. Teacher perception surveys to capture the expectations of teachers before they participated in CL4STEM. This tool was designed on Moore and Benbasat's characteristics of

[29] 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.

innovations (1991). Stages of Concern and Levels of Use from CBAM were not used in Baseline data collection as the participants were not exposed to the intervention at all during that time frame.

3. Subject impact surveys that assessed teachers' existing subject matter knowledge, pedagogical content knowledge, 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 the data from teacher perception surveys. The interview questions focused on comprehending the teacher's conceptual understanding of science/mathematics, knowledge and attitudes towards general pedagogical knowledge, pedagogical content knowledge, equity and inclusion, ICT-based teacher professional development, online Communities of Practice, and perceptions towards implementation of CL4STEM.

Baseline data collection took place in June and July 2022. As indicated in the table above, Baseline survey data was collected for all 80 teachers. However, the interview data was collected only from focus group teachers. Though data was collected from control group teachers, it has not been analyzed in this report.

Midline data collection focused on capturing the qualitative aspects of the implementation. A key component of the Midline data was classroom observations. Research fellows conducted classroom observations for 2 teachers per subject (8 teachers in total), and 3 observations per teacher (24 observations in total), while also interviewing the same teachers. Table 2.3 shows how many teachers were observed, and how many times.

Table 2.3. Midline Data Overview

Midline Tools	Classroom Observation	Interviews
Total per subject	6 (2 teachers x 3 observations)	5
Total (all subjects)	24	20

During the classroom observations, the research fellows wrote detailed descriptions of the lesson that they had observed. They also conducted pre-observation and post-observation interviews with the teacher to understand the context of the lesson. Along with the classroom observations, qualitative interviews focused on their knowledge and attitudes towards SMK, PCK & GPK, participation in online Telegram CoPs, and the teacher's perceptions of CL4STEM. The questions on perception also included those on Levels of Use and Stages of Concern from the Concerns Based Adoption Model (CBAM), along with Baseline questions on adoption. Midline data collection went on from September 2022 to November 2022.

Finally, the Endline tools consisted of the following:

1. Subject survey which essentially repeated the Baseline subject impact survey, measured teachers' knowledge and attitude towards high order teaching and learning with equity and inclusion by assessing their subject matter knowledge, pedagogical content knowledge, and general pedagogical knowledge.
2. Innovation diffusion survey also repeated the innovation diffusion survey conducted in Baseline. It included questions on the Stages of Concern and Levels of Use with regards to CL4STEM, as found in the Midline data collection phase.
3. Interviews were carried out 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 its implementation. The interviews also focused on

capturing the teachers' knowledge, attitudes and practices around higher order teaching and learning for equity and inclusion, 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 the table below:

Table 2.4. Overview of Endline Tools

Endline Tools	Innovation Diffusion Survey	Subject Impact Survey	Interviews
Focus Group	5	5	5
Others	15	15	0
Total per subject	25	25	10
Total (all subjects)	**80**	**80**	**20**

2.2 Data Analysis

For analysis of 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. This data was segregated into categories of gender, school type, teacher type, and subject for the corresponding framework to explore for possible themes. 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, and 2) Moore and Benbasat's (1991) 7 indicators of innovation diffusion, and 3) CBAM's Stages of Concern & Levels of Use for perceptions around the innovation. All classroom observations and the teachers' pre and post observation interviews were also 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 be condensed into major findings which have been presented in this report.

Social network analysis was chosen as the methodology for studying the mobile based CoPs data along with qualitative thematic analysis. Social network analysis 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" (Daly, 2010)[30]. The social network analysis graphs were created using Gephi software[31]. Each node on the graph shows a participant in that CoP, whereas a line between two nodes shows 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 the number of interactions that happened between the participants of any 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, or that every participant has interacted with every other participant at least once. The average degree is the average number of interactions each node has participated in and the maximum degree is the maximum number of

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

connections a node has in the concerned social network. The node with maximum degree would belong to the participant who has interacted the most in the Telegram CoP.

This following section on participant demographic details sets the context of the CL4STEM intervention by sharing details about the participating schools and teachers for the intervention.

2.3 Demographic Details of Participating Schools

Twenty-five schools from three states in northern Nigeria- Niger (15), Kaduna(5) and Kano(5) had participated in the project. The school principals took part in the online survey which consisted of four parts: School Demographic Information, School Team Profile, Physical Infrastructure and ICT facilities. Out of the 25 school heads, 10 were female and 15 were male. Almost all the principals (23) had B.Ed./BSc.Ed as their educational qualification, 4 had M.Ed., one of them had Post-Graduate Diploma (PGD) and one had the Nigerian Certificate of Education.

Table 2.3.1. Overview of Teachers and Staff

# teachers or staff	0 - 19	20 - 39	40 - 59	60 - 79	80 - 100	>100	Total
# School with full time teachers	5	6	6	3	1	4	**25**
# Schools with full time science & maths teachers	14	6	3	1	-	1	**25**
# Schools with full time non teaching staff	16	5	1	2	1	-	**25**

As the table 2.3.1 demonstrates, the samples are from both small and large sized schools. There are 5 schools, including federal government schools[32], which employs more than 80 full time teachers. There are 5 schools which have less than 20 full time teachers. 14 schools have less than 20 full time Science and Mathematics teachers.

Out of the 25 selected schools, 16 schools provide free uniforms, 14 schools gave free textbooks and lunch. Six schools gave free textbooks and only one school has free health check-ups. This implies that the welfare programmes for students in most of the selected schools are weak and it could have implications for teaching and learning.The schools which do not have access to constant supply of electricity and internet connectivity are in the majority with the number as high as 18. Two schools have reported that electricity is “mostly unavailable” and seven schools have reported that the internet is “mostly unavailable”. Only three schools have reported the availability of both internet and electricity for “most of the time”.

Table 2.3.2. Availability of Electricity, Internet and Computers

Availability of Electricity	Availability of Internet				Availability of Computers	No. of Schools
	Most of the time	Mostly unavailable	Some time	Total Schools		
Most of the time	3	2	2	**7**	For Office Use	17
Mostly unavailable	1	1	0	**2**	For Teachers	8
Some time	3	4	9	**16**	Computer Lab for Students	22
Total	**7**	**7**	**11**	**25**	Personal Devices for Students	4

Almost all schools (24) have separate principals’ offices, separate staff rooms and safe drinking water. Most schools have playground facilities (23), separate male/female toilets (22), all-weather school buildings (21) and access to all-weather roads (20). However, only 13 schools have inclusive access to physical infrastructures and only 7 schools have functional science and mathematics

[32] Federal government schools are controlled by the Federal government and while state secondary schools are controlled by the state Government.

resource rooms as well as libraries. Almost all the schools (24) have laboratories for Chemistry and Physics.

There are 23 schools that have biology labs. In one school, the laboratories are multi-purpose and used commonly for all the science subjects. There are 20 schools with computer rooms and 18 schools with libraries respectively. However, only 10 schools have mathematics resource rooms.

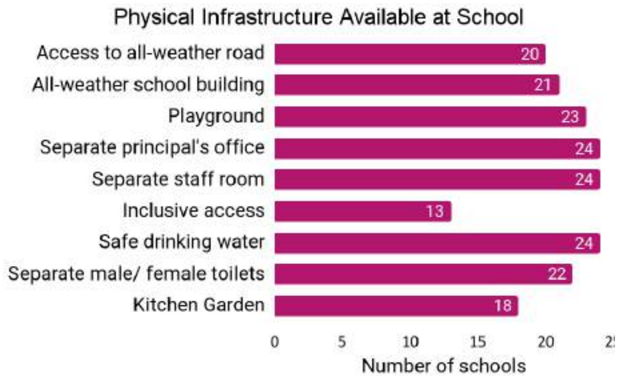


Figure 2.3.1. School Infrastructure Availability

Most schools have desktop computers (19) as these are the computers found in the offices and computer labs. UPS and printers are also available in 16 schools. Most of the schools don't have projectors (13) and copiers (11), whereas 14 schools have laptops. Smart TV and tablets are available only in 7 schools. Schools that have a computer lab for students' use are in the majority (22) and 17 schools have them for official use, especially in the principal's office and examination offices. There are 8 schools which have computers for teachers.

Table 2.3.3. Overview of Percentage of Teachers/Students

% of teachers/students	0-20%	21-40%	41-60%	61-80%	81-100%	Total
# school with teachers owning smartphone	1	1	4	5	14	**25**
# schools with students having access to smartphone	14	4	2	3	2	**25**

Good number of schools (14) have 81-100% of their teachers owning smartphones. However, only a few students have access to smartphones. This could be because the majority of the students cannot afford smartphones, and the school authorities do not approve of the use of smartphones among students in the school.

2.4 Demographic Details of Participating Teachers

The number of male teachers participating in CL4STEM is considerably more (53) than the number of female teachers (27). A majority of the teachers (45) were aged between 31-40 years. The table below shows the total number of years of experience they have in teaching and the years of experience they have at the current school. Most of the teachers (36) have 6-10 years of work experience as school teachers and 4 teachers have a total experience of 21-25 years. Initially, the plan was to include newly qualified teachers in the focus group. But it was not possible to find teachers with 0-3 years of teaching experience due to insufficient recruitment in the past 10 years by some of the state governments that participated in this study.

Table 2.4.1. Age and Gender of Teachers

Age	Other			Focus group		
	Female	Male	Total	Female	Male	Total
21-30 years	1	1	**2**	3	2	**5**
31-40 years	11	21	**32**	4	9	**13**
41-50 years	6	15	**21**	1	1	**2**
Above 50 years	1	4	**5**	-	-	**-**
Total	**19**	**41**	**60**	**8**	**12**	**20**

Table 2.4.2. Years of Experience as School Teacher

Total Years of experience as school teacher	Years of experience as school teacher in current school									
	Others						Focus Group			
	1 - 5	6 - 10	11 - 15	16 - 20	21 - 25	**Total**	1 - 5	6 - 10	11 - 15	**Total**
1 - 5	7	-	-	-	-	**7**	8	-	-	**8**
6 - 10	6	20	-	-	-	**26**	2	8	-	**10**
11 - 15	4	2	11	-	-	**17**	-	-	1	**1**
16 - 20	1	4	1	1	-	**7**	-	-	-	**-**
21 - 25	-	1	1	-	1	**3**	-	1	-	**1**
Total	**18**	**27**	**13**	**1**	**1**	**60**	**10**	**9**	**1**	**20**

The teacher education institution prepares teachers to teach at different levels of education. The Nigerian Certificate of Education (NCE) is a qualification that allows teachers to teach at the two basic levels of education - primary level and junior secondary school level. Teachers with B.Ed. or B.Sc. Ed. or B.Sc. with a diploma in education are qualified to teach at the senior secondary school level. Most of the participating teachers were qualified to teach at the senior secondary level of education in Nigeria. A large number (53) of teachers participating in this project had B.Ed. or B.Sc. Ed. and 7 teachers had M.Ed./MSc.Ed. Similarly, 11 teachers had a Post-Graduate Diploma, while 2 teachers were qualified with the Nigerian Certificate in Education (NCE) which equips them to teach at the junior secondary schools level in Nigeria.

Teacher education institutions in Nigeria allow students to study a major teaching subject and a minor teaching subject. For example, one could major in Mathematics while selecting Physics or Chemistry as their minor subject. In the case of inadequate manpower, teachers are asked to teach their minor subjects. The data on subject specialization of the participating teachers during their teacher education training is presented in the following table.

Table 2.4.3. Subject Specialization inTeacher Education

Subject specialization in teacher education	No. of Teachers
Biology	19
Biology, Basic science	1
Chemistry	21
Maths	20
Physics	19
Total	**80**

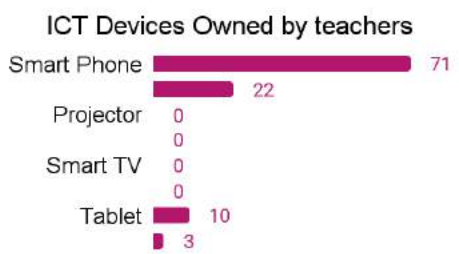


Figure 2.4.1. ICT Devices Owned by Teachers

Out of the 80 participating teachers, 71 teachers owned a smartphone and 22 teachers owned a laptop. Only 3 teachers owned a desktop and 10 teachers owned a tablet. Most of the teachers used smartphones (66) for CL4STEM lesson plan implementation as part of their assignments, followed by laptops (24) and 8 teachers used their desktops. 13 teachers used a projector and one teacher did not have access to any ICT device.

Most teachers (72) used personal data for CL4STEM implementation as indicated in the figure. Five teachers used institutional wifi/internet networks and 1 teacher used the skool media[33]. 15 teachers

[33] https://skoolmedia.ng/ organisation in partnership with the Federal Ministry of Education, set up over 100 Students Technology Experience Centers and 11 Teachers Digital Literacy Training Centers across the 6 geopolitical zones.

used internet data bundles provided by CL4STEM. Only one teacher reported that they rarely used the internet for teaching or preparation for teaching.

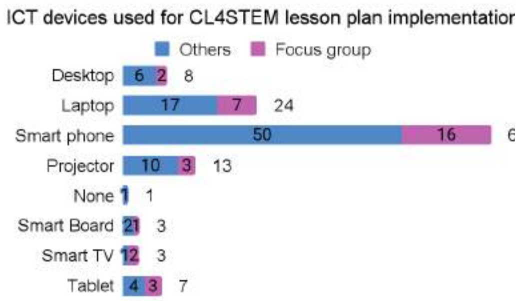


Figure 2.4.2. ICT Devices Used for Lesson Plan Implementation

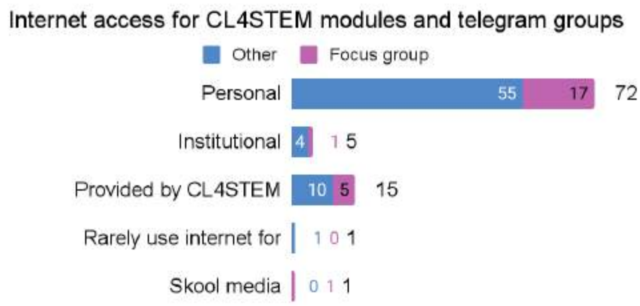


Figure 2.4.3. Internet Access for CL4STEM

37 participating teachers spent two thousand naira (₦2000.00), 34 teachers spent ₦1000.00 - ₦2000.00 and 9 teachers spent less than thousand Naira (₦1000.00) as monthly expenses for the internet. Weekly data usage was less than 1GB for four teachers. 54 teachers used between 2-4 GB for the implementation of the project, while 18 teachers used 5-10 GB weekly. Only 4 teachers used unlimited data for the CL4STEM implementation. It is important to highlight that the CL4STEM project provided stipends for data subscriptions for all the participants.

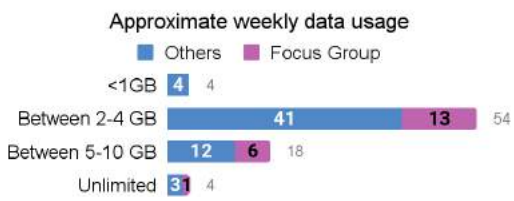


Figure 2.4.4. Approximate Weekly Data Usage

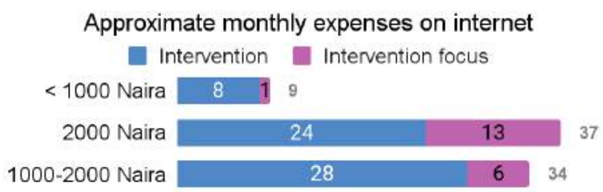


Figure 2.4.5. Approximate Monthly Expenses

This report is organized into 3 main chapters : Teachers' Knowledge, Attitudes, and Practices (KAP); Social Learning; and Teachers' Perceptions of CL4STEM. The chapter on Teachers' Knowledge, Attitudes and Practices presents the evolution of teachers' KAP from Baseline to Endline. It has three subsections of Subject Matter Knowledge, Pedagogical Content Knowledge, & General Pedagogical Knowledge. The chapter on Teacher Perceptions describes the teachers' perceptions towards participating in the innovation, as well as the key findings from Stages of Concern and Levels of Use questionnaire. Finally, the chapter on Social Learning presents the analysis of the online Communities of Practice and the evolution of teacher networks over time.

3. Impact on Teachers' Knowledge, Attitudes and Practice

All the participating teachers (80) responded to subject specific surveys which were designed to understand their change in Knowledge, Attitudes and Practices (KAP) with respect to higher order teaching and learning for inclusion and equity at Baseline and Endline. The surveys had 45 items based on the CL4STEM conceptual framework and this section is structured along the lines of those ten themes in the framework. In each theme, the change observed from Baseline to Endline in interviews conducted for the 20 focus group teachers will be presented, along with the classroom practice of eight teachers observed during the Midline classroom observations. Each of the sections below has three distinct parts: first, the interview data, followed by the insights from classroom observations and survey data for the respective theme, and finally, the summary that ties together all data for that theme.

3.1 Subject Matter Knowledge (SMK)

The following box summarises the notion of SMK as per the conceptual framework of this study.

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

The interview data collected on this theme sheds light on the teachers' opinions, perception and classroom practices around SMK. In the context of this study, the sub-theme focuses on the teachers' knowledge. However the teachers' responses mirrored the necessity of learning science among students, as depicted by this quote, "...science and chemistry in particular is [sic] important; it helps us understand the environment, prepare learners to be a good citizen [sic]." (3501, Chemistry, Endline)

In real-life application, all disciplines are interrelated and the concepts within a discipline are interrelated as well. This perception is illustrated in the following comment by a respondent: "Learning chemistry in the middle class is very important because chemistry has interrelation with the other subjects. One needs the basic knowledge of chemistry to support other subjects like physics, biology, and geology. Careers in medicine and engineering must have basic knowledge of chemistry." (3501, Chemistry, Midline). Similarly, 4 of the respondents believe that knowledge of science and mathematics subject matter will help students gain admission into science and engineering related courses.

The interview data further indicates that SMK in science and mathematics is linked to real life application as seen in the following statements: "Mathematics is important because it is linked to every aspect of life." (3101, Math, Endline) and "Biology is important because it enable [sic] them to understand more about their environment and also the system of their body, how it functions and operates." (3704, Biology, Baseline).

The respondents' remarked that learning science subject matter by the student will help them acquire skills such as that of inquiry, problem solving and critical thinking among others. The opinion of the biology teacher (3704) indicates a change from the general knowledge of biology as it relates to the environment in Baseline, to specific skills that students will acquire as a result of learning biology such as inquiry skills and science process skills in the Endline.

"Biology is important because it enables them to understand more about their environment and also the system of their body, how it functions and operates." (3704, Biology, Baseline).	*"Learning biology is very important because it will enhance the students' inquiry skills and science process skills. Biology is linked to every science subject and helps learners understand their environment." (Endline)*

Similarly, the response of a mathematics teacher (3110) changed from viewing the general importance of mathematics to the application of mathematics to specific areas such as economics, geography and engineering.

"'All that matters in life has a mathematical aspect. There's nothing you can never do again and this is it [sic] *goes up so very important and there's no mathematical aspect." (3110, Math, Baseline)*	*"Mathematics applies to all subjects. Even in chemistry there is calculus, in economics, we have calculations, you have mathematics in geography, and in biology that deals with division*[sic]*, you have to use mathematics. So you can see, for a student, in fact, to do day to day activity, you have to know mathematics and in all aspects of engineering." (Midline)*

A study of the interview data shows that the teachers began acknowledging the specific skills and applicational uses of each discipline in the Endline, compared to a generic understanding of the importance of their disciplines with regard to students in the Baseline.

From the classroom observations conducted for eight teachers, it was found that most of them require a better handle on subject matter knowledge. Two amongst the eight teachers showcased clarity in the concepts they were teaching and made no errors in all the 3 observed sessions. Two teachers made conceptual errors while teaching and one among them mentioned that they required support in SMK. One of those teachers asked the students to poke a potato with a straw to lift it and to repeat the same by closing the other end of the straw. When the students were able to lift the potato in the second attempt, the teacher said that the fact that they were able to lift the potato explains Newton's first law, without mentioning unbalanced force and inertia. There was no connection made between the activity and the law. This indicates that the teacher needs support with SMK to choose the appropriate material, activity and framing questions for teaching the concept.

All four subject surveys had items on SMK specific to the topics in the CL4STEM modules. The average percentage of biology (+10%) and physics (+5%) teachers' choosing right answers for the six SMK survey items increased slightly from Baseline to Endline. At the same time, a negative trend was observed in chemistry and mathematics.

It is safe to conclude from the observations that the SMK of the participating teachers needs further support. All the data sources such as the surveys, interviews and classroom observations indicate the same. This is an important point to be taken into consideration while scaling CL4STEM or designing any teacher professional development models and for teacher training in the region.

Nature of Science/ Mathematics

The following box encapsulates a basic understanding of the nature of science and maths as conceptualised in this study.

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

The teachers' knowledge of the nature of science and mathematics has implications for classroom practices. It was therefore an object of observation to which guidance could be offered to improve methods of teaching. One of the male respondents sees the processes of science as a component of its nature as indicated in these verbal excerpts: "They benefit from observation skills, when they see a problem in their environment, how will they solve it using scientific methods. So, they have to observe and come up with a solution. When they observe, they kind of give intelligent keys which are referred to as the hypotheses after the hypothesis, they have to carry out a kind of a test also, so they learn the skill of testing, observation, hypothesis making and making conclusions." (3503, Chemistry, Baseline)

The perception of the teachers indicates how science subjects are linked to each other and have connections between the subjects and real-world issues. For example, "..physics is the study of the physical world and is linked to all other science subjects. Understanding physics will help in the understanding of mathematics and other science subjects." (3303, Physics, Baseline)

The teachers' understanding of the nature of science includes skills students gain by learning science and mathematics. Although this perception does not really fit into the conceptualisation of the nature of science in this study, it is important to highlight their thoughts: "Biology is important because it provides knowledge about man and his environment, helps students acquire inquiry skills and there is no way you will study medical courses without the knowledge of biology." (3705, Biology, Endline). Similarly, a teacher (3316) believed that learning science could make students think like a scientist and could expose them to the inquiry method of science instruction. Teachers tend to view the nature of science as part of the learning outcome of science and mathematics in ways it could benefit the students: "Learning physics in secondary school is very important, because by the time they finish and they want to further [sic] whether they want to study engineering, medicine, or other sciences."(3303, Biology, Endline)

The theme on nature of science was difficult to capture in the classroom observations. Six out of eight teachers did not mention anything explicitly related to the nature of their subjects. One mathematics teacher mentioned during the session that, "there are multiple ways to solve problems. Not just one formula. Mathematics is always about invention." (3101, Math).

In the Baseline survey, 67% of the teachers disagreed with the statement 'many things must be accepted as true without explanations' and this increased by 2% in the Endline. Female teachers have expressed the highest rate of disagreement (81%) with accepting things as true without any explanation in the Baseline and this remained unchanged in the Endline. While male teachers and teachers with 0-5 years of experience have the least percentage of disagreement at Baseline (64%), they show a 3% increase in Endline.

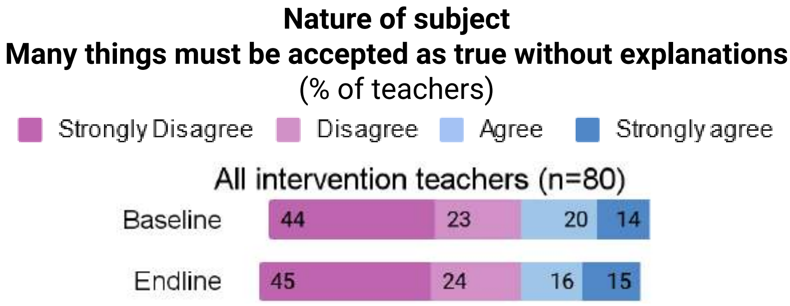


Figure 3.1.1. Nature of Subject

Based on the interviews, the respondents' understanding of the nature of science and mathematics indicate that the teachers need more support to grapple with it. Findings on the nature of science and mathematics from interviews did not seem to provide any substantial change because the theme seeks to understand teachers' knowledge of the nature of science and mathematics. The responses, however, largely focused on the learning outcomes of science and the interconnection between science disciplines and mathematics in students' learning. To conclude, there was no visible and noticeable change from Baseline to Endline. The finding could be attributed to the fact that teachers do not seem to pay more attention to the nature of science and mathematics as an important component of teaching as was substantiated by the minimal change in the Endline survey data. Another reason could be because the nature of science is not explicitly taught in pre-service teacher education institutions. However, the teachers perceived the nature of science to include inquiry and experimentation that will help learners acquire science process skills. This minimal impact could be attributed to the effect of participating in CL4STEM.

3.2 Pedagogical Content Knowledge

This section on Pedagogical Content Knowledge (PCK) has five sub-sections based on the conceptual framework. Each section details the findings from interviews (20), classroom observations (8) and surveys (80) with a summary at the end.

3.2.1 Instructional Strategies

The following box gives an overview of the instructional strategies employed throughout the study.

- 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 engagement with CL4STEM modules has impacted the teachers' knowledge, attitude and practice (KAP) in a way oriented towards the use of more learner-centric instructional strategies with a range of resources and collaborative teaching-learning methods. This section details the excerpts from interview data followed by classroom observations and surveys. The findings from 20 teacher interviews at Baseline, Midline and Endline revealed three sub-themes as elaborated in the sub-sections below.

i) Teacher-centred Instruction: The teacher is viewed as the subject matter expert in this process of teaching and learning, who is then responsible for transferring knowledge to students through lectures or direct teaching while the students listen passively. Interview responses provide evidence for the use of teacher-centred instructional strategies, whereby the teacher does the explanation while students write down the important points. According to the Baseline, 12 teachers follow this approach: "...normally the students are facing [sic] the board… So we stand at the front [sic] of the board, and we introduce our lesson, we explain... And then because of the large number, actually we have to move around the class so that each student will be able to hear what we are saying first, then we monitor them." (3719, Biology, Baseline). Baseline data demonstrated that the majority of the science and mathematics teachers in this study employ teacher-centred instructional strategies. Poor performance of high school students in science and mathematics could be attributed to the use of such traditional teaching methods in Nigeria[34]. The interview responses revealed that the number of teachers engaging in teacher-centred instructional practices in the Baseline (12) decreased considerably in the Endline (2).

ii) Student-centred Learning/Teachers as Facilitators: Student-centred instruction involves learners taking active roles in the learning process while the teacher acts as a facilitator. Moreover, teachers and students serve as instructional partners. Student-centred learning involves the process of providing a conducive learning environment where students have the freedom to engage in meaningful learning, take responsibility for their learning through the provision of activities and interaction to achieve their educational goal. The teachers' statements from the Baseline (3) and Endline (14) interviews illustrate this approach: "To teach chemistry [sic] very easy, I provide these materials to teach atomic structure. I came up with local resources such as calabash, mango leaves, cocoa nut oil and maize. Students work in groups to construct atomic structure of some elements while I go round [sic] to check". (3501, Chemistry, Endline). The practices associated with teacher-centred instructional strategies at the Baseline however, seem to have changed in the Endline as indicated by the following example of a biology teacher (3704).

"I placed a chart related to the topic of discussion at the side to avoid distraction. I asked them questions on their previous knowledge, in order to know that maybe this topic I'm about to teach, they have an insight… I explained in details to the students and after that I summarised the key point and asked them questions from the lesson delivered." (3704, Biology, Baseline)	*"…I try to see how I can engage them in learning activities that is relevant to the topic through construction or project work."* (Endline)

Similarly, the teachers' response expressed change from teacher-centric strategies in the Baseline interview to the use of hands-on materials and activities suggested in the CL4STEM modules to aid teaching as indicated by the excerpts in the Endline below:

"In normal class I make my notes from my textbook, and whatever I will source my information from and then go to class, explain to students and evaluate what I have taught them." (3501, Chemistry, Baseline)	*"...students contributing to their own knowledge is the most wonderful one and then secondly, the students are given the opportunity to participate in practical activities very often. For example, if you have a normal class, mostly the teaching is based on theory or traditional method but with CL4STEM it is based on a lot of class activities or practicals and group work." (Endline)*

[34]Ezurike, C. P. & Ayo-Vaughan, A. F. (2020). Influence of teacher-centered and student-centered teaching methods on the academic achievement of post-basic students in biology in Delta State, Nigeria. Teacher Education and Curriculum Studies, 5(3), 120-124. https://doi.org/10.11648/j.tecs.20200503.21

"I write the topic on the board, then ask the students what they know about this topic. Somebody should give me the idea of the topic in the previous lesson. I present the lesson by explaining it step by step at the end of the lesson I evaluate what I have taught." (3303, Physics, Baseline)	*"'On the topic of forces there are so many different activities that we did which include gravitational and so many activities we demonstrate the effect of force... under magnetism, we have about three activities… We use the powdered iron fillings to create a shape that is surprising to the students. The students see it physically the way the attraction is taking place. We also performed another experiment on balance forces and unbalanced forces. We start with the practical aspects to teach any topic in the majority of lessons. We have adopted the teaching strategies, the UDL principles, the principle and the knowledge of pedagogical knowledge in our subject area in the classroom." (Endline)*

"I start by revising what was learnt yesterday. Then the normal lesson that will be taught for the day. By the end I used to assign students to work on the board. If they couldn't solve it I will come and do the corrections. Then I will give another problem." (3110, Maths, Baseline)	*"Before almost all our classes were chalk and board. But now we have reduced that level* (of) *teacher-based activities, so that the students will be engaged in classroom activities. So my classroom activities have really changed, I get a new pedagogical strategy of teaching." (Endline)*

iii) Collaborative Learning : This involves students working together or doing shared tasks in groups. This could take place through peer learning, cooperative learning, collaborative learning and peer mentoring among others. The following statement can be taken as an indication of better collaborative learning in the Endline through group work : "I now teach better by engaging students in class activities, group projects and group learning. I give them tasks and move around from one to another to guide the students." (3501, Chemistry, Endline). Instances of teachers engaging students in collaborative learning approaches increased from 1 in the Baseline to 13 in the Endline.

Overall, there is a drop in the mention of teacher-centered practices from Baseline to Endline. There is also an increase in the number of teachers mentioning student-centred and collaborative teaching-learning practices in the Endline as shown in the table.

Table 3.2.1. Instructional Strategies: Interview analysis

Instructional Strategies - Sub themes	No. of teachers	
	Baseline	Endline
i) Teacher- Centred Learning	12	2
ii) Student-centred/ Teachers as Facilitators	3	14
iii) Collaborative Learning	1	13

In the classroom observations conducted, all the 8 teachers used lecture methods and collaborative learning along with other strategies. Only 1 teacher out of the 8 predominantly used the lecture method. Interestingly, all eight teachers employed collaborative learning by giving students tasks, hands-on activities, solving word problems, drawing and interpretation in groups of different sizes. This can be attributed to the impact of CL4STEM modules as the activities they used were from the modules, such as finding the difference between cells in biology and finding the area and perimeter of the classroom. Also, the use of hands-on materials and activities from the modules necessitated group work since the classroom sizes were large with not enough resources for each student. The post-classroom observation interviews attest to this development:

> "...students will be actively involved, especially the diagram part, and also in the part where they are to interact with their group members to find out the similarities and differences between these two basic types of cells.... also there is a class work activity, in which they are to point out by themselves, write it on a cardboard paper, which they will submit to me. And in cardboard, the most important activity is to differentiate between the two types of cells that we are having...You know, working in a group for students is a very good way of teaching and learning. When you group students, they tend to learn in collaboration, students learn better

> when they work with their peers... I simply move from one group [sic] to guide the students." (3710, Biology)

Group presentation by students was used by two teachers. One among them, a mathematics teacher, reflected after the class that his work was easy because three groups presented one concept each with diagrams and solved word problems related to the concepts, and all the groups had prepared problems for each other to solve. Furthermore, the teacher (3110) added that he was able to cover a lot of concepts in one session, which would have taken him a week to cover otherwise. He also added that this kind of student-centered activities would help him cover the syllabus at a quicker pace. It is an important reflection because in general a lot of teachers cite time constraints as the main reason for not employing student-centric instructional strategies. Other strategies employed by the teachers were kinesthetic activity and hands-on activities for teaching force in physics, drawing illustrations to teach cell structure, using the surroundings in geometry and using locally available materials for creating atomic models in chemistry. To conclude, the teachers employed several learner-centric instructional strategies and these can be attributed to the impact of participating in CL4STEM modules.

The subject-specific surveys had items specific to the topics in the modules in all four subjects with one right answer. From the charts below, it can be observed that the percentage of mathematics and biology teachers choosing the right answer has a slight increase in the Endline. The change is mixed in physics and chemistry.

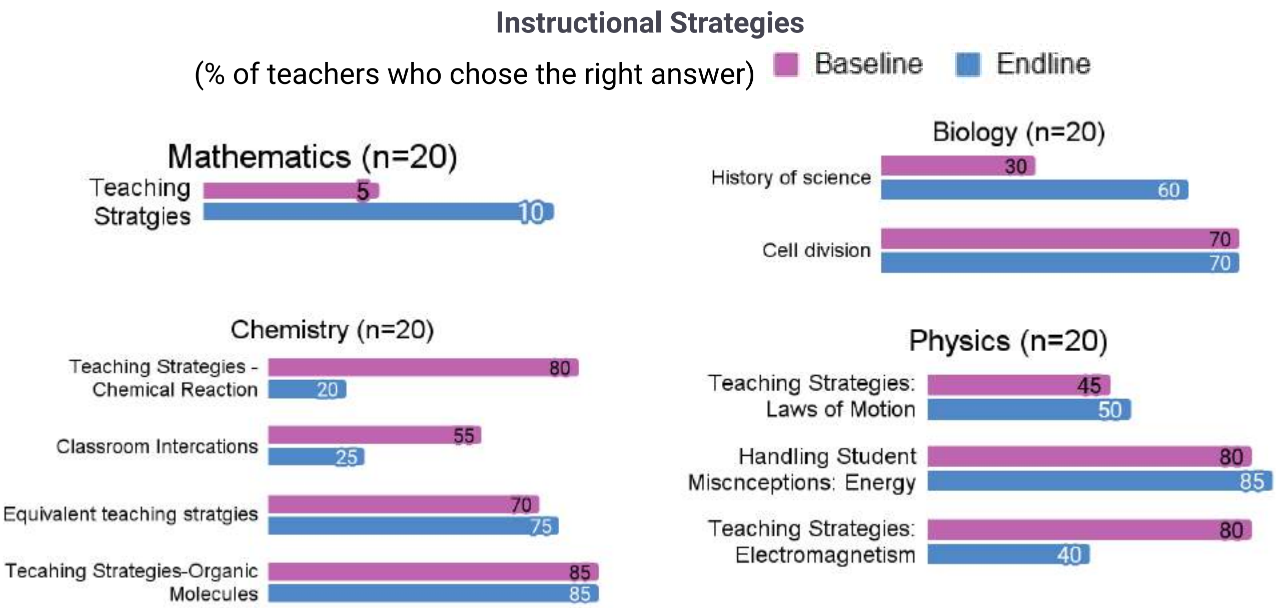


Figure 3.2.1. Instructional Strategies

One of the items on the science surveys was meant to determine the kind of teacher who would be successful in helping students learn science with instances of instructional strategy preferences. The highest percentage of teachers chose the type of teacher who would initiate and guide group discussions to explore meaning and evaluate reasoning as their answer. An observable change was not visible from the Baseline to the Endline. A decrease (-5%) in the percentage of teachers choosing lectures and giving practice to the students was observed in the Endline. There is a simultaneous increase in the percentage of teachers asking pointed questions to guide students to figure out things (+7%) in the Endline.

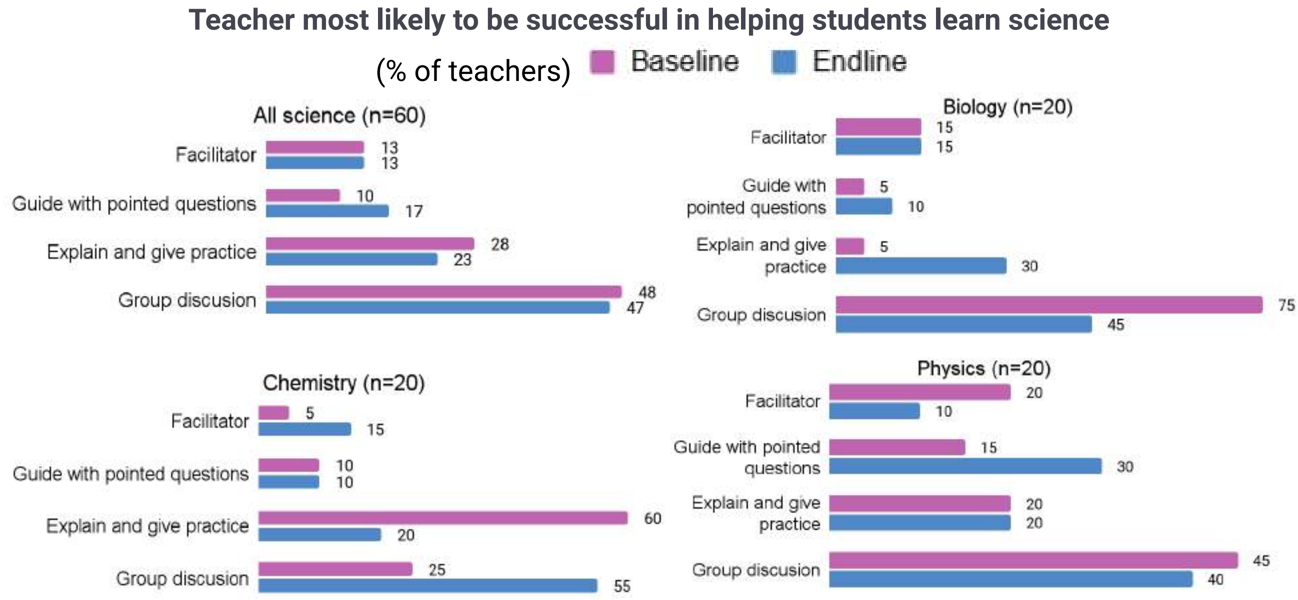
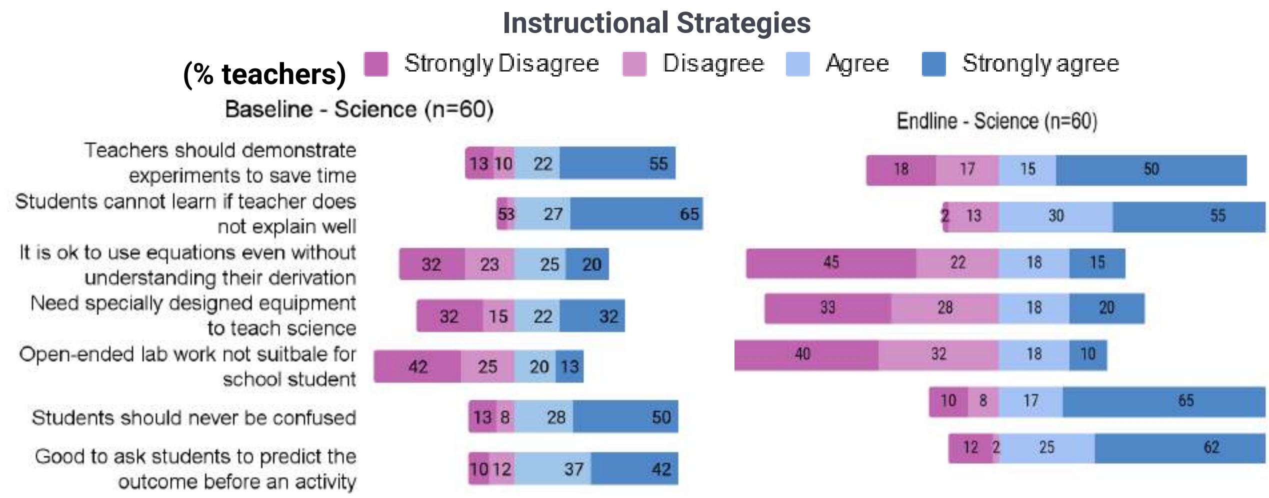


Figure 3.2.2. The Teacher Most Likely to be Successful in Helping Students Learn Science

All the three science subject surveys had seven items related to instructional strategies. Among those, six items noted a 5-12% increase in the desirable agreement level from Baseline to Endline. One item out of the seven has shown a negative agreement trend of 3% regarding whether the students should never be confused. Overall, there was 5% positive change in the science teachers' perceptions towards more learner-centric instructional strategies for them to construct their knowledge. There were seven statements in the mathematics survey on instructional strategies. The average change in desirable agreement level towards learner-centered teaching was 9%. This indicates a positive change in the teachers' knowledge and attitude towards instructional strategies.



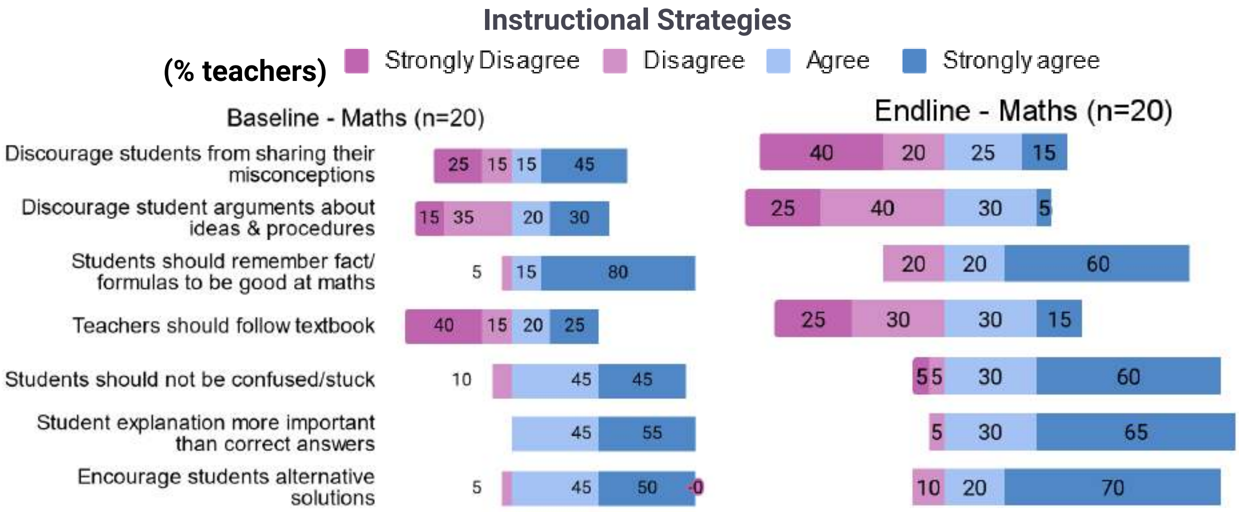


Figure 3.2.3. Instructional Strategies

Overall, there was a positive change in science (5%) and mathematics (9%) teachers' knowledge and attitude towards learner-centric instructional strategies for them to construct their knowledge. Given the verbal excerpts from the interviews, the change in teachers' KAP in their instructions could be clearly seen. This suggests that the teachers' conception of instructional strategies has also improved. Classroom observation data has concrete evidence of teachers using learner-centric and collaborative learning strategies from CL4STEM modules. They were also able to reflect on how it has impacted their practice. These changes could be attributed to the impact of the CL4STEM intervention.

3.2.2 Students' Misconceptions & Conceptual Difficulties

The following box outlines the points on student misconceptions and conceptual difficulties as conceptualised in this study.

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

The teachers had stated difficult topics in their subjects in the Baseline and in the Endline they were able to state topic-specific misconceptions and learning difficulties. Along with that, in the Endline more teachers identified resources and group work as a strategy to address those difficulties. Some teachers think that the students' socioeconomic background and motivation are reasons for difficulties in learning which requires further support and focus in the modules for ensuring equity and inclusion. This section elaborates the trends emerging from the interviews, followed by classroom observations and then the surveys.

An overview of the change in interview data from Baseline to Endline indicates that science and mathematics teachers have an understanding of difficult concepts in their subject, factors associated with those difficult concepts, and classroom practices to address them. The trend in the data provides the following three sub-themes:

i) Understanding Misconceptions: The interview data gathered from this study show that the teachers could not give specific examples to show clear conceptual understanding of students' misconception in science and mathematics. The teachers stated that conceptual difficulties occur due to poor teaching, lack of instructional materials and the students' lack of interest is taken as a misconception. Therefore, teachers do not seem to have the conceptual understanding of misconception that is demonstrated by their inability to give an example of a misconception specific to topics in their subject area in the Baseline as indicated by this excerpt: "There are some topics that students find abstract and that makes it difficult to learn, especially those with poor basic knowledge, poor background find physics at the senior secondary school challenging." (3313, Physics, Baseline).

The teachers mentioned that in their subjects most of the difficulties are caused by the abstract nature of science and mathematics subjects. The teacher's interview data clearly show the change from attributing difficulty in learning to the students' background and ability to thinking about what a teacher can do to address them. This impact of the intervention on teachers' KAP in helping the students address conceptual difficulties is indicated by the following change from Baseline to Midline:

"Some don't have interest in the subject, some believe that mathematics is difficult and when you now start teaching in the classroom they don't concentrate. Students have a poor foundation in the subject which is not easy for them to cope with." (3118, Math, Baseline)	*"If the teachers didn't have the teaching aids to use, students will see mathematics as a difficult subject because the teachers teach mathematics as an abstract subject. Students find mathematics difficult. When you ask them to do group work, the student finds it simple as they can easily communicate with [sic] themselves." (*Midline*)*

> "...it is quite different from the way we are teaching before. As I said earlier, physics is very abstract. We have this module that comes with videos and animations, it helps a lot. The students understand the abstract part of the topics." (3302, Biology, Endline)

ii) Sources of Conceptual Difficulties: The interview data reveal the factors responsible for conceptual difficulties in science and mathematics. These include students' lack of interest, abstract nature of the subject, poor use of teaching methods, lack of instructional materials, students' background, attitudes, interest, class size and students' learning abilities The factors attributed to conceptual difficulties could be classified into student and teacher factors as perceived by the respondents.

The sources of learning difficulties are attributed to the students' background and interest factors as indicated in the following quotes: "Most of the students find chemistry difficult because of lack of interest, poor background and poor attitudes to learning chemistry" (3501, Chemistry, Baseline) and "...biology is difficult because of language barriers, issues with pronunciation of the words in biology, abstract nature of the subject, and students lack interest." (3705, Biology, Baseline). Sources of conceptual learning difficulties that are attributed to pedagogical factors are highlighted in this verbal excerpt: "where you use materials that may not give clear understanding of what you are teaching could lead to misconceptions of that subject matter. Chemistry is an abstract subject." (3515, Chemistry, Baseline)

Comparative analysis of the interview data from the Baseline to Endline indicates a change in the teachers' KAP from identifying the causes of conceptual difficulties in the Baseline to suggesting or engaging in instructional practices that could address conceptual difficulties. This is reflected in the following quotes from a biology teacher:

"the difficulties we face in teaching a particular topic is its abstract manner or nature of science, when the thing is not real, or you do not bring good learning resources for that topic you are teaching, it used to confuse the student." (3704, Biology, Baseline)	*"how to deal with individual differences in the classroom is through the use of audio visual materials and engaging students with different background* [sic] *and abilities in group work."* (Endline)

iii) Strategies for Addressing Conceptual Difficulties: The findings from the interview data highlighted instructional strategies that help address conceptual difficulties which result from the abstract nature of science and other factors as highlighted earlier. The following mathematics teacher (3118) had this change from Baseline to Endline in identifying resources for addressing abstract concepts:

"The difficulties we face in teaching a particular topic is its abstract manner or nature of science, when the thing is not real, or you do not bring good learning resources for that topic you are teaching, it used to confuse the student." (3118, Biology, Baseline)	*"For some of the students maths is abstract and difficult, but if you use the locally available materials and video as teaching aids, they will understand it."* (Endline)

Given the above quotes, it is logical to infer that teachers believe that multiple representation and the use of group work would probably assist to address conceptual difficulties in science and mathematics instruction. This perception could be attributed to the impact of the CL4STEM intervention.

Table 3.2.2. Misconceptions & Conceptual Difficulties: Interview analysis

Students' Misconceptions & Conceptual Difficulties	No. of teacher	
Sub-theme	Baseline	Endline
Teachers' understanding of students' misconception	1	1
Identifying sources of students' conceptual Difficulties	16	12
Strategies for addressing conceptual difficulties	0	6

From the classroom observations and pre and post observation interviews, the teachers' understanding of students' misconceptions, common errors and difficulties included some common subject specific difficulties such as: "Arithmetic calculation is difficult when division or cross multiplication is involved. Students have difficulty in using protractors to measure angles." (3110, Math) and "Unit conversion was difficult for students." (3303, Physics). Five out of eight teachers talked about the difficulties students face and the misconceptions specific to CL4STEM modules during pre and post observation interviews such as conversations shared below.

> "Cyclic geometry is difficult for students, because it involves proving theorems and not just about getting the right answer... they used to find it difficult to identify which one is the coordinate of latitude or which one is the coordinate. And if you interchange them, the position of that point or the position of the city is going to change. So that one is also difficult." (3110, Math)

> "Students sometimes misconceive elements to be compounds and vice versa" (3501, Chemistry)

> "...there are little misconceptions in the area of elements, mixture and compounds. Usually they think that atoms of same elements may be different, but atoms of the same element are exactly the same..., that molecules or compounds are made from a combination of maybe the same atoms, but it can be from different atoms. The other one is also on Law of Conservation of Matter. They think that when we have our action, atoms are destroyed. But an atom is neither

created nor destroyed, but transformed from one form to another...students usually have misconceptions about what an [sic]electron orbit and electron shell. And usually they used to mix up what is an orbit, orbital and a shell." (3513, Chemistry)

Even though teachers were able to identify common difficulties and misconceptions, they did not plan strategies and resources to address them in the sessions observed, except for two biology teachers. Only one biology teacher identified the source of students' misconception regarding cell structure and planned for using appropriate resources to address it. She explained her choice of using a microscope and video during the classroom observation. She commented thus: "Cell structure is a difficult concept as it is abstract. Students may have misconception of the (cell) structure because in textbooks the shape of the different cells looks similar. So I used video and microscope [sic]"(3702). Another biology teacher (3710) mentioned that students think that a cell is two dimensional in shape because of the textbook image, but the images given in the CL4STEM module depicted that the cell has three dimensions and they were better representations for teaching the concept.

Three out of eight teachers attributed difficulties in learning to students' ability and background in the interviews pre and post classroom observation interviews: "students learning difficulties is [sic] caused by students background. Causes of difficulties is [sic] caused by lack of mathematical knowledge of square and trapezium especially [sic] low achievers." (3313, Physics)

"...not all students face learning difficulties, most low achieving students face learning difficulties than high achievers. so also [sic] students from good background do better than students from poor background."(3501, Chemistry)

"..some students will need special attention as they have difficulty in learning" (3710, Biology)

The mathematics survey had an item with a figure divided into unit cubes. Teachers were given five options to choose from regarding the ability of students in finding the area of the figure. The response to the three right options increased by 10-45% in the Endline as shown in the chart. All four subject surveys had items specific to the topics in modules regarding students' misconceptions. For example, the teachers had to identify the common misconception regarding genetics, and also identify a strategy to alleviate the misconception regarding mitosis and meiosis. There was also an increase in the percentage of teachers answering them correctly in mathematics (+15%), chemistry (+5%) and physics (+35% and +20%). In biology there was no change noted for two items and in the other two items a negative drop was noted.

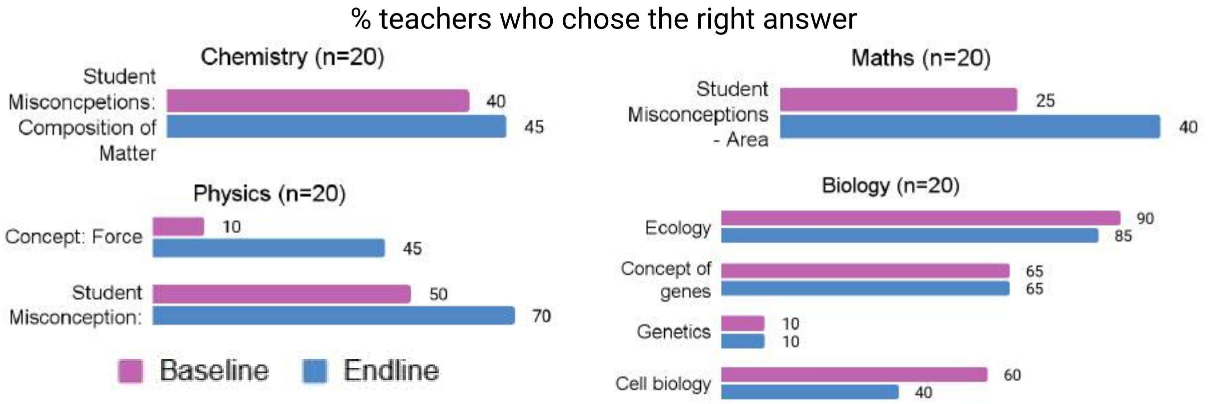


Figure 3.2.5. Students' Misconceptions & Conceptual Difficulties

Given the proceedings in this section, it is logical to conclude that teachers have a clear understanding of conceptual difficulties and its causes at the Baseline and which progressively advances towards the Endline. More teachers highlighted the sources of conceptual difficulties and the instructional practices that could assist them to address these conceptual difficulties in the Endline. But some teachers still attributed the difficulty in learning to students' soci-economic background, motivation and interest towards learning. This attitude of teachers towards the educability of students requires more focus while scaling the CL4STEM modules for ensuring equity and inclusion.

More teachers in the Endline stated that multiple representations and the use of group work would address conceptual difficulties in science and mathematics instruction. In addition, the teachers have changed from citing students' background, interests and abilities as reasons for conceptual difficulties to exploring instructional strategies to address them. Classroom observation has evidence of two teachers using it in their classroom practice. This perception could be attributed to the impact of the CL4STEM intervention. Overall, the CL4STEM seems to make a positive impact on teachers' KAP with regards to strategies that could address conceptual difficulties. Their knowledge, however, of students' misconception specific to the topic in the CL4STEM modules needs further support.

3.2.3 Representation of Content

The following box summarises what the study means by representation of 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

The findings from the data indicate that teachers use multiple forms of representation of content including visual representation such as charts, pictures, diagrams, models, audio-visual materials, locally available resources, print and non-print materials to enhance classroom experience and engagement. This section details the trends in change from Baseline to Endline from the interviews, followed by classroom observation and surveys.

The trend in the interview data on teachers' KAP around the representation of content could be classified into the following three sub themes:

i) Visual Representation : In the context of this study, visual representations are instructional materials that appeal to the sense of sight and encourage meaningful learning. The interview data demonstrates that the teachers employed visual representations such as charts, pictures, models, maps and slides as indicated by the following excerpts:

> "Instructional materials for teaching the concept such as charts, pictures and notes for the students". (3305 Math, Endline)

> "I take my charts to class for them to further understand what I will be teaching. I will have to show them drawings and charts." (3705, Biology, Baseline)

ii) Multiple Representation: This involves using several forms of representation of content to include both visual, audio visual, text and hands-on interactive materials to enhance the learning engagement leading to meaningful learning of diverse learners in the classroom. Learning becomes more engaging, useful, realistic, and appealing when appropriate instructional resources are used to actively and effectively engage students in the learning process. In the Endline, the teachers reported using multiple representations such as videos, diagrams, charts, pictures, locally available hands-on materials and ICT resources. The interview data showed the use of multiple representations by 3 teachers in Baseline and 16 teachers in Endline to cater for diverse students.

> "Geometry is the best topic that I teach. I provided the students with graph sheets, charts and exposed them to GeoGebra from the module. I give them a problem to solve and I just go around and make necessary corrections from one group to the other." (3118, Maths, Endline)

> "I employed charts, local materials and videos to demonstrate the cell in a hypotonic, hypertonic and isotonic environment." (3704, Biology, Endline)

iii) Text/Textbooks: Two teachers indicated the lack of instructional materials in their schools for effective teaching and learning. One of the teachers pointed out that textbooks are the only available instructional resource to teach his students as indicated by the following quote in the Baseline. The dominant kind of instructional materials in their schools before the CL4STEM intervention were in fact textbooks. The same teacher, however, mentioned the adoption of visual and audio visual materials in the Endline.

"'We teach them from materials that are already in textbooks. In terms of resource availability, resources are not available, or there are very limited resources." (3515 Chemistry, Baseline)	*"On atomic history there was a chart on it, that shows how Dalton was able to now define or identify an atom. So, I pick that, and use this as an instruction material for that. I use charts, when talking about the history of atoms, I use the CL4STEM module to include the name of the scientists and their own contribution, their discoveries. etc. Also I use videos of previous tutorials taught on that particular concept. I played it for them to watch the videos, and I'll ask* [sic] *them what they deduce from such a video that they've watched* [sic]*." (Endline)*

It is important to note that a teacher (3103) claimed that there was no instructional material in the school for teaching and learning in the Baseline. In the Midline data, however, the teacher reports the use of his smartphone as an instructional resource to show videos and picture as seen from this excerpt:

"'As a teacher in state schools, the challenges we face is [sic] *unavailability of instructional materials, and we don't have enough time to cover the curriculum."* (3103, Math, Baseline)	*"I use my smartphone to project some videos and pictures for the students during mathematics lessons for the students to understand."* (Midline)

Interview data yields consistent change from the Baseline to Endline. The table below shows the frequency of participants' response on each sub theme. The data indicates 11 of the respondents used single representation - visual representation did not mention using any other forms of representation. In the Endline, only 4 respondents reported to have integrated single representation into their teaching. Teachers using multiple representations were 3 in the Baseline and 16 in the Endline, indicating that most of the participants engaged in or recommended the use of multiple representations in teaching and learning since. Furthermore, none of the teachers mentioned the use of only text and textbooks materials for instruction in the Endline. This could be attributed to the impact of the intervention as the teachers have changed to the use of multiple representation to teach diverse learners.

Table 3.2.3. Representation of the Content: Interview Analysis

Representation of the Content - Sub-themes	No. of teachers	
	Baseline	Endline
i) Visual Representation	11	4
ii) Multiple Representation	3	16
iii) Text/ Textbooks	2	0

Out of 8 focus group teachers whose sessions were observed, 6 teachers used multiple means of representations like video, slides and pictures on smart TV/projectors, students' own examples, drawings, students' group presentations, locally available materials, physical models and charts. One amongst them used charts predominantly and a physics teacher used lots of hands-on activities and experiments.There was a biology teacher who used visual representations like digital images and drawings. Overall, the use of multiple representations could be attributed to CL4STEM as the resources employed by teachers were from the suggested activities in the respective modules.

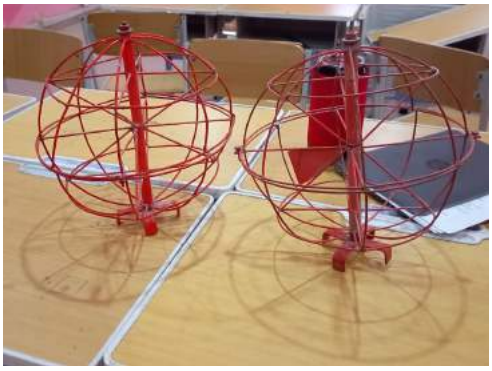
One constraint mentioned by teachers was the lack of ICT infrastructure and even in the schools with enough ICT devices unstable power supply was a problem. An organisation called Skool Media provided ICT infrastructure in federal government schools. The cost of the internet also became a constraint for some. In terms of resource availability, the federal government schools are better equipped with spacious labs and equipment. A mathematics teacher used a physical model relevant to the concept as it was available in the mathematics resource rooms in the federal government school. Some of the resources used by the teachers are shown in the images below.

Atomic structure - Hands-on activities with balloon covering an empty bottle's mouth

Atomic Structure - Dividing droplets hands on activity

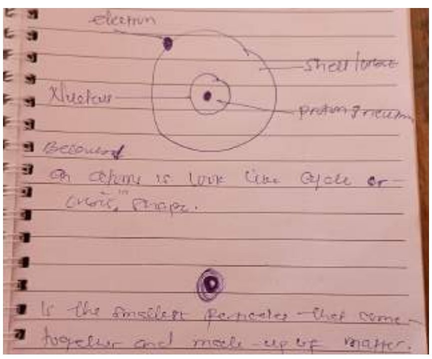
Force - Students lifting potato with straw

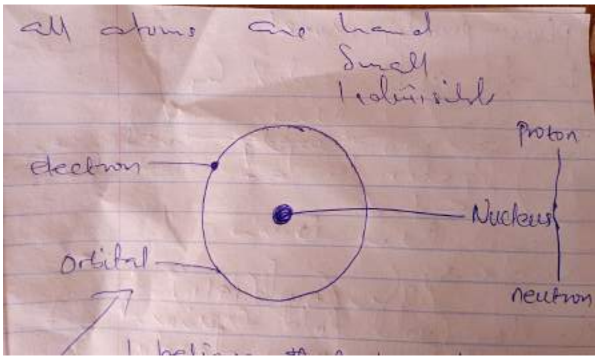
Force - Students using magnet and iron filings, observing the pattern (on the right)

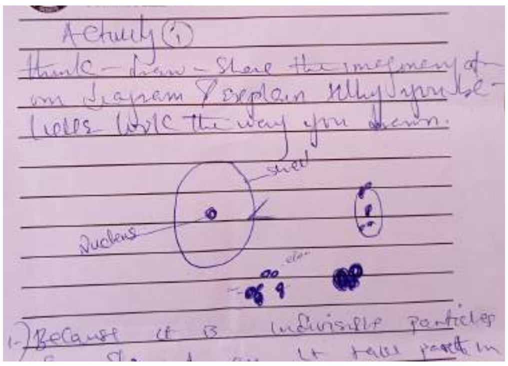


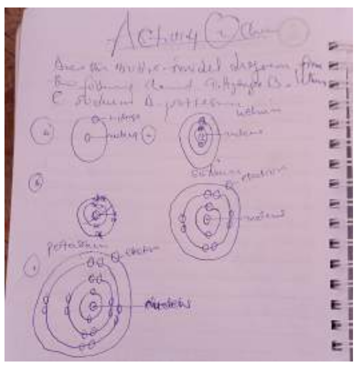
Geometry - Physical model to touch and see latitudes, longitudes and coordinates

Geometry - Measuring the dimension & calculating area, perimeter in groups









Atomic Structure - Students' drawings

Figure 3.2.6. Variety of Resources used in Classrooms

All four subject surveys had listed the resources that the teachers used. They were asked to select from four options: major resource, minor resource, don't use it and dont have access to the resource. In general, there is a slight change observed in surveys on the resources teachers use for science and mathematics teaching. There is a slight drop in the use of textbooks (-3%) and other books (-11%) by teachers and an increase in the use of surrounding contexts (+3%), ICT resources (+4%) and other talks and lectures available offline and online (+9%) has been reported. This is in alignment with the observations from the interviews.

Both male and female teachers have reported a drop in the use of textbooks, other books and a subsequent increase in use of talks and lectures. Female teachers have reported a drop in the use of charts, models and ICT resources and an increase in the use of surrounding contexts. However, only male teachers have reported an increasing use of digital resources.

When comparing early career teachers (with 0-5 years of work experience) and experienced teachers, it was found that both the groups reported a decrease in the use of books other than textbooks and an increase in the use of lectures and talks. There is a decrease in the percentage of early career teachers using textbooks (-7%), charts, models (-4%) and digital resources (-7%) and an increase in the use of surrounding contexts (+7%). Experienced teachers too have reported an increase in the use of digital resources (+10%).

When comparing teachers from federal and state government schools, there is an increase in both sets of teachers using surrounding context, digital resources, talks and lectures. The percentage increase is more in federal school teachers. The state government school teachers have also reported a decrease in the use of textbooks (-3%) and other books (-13%).

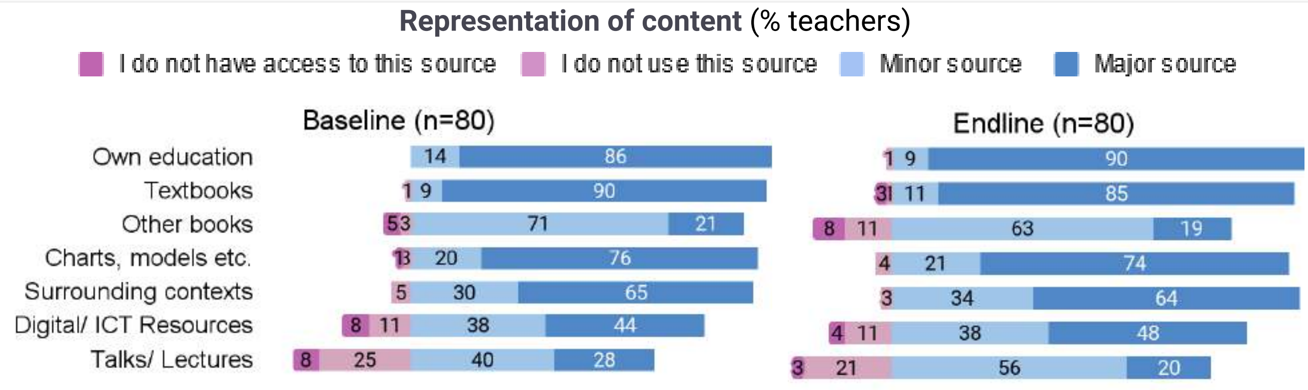


Figure 3.2.6. Representation of Content

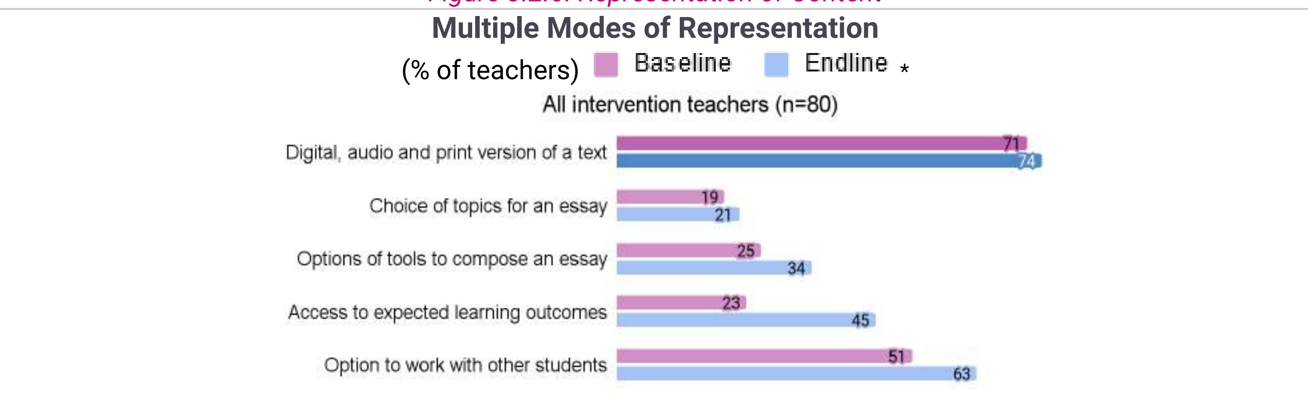


Figure 3.2.7. Multiple Modes of Representation

*the lighter coloured options are not desirable ones

A slight increase of 3% was noted in the correct answers in Endline, when the teachers were asked to give an example of multiple modes of representation. A sizable number of teachers chose “option to work with other students” (63%) and “access to expected learning outcomes” (45%) as examples of multiple modes of representation in the Endline.

We see a notable gain in the percentage of teachers considering the importance of distributive properties in understanding algebraic expression (+20%) from the mathematics survey. In the maths survey, the teachers were quizzed on ways to help a student, who is good at making different objects and figures using paper, but finds it difficult to understand the meaning of algebraic symbols and solving linear equations. Though 15% of teachers chose repeated practice as a strategy in the Baseline, this figure was brought down to nil in the Endline. At the same time, teachers choosing the tile model with pictorial representation (+15%), tile model with hands-on manipulation (+25%) and number line model (+10%) have increased. This indicates a change in the knowledge of mathematics teachers towards active learning using multiple representations, specially in teaching linear equations.

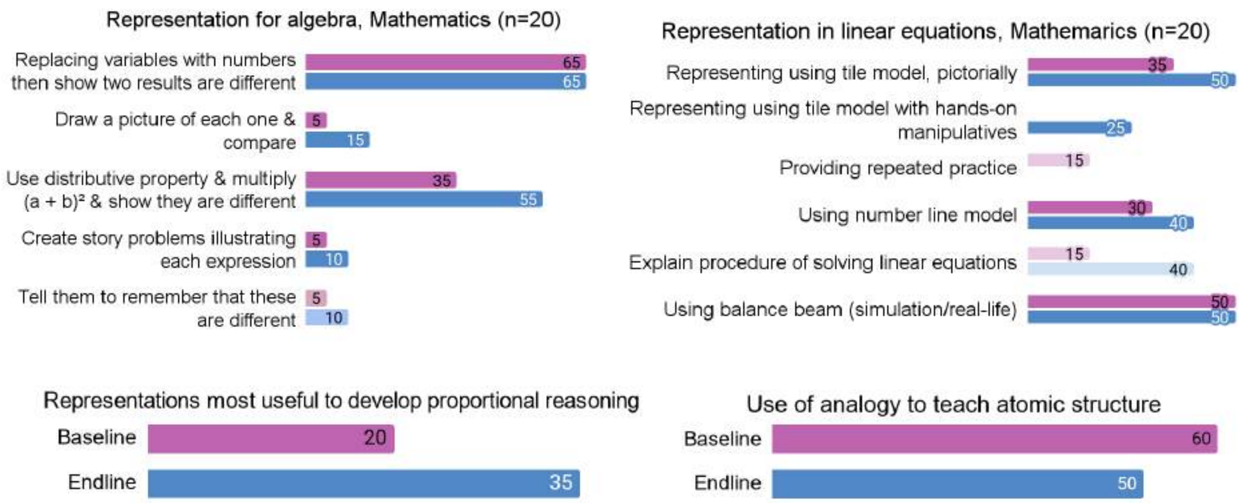


Figure 3.2.8. Mathematics: Representation of Content

*the lighter coloured options are not desirable ones

Mathematics teachers choosing the kind of representation most suited for the development of proportional reasoning increased by 15% in the Endline. There is a 10% decrease in chemistry teachers choosing the appropriate use of analogy to teach atomic structure. This indicates that teachers need further support in representations for teaching atomic structure.

From the interviews, classroom observations and surveys, it is clear that teachers have tried to use multiple means of representation after participating in CL4STEM. Teachers have been exposed to different resources that can be used for the topics in the modules. Classroom observation has evidence of teachers using hands-on activities, visual representations and tactile materials. Even with severe constraints on ICT devices and electricity, the teachers have attempted to use ICT in their instruction. The survey also confirms the change in the use of multiple representations as the number of teachers reporting the usage of surrounding contexts, talk and lectures has increased in the Endline along with a decrease in the use of textbooks alone.

3.2.4 Context for Learning

- Knowledge of the larger school/regional infrastructural, discursive context which shapes their pedagogical choices.
- Knowledge of the environmental/ lab/ material resources available in the context 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

The teachers' conception of context for learning from the interview responses is generally focused on those conditions that support effective teaching and learning in the classroom. The interview responses therefore centred on the availability and use of teaching resources, improvisation, adoption of digital resources for teaching, making learning relatable to the daily life experiences of students, students' considerations, etc. Inadequacy of instructional materials and ICT resources is the most often cited challenge they face.

> "A particular challenge I face is the lack of digital devices. We don't have a projector to display most of the videos and animations. So I can say the most [sic] the biggest challenge I have is the lack of technology, especially something like the projector and maybe the laptop also." (3302, Physics, Midline)

> "Lack of instructional materials like monitor, projectors, the materials should be sufficient in order to improve teaching and learning in the school... in fact, large classes and secondly, lack of instructional materials are my challenges in teaching mathematics." (3101, Math, Midline)

Inadequacy of instructional materials in the context for learning is identified as a teaching challenge at both the Baseline and the Endline. However, at the Endline, it is deduced that the teachers have learnt to adopt appropriate use of local materials, hands-on learning activities and group work to address the lack of material resources. This change in the teachers' general perception of the context for learning that is focused on challenges at the Baseline to one which addresses the challenges at the Endline could be associated with the teachers' experience with the CL4STEM module implementation in which consideration is given to improvisation and group work. This change in teacher perception from the Baseline to Endline are indicated in the following verbal quotes:

"The difficulty we are facing is a factor of interest. Students don't have much interest in science and there is lack of instructional materials." (3501, Chemistry, Baseline)	*"...in atomic structure, I employed local materials to demonstrate atomic structure and engage students in hands-on activities, students work in group to perform the class activities."(Endline)*
"...we don't have the actual or the right apparatus to use for the practicals" (3302, Physics, Baseline)	*"Well, one suggestion is that grouping helps a lot to improve this challenge of instructional materials, engaging in activities and project methods with good instructional materials also help." (Endline)*

The data from classroom observations indicate that teachers adapt resources, use locally available materials to teach their students as seen in these pictures. It was also observed that the teachers attempt to connect the instructional content with the everyday experiences of the students. For example, a physics teacher asked his students to push a trolley and asked another one to close the door to demonstrate force and motion. Group work was a prominent classroom activity that was observed which substantiated the interview findings.

Figure 3.2.9. Students Constructing Atomic Structure Using Local Materials

In the mathematics survey, the teachers were asked to note their level of agreement with relating mathematics to everyday life. All the teachers agreed to it in the Baseline and there was a 10% increase in the Endline who strongly agreed with the statement.

The findings from the interviews and classroom observations seem to corroborate the change that was noticed in the survey. The classroom activities of employing local materials, connecting classroom instruction to real life situations, adapting resources to meet the needs of learners could be attributed to the impact of participating in CL4STEM. The teachers also acquired knowledge on the use of OERs as effective tools to enhance meaningful learning. Teachers' engagement with the CL4STEM module implementation has positively impacted science and mathematics teachers' use of group work. It can be thus concluded that the innovation has implications for teacher practices, continuous professional development and the development of online modules for effective learning of science and mathematics in Nigeria.

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 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

The interview responses with respect to goals and purposes of teaching science and mathematics revealed that the teachers have broad but limited knowledge of the goals and purposes for teaching at the secondary school level. The interview excerpts indicate their view of curriculum knowledge, and the goals and purpose of learning being oriented towards students' future careers:

> "Learning physics in secondary school is very important because by the time they finish, it will enable them to study engineering, medicine, or other sciences." (3303, Physics, Endline)

> "Serves as the basic foundation of every science specialization. It helps students to acquire thinking skills also; it is important because it is the requisite for a career like for a student to become a medical doctor, engineering, pharmacy or teaching science." (3505, Chemistry, Endline)

From the above excerpts, it is evident that the teachers' knowledge regarding learning is leaning more towards providing a foundation for further studies in specialised disciplines and career aspirations in STEM related disciplines at the Endline. The goals related to scientific thinking abilities and skills and application to technology were less mentioned, although the teachers did reflect on them at the Midline and Endline. The goals related to scientific attitudes and the social context of science were not mentioned. Teachers' expressions of the goals of science and mathematics teaching were mostly similar at the Baseline and the Endline indicating little or no change.

Survey analysis also reveals that there is not much change in the curricular knowledge of teachers. The agreement level has shown an increase in the undesirable direction in which the teachers should be required to know the topic in other grades. There is a drop in the percentage of teachers answering right in the physics survey and no change was observed in the mathematics survey.

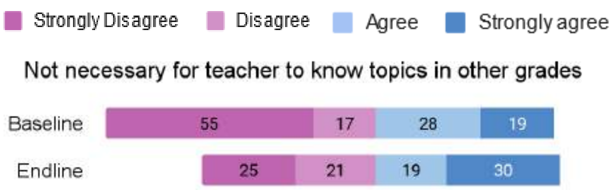


Figure 3.2.10. Curriculum Knowledge

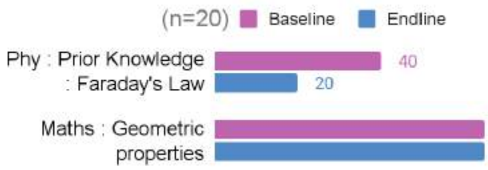


Figure 3.2.11. Maths Curriculum Knowledge

Data from classroom observations on curriculum knowledge indicate that teachers did not seem to demonstrate a clear understanding of curriculum knowledge with regards to hierarchical sequence of foundational concepts for teaching and its inter connection with other concepts in curriculum across grades. It was observed that teachers did not demonstrate knowledge of linkages between their subject matter and other disciplines. This observation corroborates the findings from the survey.

However, it was observed that the teachers demonstrated a good knowledge of planning lessons and presentation in a hierarchical sequence. The 8 teachers whose classrooms were observed began their lesson with an introduction link to real life and engaged the students in group work and hands-on activities. This could be attributed to the impact of the CL4STEM module.

To conclude, the teachers' KAP reflected more on providing foundation knowledge for further studies in specialised disciplines and careers. Furthermore, the goals related to scientific attitudes, and the social context of science were not clearly highlighted. The teachers' expressions of the goals of science and mathematics teaching are mostly similar at the Baseline and the Endline.

3.3 General Pedagogical Knowledge

In the context of this study, the theme of General Pedagogical Knowledge (GPK) deals with teachers' knowledge, attitudes and practices with respect to subthemes common across subjects which includes equity and inclusion, classroom management and assessment to foster Higher Order Thinking with Equity and Inclusion (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 meet diverse needs of learners

This section examined the trends in the interview, classroom observation and survey data to gain insight into the changes in teachers' KAP towards equity and inclusion from Baseline to Endline. The section starts with the findings from interviews of 20 teachers, followed by classroom observation, two Likert scale survey items specific to science and mathematics, and seven Likert scale items and one multiple choice item common across all four subjects. The responses to those eight common survey items were further analysed to see if there were differences in impact based on gender, years of experience and types of schools. The following three sub themes emerged from the interview analysis of change from Baseline to Endline:

i) Understanding of Equity and Inclusion : The respondents seem to perceive equity and inclusion in terms of academic ability, family and socio-economic background in the Baseline and Endline. The overview of the data suggests that the teachers do not consider gender of the students as having an impact on students' learning and performance.

> "I realized that gender is not a big factor to consider in terms of the intellectual ability of the students. And I think what matters is the background of the students and not necessarily the tribal, or ethnic background. Some of the students, the economic background of their parents will contribute to how they learn and perform in the classroom." (3302, Physics, Midline)

> "It all depends, sometimes the girls find it easier than the male and sometimes the male find [sic] it easier than the female, and sometimes differences do not exist." (3103, Math, Midline)

ii) Planning for Equity and Inclusion: There seems to be a slight change in planning lessons to address equity and inclusion as indicated by the following excerpts. In the Endline, a chemistry teacher included the use of instructional materials and methods of teaching to address individual differences.

"Once you are short, and you're sitting behind, I will bring you to the front. And the tall ones to the back." (3702, Biology, Baseline)	*"I teach my students to work as a group, and as a team. I mentioned that in every topic we teach, they carry out practical experiments. I also group them according to their capability, or their intellectual ability, so that they'll be able to blend with each other." (Endline)*
"I also group the students and pick the smart student to lead the group in areas where it's not clear and that enhances their learning ability during the lesson." (3104, Math, Baseline)	*"I will make sure the class is not boring. I take note of individual differences in the class. Highlight the objectives of the lesson, present the lesson with the help of audio-visual materials and group work to cater to individual differences." (Endline)*

iii) Instructional Strategies: Similarly, verbal excerpts from teachers on equity and inclusion indicate that there is change in teacher practices. For example, a maths teacher highlighted in the Midline that group learning could address individual differences. But in the Endline, she highlighted that the use of a variety of instructional materials could address diverse learners in the classroom.

"Some students are easy to learn[sic] *, some of them are slow learners. So grouping will make sure that they are participating and to* [sic] *learn from each other." (3118, Math, Midline)*	*"For some of the students maths is abstract and difficult, but if you use the locally available materials and video as teaching aids, they will understand it." (Endline)*

Excerpts from teachers' interviews also show that teachers engage in classroom activities to address equity and inclusion and this could be attributed to the impact of the CL4STEM project as the following table indicates.

"I teach my students to work as a group, as a team. I mentioned that in every topic we teach, they carry out practical experiments, I also group them and take some things into consideration. When I'm grouping them I group them according to their capability, or their intellectual ability, so that they'll be able to blend with each other." (3702, Biology, Midline)	*"...CL4STEM project has helped us because if you look at the visuals, the group work, and the teamwork that they are doing have really helped everyone to be carried along during the teaching."(Endline)*

"We group them together in a group of five students to 10, they work in a group, those groups will contain the different categories of students; slow learners, and those that learn very fast. So that they can share ideas together." (3503, Chemistry, Baseline)	*"I managed to devise a different method or different material for students to understand. Most of the time I use audio-visuals. Sometimes we use local material for us to meet up with the need of different learners grouping* [sic] *students to help the low learners to learn from their peers." (Endline)*

Based on these verbal excerpts, it could be deduced that there is a change in teachers' practices with regards to equity and inclusion from attributing learning to students' abilities to exploring pedagogical techniques such as the use of group work and multiple representation to meet different student needs.

There are special schools that accommodate students with special needs. These categories of students are not found in the conventional secondary schools science and mathematics classroom. However, the teachers proceeded from identifying individual differences in the Baseline to implementing classroom practices of equity and inclusiveness. This could be attributed to the impact of CL4STEM interventions.

The table 3.3.1 shows that the number of teachers demonstrating an understanding of equity and inclusion has increased from 3 at Baseline to 7 at the Endline. Similarly, there is an increase in teachers planning lessons to address equity and inclusion from 5 at Baseline to 10 in Endline. The number of teachers adapting instructional strategies targeted towards catering individual differences increased at the Endline (+7).

Table 3.3.1. Equity and Inclusion: Interview Analysis

Equity and Inclusion	No. of teachers	
Sub-theme	Baseline	Endline
i) Understanding of equity and inclusion	3	7
ii) Planning for equity and inclusion	5	10
iii) Instructional strategies	4	11

In the classroom observations conducted at the Midline for all the eight teachers, the teachers could be seen organising students into groups which accounts for the individual differences as indicated by this excerpt from a chemistry teacher: “I formed the group taking into consideration of their different learning abilities, I mixed the different learning abilities together to form a group.” (3501, Chemistry). Another teacher in the post-observation interview highlighted that: ‘...they were formed (grouped), taken into consideration different students with different learning ability, the fast learners, the slow learners, maybe the introverts being in a group with extroverts, or are willing to speak up in the class. So that's what I do to motivate them to participate fully in the class activities.” (3513, Chemistry)

> “I distribute them with gender equity, I distribute them according to the number of the boys, the girls so that we can mix them.” (3110, Maths)

These findings from grouping students based on a mix of gender, and academic ability could be attributed to the impact of the module. The following is a teacher’s response on grouping: “I plan to mix them up with those that are very good. I'll mix them up and make sure that during the activity they interact more. The intelligent ones will lead the activities so that everyone will be carried along.” (3702, Biology). Collaborations or group learning was a very prominent feature in the classroom and this could be linked to addressing individual differences. The students in the groups were seen discussing and exchanging ideas in the classroom as seen in these photos of a student discussion on the differences between animal and plant cells.

Figure 3.3.1. Students Engaging in Hands-on Activities in Groups

One of the teachers was observed to be paying more attention to certain students and responded that: “I had to call some particular students who are introverts mostly, that shy away from group activities. So if I call out the name, they have no option, they have to participate. For example, I called one because he does not want to participate, so I paid greater attention on [sic] him.” (3710, Biology)

It was also observed that at the end of each lesson teachers evaluated their lesson by giving equal opportunity to students to answer questions. This observation was supported by the teachers’ post-observation interviews excerpts: “I give more attention to low ability students because of what I learn from the module. I asked questions and pointed at lower achievers to answer so that we can carry them along.” (3513, Chemistry)

“Ask question to both low and high achievers and appoint one student from each group.” (3313, Physics)

The teachers’ pre and post observation interviews indicated that the CL4STEM project has a positive impact on teachers’ attitudes and practices towards equity and inclusion as indicated in the following excerpt: “I employed UDL to take care of different learners. I use videos to take care of the different learners." (3501, Chemistry). These changes could be attributed to the impact of the project.

Two statements in mathematics surveys regarding students' natural ability and interest to learn mathematics had lesser agreement in Endline than Baseline. The teachers who disagreed that mathematics is a subject in which natural ability matters much more than effort increased by 15% in the Endline. All the teachers agree that to be good at mathematics, the learners need to be interested in mathematics both in Baseline and Endline. There is, however, a 10% decrease in those who strongly agree. This shows that there is a slight change in teachers' attitude towards attributing learning of mathematics to students' abilities and interest. There is an increase in the number of science teachers who agree that teachers should use a system for calling out students to speak so that everyone gets an equal chance to speak (+3%). Simultaneously, there is a decrease in teachers (-2%) who agree that using examples relevant to students with different cultural experiences helps in understanding science.

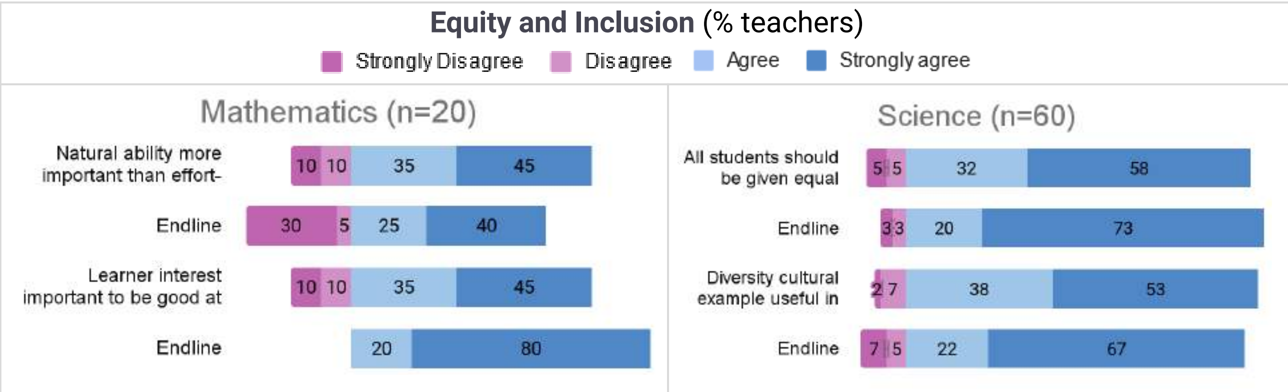


Figure 3.3.2. Change of Perceptions in Students' Ability and Interest

Teachers were asked to choose which group of students pose a challenge for them to teach effectively in the survey. There is an overall increase in the number of teachers who have chosen each group given in the table below. This could be attributed to the fact that there is more awareness about diverse learners. Students with special needs, physical or psychological, were chosen by the highest percentage of teachers in Baseline(50%) and Endline (63%). In Baseline, the least number of teachers chose students with poor motivation (25%) as a challenge to teach. In Endline, students from a wide range of social, ethnic or religious backgrounds have the least number of takers (38%).

There is an increase in male teachers (+26%) finding students from a wide range of social, ethnic or religious backgrounds and students with special needs (+36%) challenging. While female teachers find students who are disinterested (+30%) and with disruptive behaviour (+19%) as more challenging. In the Endline, the number of early career teachers reporting students with special needs as a challenge decreased by 18%, while there is a significant increase in experienced teachers (+23%) who find them challenging. The increase in teachers choosing more groups of students as challenging in the Endline can be attributed to the fact that teachers had to plan and implement CL4STEM lesson plans addressing diverse learners. This has resulted in increased awareness.

Table 3.3.2. Students who Pose a Challenge to Teaching

Which group of students pose a challenge for you to teach effectively (% of teachers)	Baseline					Endline					Change				
	B	C	P	M	Mean	B	C	P	M	Mean	B	C	P	M	Mean
With different academic abilities	28	48	28	52	**39**	35	60	50	55	**50**	7	12	22	3	**11**
From wide range of social, ethnic or religious backgrounds	36	32	32	28	**32**	35	55	40	20	**38**	-1	23	8	-8	**6**
With special needs, physical or psychological	60	40	64	36	**50**	65	60	80	45	**63**	5	20	16	9	**13**
Students who are disinterested	40	36	44	56	**44**	60	40	50	60	**53**	20	4	6	4	**9**
Students with poor motivation	28	20	32	20	**25**	45	40	35	40	**40**	17	20	3	20	**15**
Students with disruptive behaviour	20	24	28	44	**29**	45	50	55	35	**46**	25	26	27	-9	**17**

There are three statements around students' abilities in all the four subject surveys. They are negatively worded; it is impractical for teachers to tailor instructions to students of different abilities, and better for students of different achievement levels to be divided into separate classes and it is not always possible to include students with disabilities in a regular classroom. The average increase in percentage of teachers' disagreement to these statements was 2%.

Overall, 90% of teachers agree that they try to ignore gender, ethnic or religious differences amongst their students to help all their students understand mathematics or science. The percentage of agreement remains unchanged in the Endline. There is a slight decrease (3%) in teachers disagreeing with the statement, members of some religious/ethnic/cultural groups are just not as motivated as others to learn irrespective of the teaching method. There is a 2 percent decrease in the desired level of agreement to the statements. This shows that teachers' knowledge and attitudes towards being inclusive of different ethnic and religious groups needs further support.

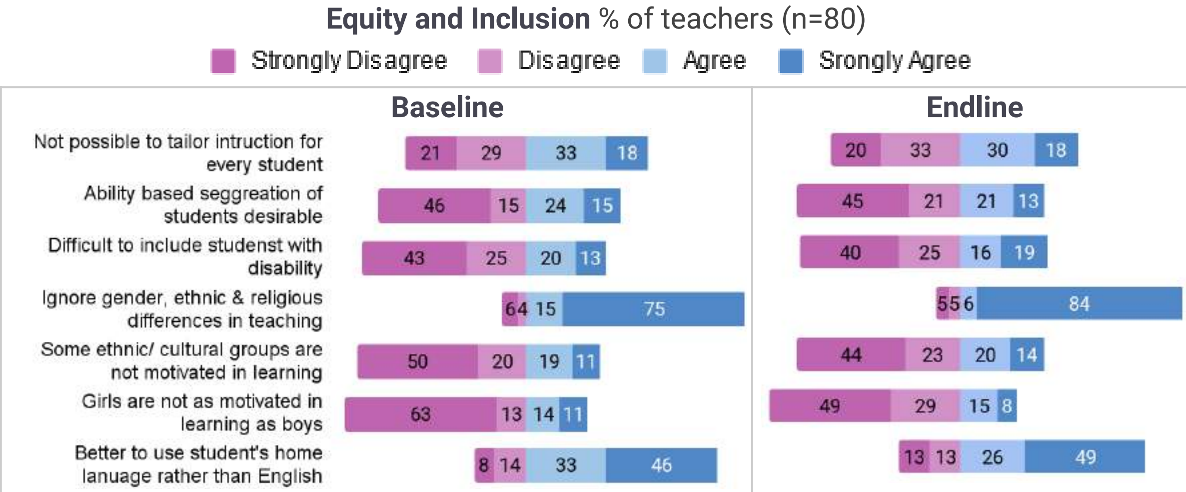


Figure 3.3.3. Change in Equity and Inclusion

The other two aspects of equity covered under the survey were gender and language. There is an increase (+3%) in teachers disagreeing with the statement that boys tend to be naturally better than girls. There is a 4 percent decrease in teachers who think it is better to use students' home language rather than only English. Science and mathematics at secondary school are available only in English in Nigeria and in some schools the use of English is mandated by school management. So the teachers do not have much choice to switch to the students' home language.

Table 3.3.4. Classroom Management: Interview Analysis

Sub themes	Baseline	Endline
Class settings and regulatory practices	9	1
Socio-psychological learning environment	0	2
Group work	5	12

To conclude, a positive change was observed in science and mathematics surveys on teachers' knowledge and attitude towards the adoption of the UDL principles to address diverse learner needs in the classroom. Though there is also a positive change in the teachers' perception of students with different abilities and gender, an inclusive perception of different ethnic and religious groups needs further support. The use of local language in the classroom needs to be evaluated as an inclusive practice both at the school management level and the educational policy level to support teachers in that regard. The observations and interview findings corroborated the survey data that there is a change in teachers KAP with regard to equity and inclusion. The major highlight of the CL4STEM project is the adoption or use of group work and multiple representation to cater for the learning needs of diverse learners which is a major shift from their usual classroom practices. These findings, as a whole, would provide the required motivation for the scaling of this project.

3.3.2 Classroom Management

- Knowledge of multiple modes of classroom interaction such as 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

The teachers' interview provided the qualitative data on the teachers' classroom management practices. The management practices include grouping students as strategy for managing large classes, organising sitting arrangements that consider individual differences and needs, and the use of regulatory measures to ensure orderliness in the class. The analysis of interview responses regarding the classroom management practices of the focus group teachers at the Baseline and Endline phases of the CL4STEM project are summarised and classified in table below.

The predominant classroom management strategies employed by the teachers involves grouping students for learning activities and as a way controlling large classes, in addition to maximizing the use of limited learning resources. There is a noticeable upward (+7) trend in the teachers' responses to the use of grouping from Baseline to Endline. The use of regulatory practices to maintain orderliness and discipline declined from 9 teachers at the Baseline to just one teacher at the Endline as the teachers began adopting more frequent group work in their classes. Also, the teachers have initiated steps towards creating a friendly learning environment at the Endline which satisfies students' needs, motivating the students to remain calm as they engage in group work.

In the context of the above, the majority of the focus group teachers (12) at the Endline use group work as classroom management strategy which helps in managing large classes, organising the sitting arrangement and time management. It should be noted that though the teachers (5) have noted grouping as a management strategy even at the Baseline, the adoption of it gets embedded over the time from the Baseline to Endline. The trend in classroom management change from physical seating arrangement and teacher correctional practices in the Baseline to grouping students as part of classroom management in the Endline is evident in the following verbal excerpts.

"If I find you misbehaving, I will ask you to stand up facing the board. I'll give you a problem to solve." (3103, Math, Baseline)	*"I used to group them. Okay, grouping. Maybe a class of 70, I group them into 4. The only thing that's available in school is textbooks and even the textbooks are outdated so I have to improvise the instructional materials and local resources." (Midline)*	*"I also ensure a learning environment that promotes cooperation by getting students to work in their respective groups." (Endline)*

Similarly, a change was observed in the perception of the following chemistry (3502) and biology (3710) teachers as can be discerned from the Baseline and Endline excerpts:

"I make sure they are correctly seated then I introduce the lesson of the day." (3502, Chemistry, Baseline)	*"...most cases, I noticed that grouping helps to manage my class and to meet the learning needs of the students" (Endline)*
"Because, some of the times these classes are conducted in the lab, so when you take them to the lab, right from the rules of the lab, they know that they are supposed to behave themselves and listen, or obey the teacher in the classroom" (3710, Biology, Baseline)	*"You see like the groupings when I grouped my students, the next time I was having a class with them, I just simply asked them to join the previous groups, there was no hectic* [sic] *or waste of time, everyone went into his respective group and the class continued without any extra stress."(Endline)*
"...whenever I am in the class, they don't talk except the ones who want to ask questions, and when the student wants to ask a question they have to indicate by raising their hand." (3305, Physics, Midline)	*"Group work sometimes help* [sic] *us to control the class and students also concentrate and interact with each other." (Endline)*

From the analysis of the teachers' interview responses, the teachers have made great strides in adopting grouping as a classroom management strategy from the Baseline through to the Endline. Their perceptions regarding the adoption of grouping in classrooms have also evolved. Sitting arrangement in the classroom/laboratory was earlier thought to ensure orderliness and avoid disruptive behaviors. The idea that the same could be used for inclusive practices, overcoming large class challenges and for the efficient use of learning resources was comparatively new and also welcomed. Gradually, from Midline to Endline, the teachers successfully enhanced the concept of group work as classroom management strategy and developed practices which promote greater students' interaction and participation with consideration for individual learners' needs and interests, learning activities, experimental work and group assessment practice. Overall, positive changes have been noted in teachers' perceptions and the use of classroom management practices from the Baseline to the Endline with particular reference to using grouping to enhance learning with equity and inclusion.

In the classroom observations conducted to record teachers' attitudes and practices with regards to classroom management, all the 8 teachers demonstrated the ability to organise and manage their classroom. They have also been found to be skilled at arranging group activities as an approach to manage large classes.

> "Keep changing the groups according to abilities and to manage disruptive behaviour. Everything went quietly and smoothly. The best ones are made by the group leaders." (3110 Math).

> “Grouping was based on the table arrangement, size of the group is based on population. Maybe I have to make them into six groups. But it will be difficult to manage the pre-test and adequate materials. Grouping is based on how they arrive in the lab - first come sit on first row” (3303, Physics)

The teachers demonstrated the ability to manage time, space and employ learning resources effectively, along with managing students’ behaviour. The disruptive students were asked to stand up for 5 minutes by a particular teacher. The classroom was well managed by the teacher as he cautioned some of the students about not paying attention. However, one of the teachers observed that CL4STEM approach may not be appropriate for large classes: “No, it (CL4STEM) is not suitable (for large classrooms), there will not be total class control. And maybe, definitely, some will never participate, you cannot control and see who is participating or not, and some will always lag behind. Because the population is so large, it cannot cover all of them. Maybe when you divide them into different classes and take them separately. You can overcome that difficulty.” (3513, Chemistry). The findings from Midline observation seem to triangulate the findings from the interviews.

In the survey, the teachers were asked about the practicality of teaming students of varying capacities to work together, as it is possible that the brighter students would end up doing all the work. Most teachers disagreed with the statement in both Baseline (68%) and Endline (77%) indicating an upward growth in the teachers (+9%), who consider it beneficial to group students of mixed ability together. When the responses were sliced based on gender, years of experience and type of school, there was an 8-10% increase in disagreement with the statement, except for federal government school teachers. From the Endline it can be inferred that more teachers prefer students to work in mixed ability groups.

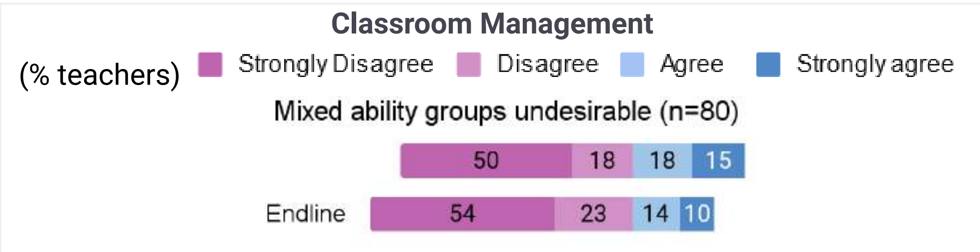


Figure 3.3.4. Change in Classroom Management

Given the findings from the survey, interviews and classroom observation data, there is a change in the perception of classroom management in terms of sitting arrangement, correctional practices and class control to create a conducive learning environment. The same can be said for the adoption of management practices that ensure collaborative learning through group work at the Endline. A change from adopting sitting arrangement in the class to employing group-task strategy to manage large classes and for effective supervision is noted among the teachers. The change created in teachers’ KAP on classroom management could be associated with the implementation of the subject modules designed for teachers to engage students in group work in an inclusive classroom setting.

3.3.2 Assessment

- Knowledge of multiple methods and tools of assessment for students to express in multiple ways
- Ability to use assessment for and of learning
- Ability to design and use a variety of methods and tools of assessment, including task-based assessment

The interview analysis demonstrates the fact that teachers administer tests, assignment, examination, class activity, group work, students' presentation and project work as assessment tools. For the purpose of interpreting, the teachers' perception and assessment practices could be classified into three sub-categories as presented in table 3.3.5.

i) Summative Assessment Methods: Examination, tests, quizzes and homework are frequently used in traditional assessments as the primary methods to ascertain whether the objectives of learning have been achieved. It mostly focuses on learning products rather than the learning process. Science and mathematics assessment can be used to evaluate how well the students have achieved learning goals. The majority of teachers (11) perceive classroom assessment as a summative assessment in Baseline as indicated by the following verbal excerpts: "Quarterly, through tests and assignments, we assess the students. I usually do assessments and if 90 or 95%, even 60% respond positively to the question, I think I've achieved the objectives of the lesson to some reasonable extent." (3102, Chemistry, Baseline).

ii) Diagnostic Assessment: This type of assessment helps the teachers to identify gaps in students' knowledge so as to support their learning. In order to build on the students' strengths and address their specific needs, teachers may find diagnostic assessments helpful in determining students' prior knowledge or understanding. It is a systematic process of making decisions pertaining to students' learning and growth in cognitive, affective and psychomotor skills as understood from this example: "I give the question to the student in order to evaluate their understanding, asking them questions or asking some questions related to what I teach them. Their ability to answer questions correctly shows that the student understands the lesson." (3303, Physics, Baseline)

iii) Formative Assessment: These are assessment practices that focus on the learning process rather than the learning product. Students are engaged in group work, hands-on activities and learning in a social context as a means of assessment. The teachers' perceptions mirror these activities as indicated in the following excerpt "...they were able to respond to my own questions. And even when they were given an opportunity to team work, and make a presentation at the end of the group work or project. So they give me the confidence that they were all carried along." (3702, Biology, Endline)

There seems to be a consistent change from the Baseline to the Endline interview analysis. The result indicates a decrease in the number of teachers using only summative assessment (-7) and an increase in teachers (+2) using diagnostic assessment, and adopting group and project work as means of assessment. The change could be attributed to the impact of participating in CL4STEM project learning as evidenced in the change from traditional assessment practices to assessment for learning practices as the following excerpts show:

Table 3.3.5. Assessment: Interview Analysis

Assessment	No.of teachers	
Sub-themes	Baseline	Endline
Summative Assessment	11	4
Diagnostic Assessment	2	4
Formative Assessment	1	8

"I give the question to the student in order to evaluate their understanding. asking them questions or asking some questions related to what I teach them. Their ability to answer questions correctly shows that the student understands the lesson." (3303, Physics, Baseline)	*"I engage students in group lessons, then I give them group exercises. Through asking them questions and assessing their presentation." (Endline)*
"I ask some questions in between the teaching, I ask questions after the teaching and based on my behavioral objectives, and sometimes when I enter a class, and I'm introducing a new topic or continuing a previous topic, I draw their attention back to the previous lesson we had by asking them questions based on what I have taught them to make sure that they are coming along" (3702, Biology, Baseline)	*"...they were able to respond to my own questions. And even when they were given an opportunity to carry out teamwork, and make a presentation at the end of the group work or project. So that will give me the confidence that they were all carried along." (Endline)*

Given the verbal excerpts above, it could be said that teachers mostly engage in summative evaluation and focus on the product of learning at the Baseline. This is further complemented by the change in KAP towards assessment for learning in the Endline.

From the survey it can be observed that there is an overall decrease in the percentage of teachers using standardized exams produced outside of school (-5%) and projects/practical/laboratory activities (-1%). There is a simultaneous increase in the use of tests that require students to describe/explain their reasoning (+6%) along with observation and participation of students in the classroom (1%). Both male (9%) and female (4%) teachers have reported the increased use of tests that require students' reasoning. A four percent increase in female teachers have also been reported to be using projects/practical/laboratory activities in the Endline. Male teachers increasingly use observation and participation of students in the classroom (6%) as assessment.

The percentage of early career teachers has shown a considerable decrease in using standardized exams produced outside schools (-21%). There is also a 4% increase in teachers with more than five years of experience using standardized exams produced outside school. The percentage of early career teachers employing tests that require students to describe/explain their reasoning along with the observation and participation of students has also increased by 4 percent. Among the more experienced teachers too there is an increase of 8% when it comes to the usage of tests that require students' reasoning.

There is an increased use of standardized tests by 38% among the teachers of federal government schools, while the teachers from state government schools report a decrease in the usage of such tests by 8%. There is an increase among the latter group of teachers using tests that require students' reasoning and the observation and participation of students in the classroom.

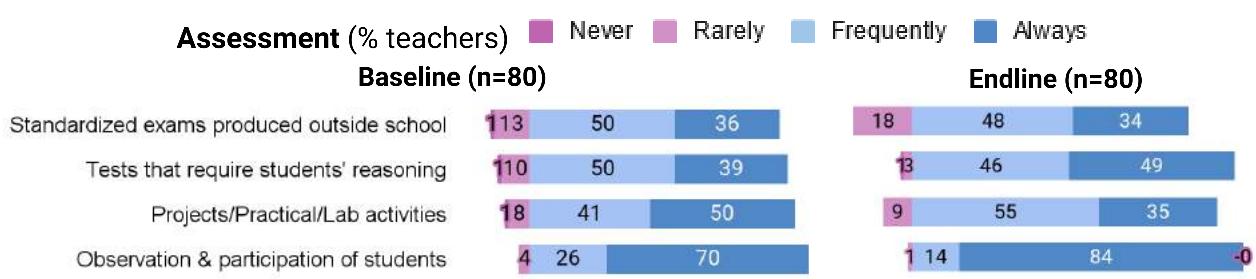


Figure 3.3.5. Change in Assessment

In the classroom observations conducted to record teachers' perceptions, attitudes and practices with regards to classroom assessment, all eight teachers were found to be engaging in diagnostic assessment. One of the mathematics teachers tested prior knowledge by asking questions in the beginning of the session. Assignments were also given prior to the session to test the prior knowledge. (3101, Maths). One of the respondents from chemistry also did share their plan to test prior knowledge: ”I will give the students a pre-test to understand their level of understanding.” (3501, Chemistry)

The teachers were also observed to engage in informal assessment and peer assessment. For example, a mathematics teacher used group presentation and peer assessment (It was written as PIERS assessment in the slide and the teacher also pronounced it the same way. This can be an indicator that the teacher is using it for the first time- trying something suggested in the modules). This finding is supported by the following excerpt: "I think I have achieved my objectives because you can see we have four different groups. Among those four groups, three groups performed very well, for both two activities there was only one group that had some mistakes along the way. So I think we have achieved our aims and objectives for the lesson." (3110, Math)

It was observed that at the end of the lesson all the 8 teachers asked evaluation questions to determine if the objectives of the lessons have been achieved. More than 70% of the students in each class gave correct answers. This was supported by teachers verbal excerpts:

> “The objectives of the lesson were achieved because the students participated in the lesson and answered all the questions I asked during evaluation.” (3501, Chemistry).
>
> “The objectives of this lesson have been achieved. It has been achieved, because at the end of the lesson, I was able to ask one or two questions to ensure that my goals and objectives are achieved. In fact, the response from the students [sic], I was so impressed.” (3702, Biology)
>
> “You see if I ask those questions, and you're not giving me answers, it means I have to go back to explain [sic] certain points, maybe that I have passed. But as they are answering, it's telling me go ahead, go ahead, go ahead [sic]. At the end of the lesson, I asked the students questions and about 90% of the students responded correctly.” (3710, Biology).

These excerpts indicate a clear case of formative assessment which is employed throughout the teaching and learning process and not at the end of the learning session. The findings of the survey and the classroom observations corroborate the findings of the interviews that show that teachers meaningfully engage in diagnostic and informal assessment which can be attributed to the impact of CL4STEM project. One of the important highlights is the use of peer assessment and group presentation as an assessment strategy, which is a clear shift from the usual summative assessment practices that seem to characterise the traditional science and mathematics learning environment in Nigeria. Therefore, it is logical to conclude that the change could be the result of the impact of the CL4STEM project.

4. Teachers' Perceptions on CL4STEM

To study the perceptions and understandings of the participating teachers over time regarding CL4STEM , research on innovation diffusion was conducted. The widely accepted Concerns Based Adoption Model (CBAM)[35] developed by Hall (1974) was used to study the diffusion of the innovation using Levels of Use (Hall, Dirksen & George, 2006)[36] and Stages of Concerns (George, Hall & Stiegelbauer, 2006)[37] interview questionnaires and surveys. These surveys focus on understanding the practices and attitudes of participants towards a particular intervention. As discussed in the chapter on methodology, Levels of Use focuses on the different levels of engagement and practice of participants with the CL4STEM TPD components (Modules and CoPs). Twenty interview participants shared their responses for Stages of Concern (SoC) and Levels of Use (LoU) questionnaires at Midline and Endline. At the Endline, along with focus group participants, all the 80 teachers participated in the SoC and LoU survey.

This section presents the varying needs and concerns of participants during the pilot implementation from analysis of these surveys and interviews. It is followed by teachers' perception of CL4STEM using Moore and Benbasat's Innovation Diffusion framework (1991)[38] comprising 7 characteristics.

4.1 Levels of Use

Levels of Use (LoU) identifies 8 levels of use for participants with respect to an innovation as given in the table 4.1. In CL4STEM, 8 statements were used to capture these different levels of engagements. Interviews were conducted with 20 focus group teachers in Midline and 17 in Endline. The analysis is presented below:

Levels 0-3: None of the teachers at Midline and Endline interviews were at the Non-use, Orientation and Preparation level. At the Midline, 2 teachers were at the Mechanical Use stage of learning how to effectively navigate CL4STEM modules and Telegram group (CoPs) and none reported to be at this stage at the Endline indicating an improvement in their Level of Use.

Levels 4a & 4b: 7 teachers at the Baseline were comfortable with CL4STEM modules and Telegram groups. They were able to implement the teaching strategies in class as per instructions given in the modules and discussed in the Telegram groups. It decreased to 6 at the Endline. This was reflected in the following interview excerpt: ". . . I'm able to access the online modules fairly easily and I find the CoP Telegram group very helpful" (3316, Physics, Endline).

3 teachers reported to have adopted CL4STEM teaching strategies to meet the different needs of students without diluting the core objectives of CL4STEM at the Baseline. It decreased to 1 at the Endline.

[35] Hall, G. E. (1974). The Concerns-Based Adoption Model: A Developmental Conceptualization of the Adoption Process Within Educational Institutions.
[36] 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
[37] 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
[38] 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.

Levels 5-6: 7 teachers reported that having internalized the CL4STEM teaching strategies they are able to collaborate with other teachers around CL4STEM teaching strategies to meet the different needs of students. Teachers choosing this level of use increased to 9 in the Endline. During the interview, a teacher responded to the usage of modules and CoP as follows:

"If I'm to assess myself based on our implemented module, I think I can actually teach someone details on how to use the module" (3502, Chemistry, Midline).	*"Because we compare our ideas, it's like making the learning process better. In the light of CL4STEM, I'm able to meet the different needs of students, and now I'm well, using very different teaching approaches."(Endline)*

Only 1 teacher reported that they had internalized the CL4STEM teaching strategies and was in a position to suggest well thought out modifications and alternatives to the present innovation at both Midline and Endline.

Table 4.1. Levels of Use

Levels of Use	Statements	Focus group (20)	
		Midline	Endline
0. Non- Use	Little or no knowledge of CL4STEM, No involvement and/or no intention to be involved	-	-
1. Orientation	Trying to know more about CL4STEM	-	-
2. Preparation	Not yet assessed CL4STEM modules and Telegram groups (CoPs) but plan to do so soon	-	-
3. Mechanical use	Still learning how to effectively navigate CL4STEM modules and Telegram groups (CoPs)	2	-
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)	7	6
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	1
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	7	9
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	1
	Total	**20**	**17**

Teachers mentioned in the interview that they find the modules easy to access and understand. They expressed that they are more capable to employ CL4STEM teaching strategies like organising group work, engaging students in learning activities, and using UDL principles for ensuring equity and inclusiveness in teaching strategies even when needed apparatus are not available. The teachers mentioned that they also use these strategies to teach other topics in the curriculum. It can be deduced that the teachers have improved from low Levels of Use of the modules and CoP at the Midline to higher Levels of Use, revealing a trend towards higher order of engagement. The

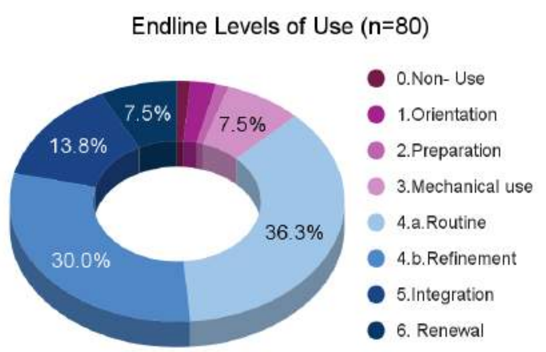


Figure 4.1. Endline Levels of Use

reasons the teachers gave for their choice of Level of Use are an expression of positive perception towards the CL4STEM TPD model which is reflected in the experiences teachers had during the implementation of the modules.

At the Endline, LoU survey was conducted with all 80 participating teachers. The highest percentage of teachers (36%) reported to be at the level of Routine, that they are comfortable with the CL4STEM model and able to implement the teaching strategies in their class. 30% of teachers reported to be at the level of Refinement, that they have adopted CL4STEM teaching strategies to meet the different needs of their students. About 14% of teachers reported that they were able to collaborate with other teachers around CL4STEM strategies. Overall, the largest percentage (53%) of teachers were at the stage 4 of Levels of Use at the Endline.

4.2 Stages of Concern

Stages of Concern (SoC) is another part of the Concerns Based Adoption Model which keeps people at the centre of the change process, in this case, the teachers. It focuses on the teachers' attitudes towards the CL4STEM model. The original 35 item questionnaire from CBAM was adapted into a 7 item survey for meeting the practical constraints of implementation. Teachers' response on the stages is indicated by 19 teachers in the Midline interview and 17 teachers in the Endline. The SoC teacher interview analysis along the various stages is presented below.

Table 4.2. Stages of concern

Overall Stages of Concern[39]		Focus group (20)	
		Midline	Endline
0. Unconcerned	Not interested to participate in CL4STEM	-	-
1. Informational	Know about CL4STEM, and would like to use at some point in time	-	-
2. Personal	Concerned about the demands of CL4STEM vis-a-vis existing workload and how it fits in the existing working conditions	3	7
3. Management	Grappling with how to effectively navigate the online modules and participate in the Telegram groups of CL4STEM	4	2
4. Consequence	Evaluating how CL4STEM teaching strategies impact/help in student learning	-	-
5. Collaboration	Exploring ways of collaboration with other teachers and educators to help impact student learning using CL4STEM teaching strategies	11	3
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	5
	Total	**19**	**17**

None of the teachers reported to be in stages 0, 1 and 4 of the Stages of Concerns. There is an increase in the numbers of teachers at stage 2 concerned about demands of CL4STEM with existing workload from 3 at the Midline to 7 at the Endline. The reasons of reference cases at Midline and Endline were reflected in the following interview quotes:

[39] Southwest Educational Development Laboratory, George, A. A., Hall, G. E., & Stiegelbauer, S. M. (2006). *Measuring Implementation in Schools: The Stages of Concern questionnaire (includes*. Southwest Educational Development Laboratory.

> “. . . because most of the time when we are working for this, we are also working with our curriculum for our school that makes the work bulky for us” (3110, Math, Endline).
>
> “I want the modules to align with the curriculum and with the scheme of work” (3501, Chemistry Endline).

2 teachers at the Endline were still grappling with how to effectively navigate the online modules and participate in the Telegram groups of CL4STEM as compared to 4 at the Midline. There is a decrease in the number of teachers from 11 at the Midline to 3 at the Endline who are exploring ways of collaboration to help impact student learning using CL4STEM teaching strategies. Teachers mentioned collaboration in interviews as follows:

> “. . . collaborating on a platform helps me to share online resources for teaching” (3303, Physics, Midline).
>
> “I have a collaboration with my teacher educator and other teachers in different schools” (3705, Biology, Endline).

The number of teachers exploring ways to improve CL4STEM teaching strategies through further refinement of the modules and CoP participation increased from 1 at Midline to 5 at Endline at stage 6. A physics teacher mentioned in her interview that “...we are in the process of exploring CL4STEM and all sorts of strategies.” (3303, Physics, Endline)

The reasons given by the teachers for their various choices of Stages of Concern are generally centred on the following challenges they experienced while implementing the modules:

I. High workload and a large number of students (6)
II. Lack of ICT facility and internet challenges (2)
III. Misalignment of the module with the school calendar was the most mentioned concern (9). Consequently, the teachers have often scheduled separate lesson time for the teaching of the CL4STEM topics which further compounded their workload.

At the Endline, SoC survey was conducted with all 80 participating teachers. It was seen that the highest percentage of teachers (37.5%) reported to be at stage 5, exploring ways of collaboration with teachers and teacher educators to help impact student learning using CL4STEM teaching strategies. This was followed by 23.8% of teachers at stage 4 and 18.8% at stage 6. In total 80% of participating teachers have selected sophisticated stages of concerns and it indicates a nuanced understanding of the CL4STEM model of professional development.

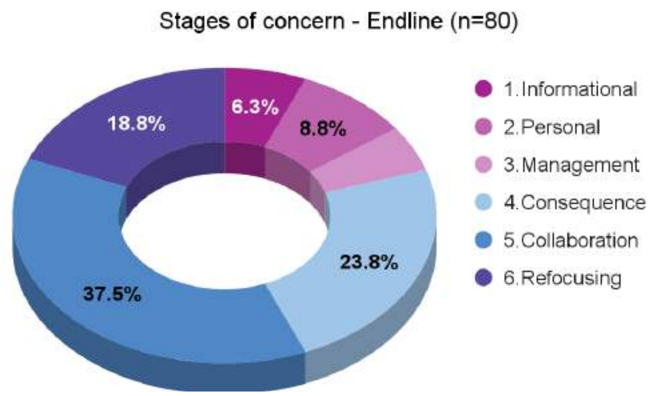


Figure 4.2. Endline Stages of Concern

4.3 Perceptions

Perception survey was designed based on the Moore & Benbasat (1991[40]) instrument to measure the perceptions of adopting an Information Technology innovation. The survey had 23 items on seven themes. The changes from Baseline to Endline on these seven themes are presented in the sub sections below.

4.3.1. Voluntariness

In the context of CL4STEM, voluntariness seeks to ascertain whether the participating teachers freely joined and participated in the project or were compelled by their principals or heads of their schools to participate in the CL4STEM project. Data from interviews on voluntariness indicated that most teachers were nominated by their principals but they were not compelled by the principals to stay in the project as indicated in the following Baseline verbal excerpt: "Voluntary participation. I didn't know who chose me, but I was called upon by my head of department and I agreed to fill a consent form" (3710, Biology, Baseline).

There is an increase in the number of teachers claiming voluntariness from 12 in the Baseline to 15 in the Endline. This is indicated by teachers providing reasons for their participation in the CL4STEM voluntarily as indicated in the following excerpts: "I was one of the participants selected by my school, and since then I did a lot. I developed an interest, as a teacher to get more knowledge, exposure, and additional certificate and a little token to your pocket because of the resources we were given."and in the Endline the same teacher said: "As a qualified teacher, I joined voluntarily" (3103, End line, Mathematics).

Similarly, another teacher indicated the reason for his voluntary participation in the excerpts below:

> "At first, I was influenced but now I found it more interesting." (3710, Biology, Midline).
>
> "CL4STEM, I see, is important to me. So I think it's an opportunity. I will say it's an opportunity that comes to me and I cannot deny I'm very happy to be part of it." (3118, Biology, Midline).

The measurement of voluntariness is based on two 7-point Likert statements in the survey. The first statement was regarding whether the teachers felt that their school principal required them to participate in the project. The second statement mentioned that participation in the project was not compulsory. Only 15% of teachers agreed that the school principal does not require them to participate in the CL4STEM project in Baseline and this number decreased by 8% in the Endline. 46% of teachers confirmed that the participation was not compulsory and it increased by 9% in Endline. Voluntariness was on average 31% in the Baseline and there was no change in the Endline. Female teachers, teachers with more than 5 years of experience, chemistry teachers, and physics teachers have shown a positive change with regard to voluntariness.

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[40] 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.

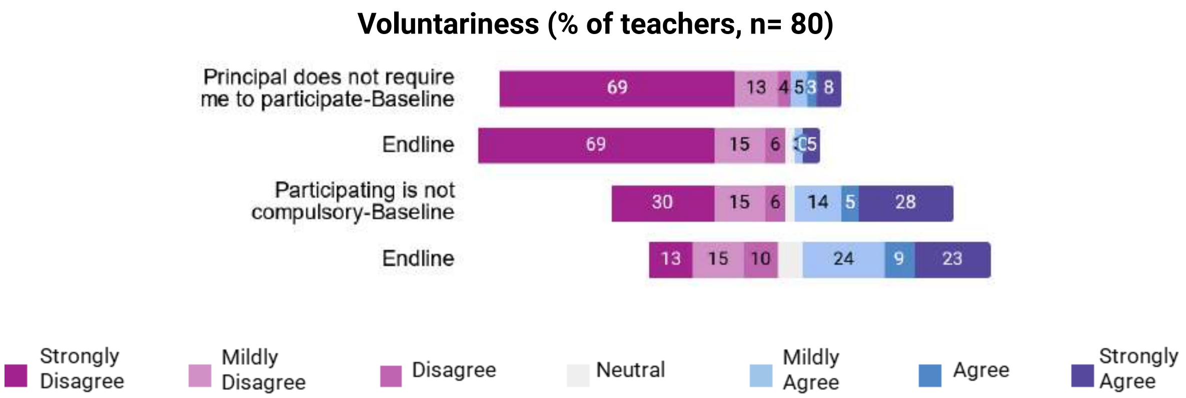


Figure 4.3. Change of Perceptions in Voluntariness

Even though the teachers were selected by their principals or school management, they generally agreed to participate. This indicates that the principals' permission was required for participation but it was not compulsory. As it is a pilot of the TPD innovation, not all science and mathematics teachers from a school could participate and therefore, they were chosen by the principals. Interviews and survey data show that school heads have a greater role in selecting teachers for CL4STEM professional development, even though the teachers were not compelled to join.

4.3.2. Relative Advantage

Relative Advantage refers to the degree to which an innovation is perceived as being better than its precursor. In this study, it is the degree to which science and mathematics teachers perceive CL4STEM or the innovation associated with CL4STEM instructional practices as better than their existing classroom practices which are mostly characterised by traditional classroom practices. The teachers' interview responses clearly indicated that the project has relative advantages over their usual classroom practices as indicated by a teacher: "The advantage is I can teach the students better. I have no idea how to teach this to date, but within a very short time, the students understand the concepts. Based on the modules, I learn from the CL4STEM, the animations and the videos attached to the modules help a lot. I have an idea on how to get more videos, not necessarily from the modules, to incorporate into my lessons. So it gives me more advantage."(3302, Math, Midline)

One mathematics teacher mentioned how the project has helped him teach geometry in mathematics: "Geometry in mathematics is a very difficult topic, the students find it very difficult. In fact, even with the teachers. But in fact, when I picked the topic and with help of a CL4STEM like a CoP and other teachers, I later found that yes, geometry is very, very simple and even the students love it." (3101, Maths, Endline) All the 20 focus group teachers indicated in the interview that CL4STEM has helped them to teach their students better.

Relative advantage contains a total of five 7-point Likert statements in the survey. These statements include:

(i) Participating in the CL4STEM will allow me teach science and math topics faster
(ii) Participating in the CL4STEM will improve the quality of my teaching
(iii) Participating in the CL4STEM will make it easier for me to teach
(iv) Participating in the CL4STEM will enhance the effectiveness of my teaching
(v) Participating in the CL4STEM pilot gives me greater control over my teaching

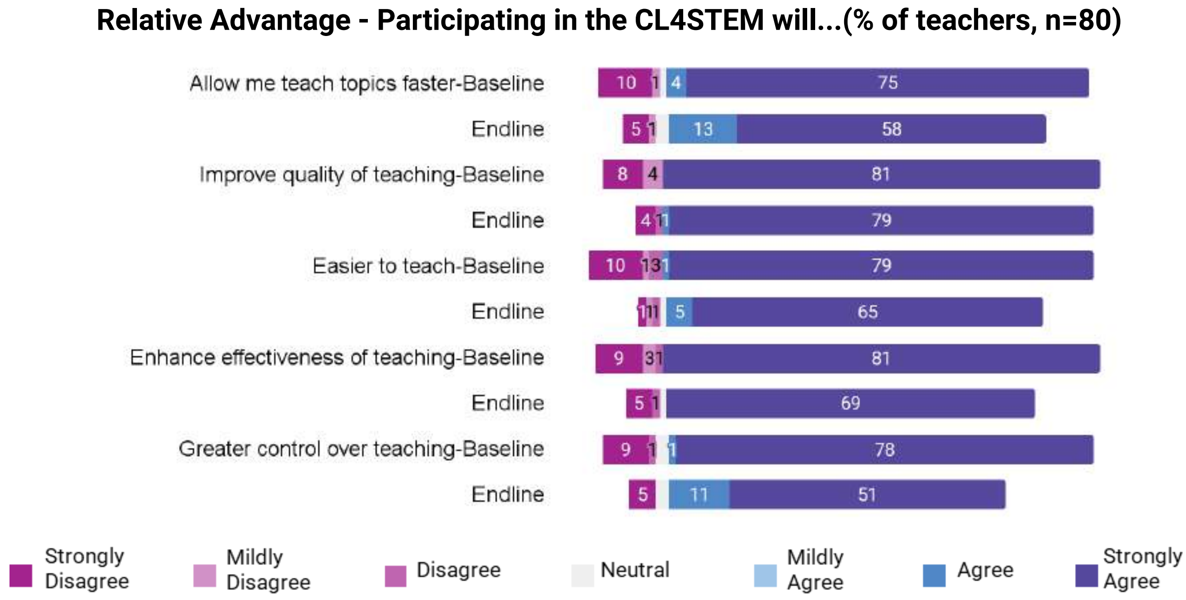


Figure 4.4. Change of Perceptions in Relative Advantage

In the Baseline itself, the average agreement to the five statements was 88%. And there was a 6% average increase in agreement with all statements in the Endline. Interview and survey data shows that teachers perceive the CL4STEM model of TPD as more advantageous than the existing ones. Teachers with 0-5 years experience, mathematics teachers, and physics teachers have especially shown considerable positive change in the Endline.

4.3.3. Compatibility

Compatibility indicates the extent to which CL4STEM innovation is perceived to be consistent with the instructional experience of teachers in the classroom. In the context of this study, it could be seen as a state in which the innovation and the teachers' everyday classroom are able to exist together without conflict. The interview data indicates that the innovation is very compatible with their experiences. This can be exemplified by the following excerpts:

> "CL4STEM fit into my everyday teaching, as I told you that I taught angle of elevation and depression with idea from it." (3118, Maths, Endline)

> "CL4STEM will fit into your everyday teaching in the classroom. The CL4STEM excites me because I learn about lesson plans, how to engage students in the activities, how to make use of ICT to engage students and to come up with the activities." (3303, Physics, Endline)

One of the teachers believed that CL4STEM was compatible with his classroom activities but different from current practice, validating the relative advantage as indicated by the teacher's verbal excerpt: " It fits with my style of teaching but I find it different from the way I teach before" (3305, Physics, Endline). Overall, teachers believe that the CL4STEM is compatible with their everyday classroom experiences.

The findings from the interviews corroborate the results of the survey data. The Perception survey had three 7-point Likert statements that aim to assess the compatibility. These statements include:

(i) Participating in CL4STEM is compatible with all aspects of my teaching.
(ii) I think that approaches in CL4STEM fit well with the way I like to teach.
(iii) Participating in CL4STEM fits into my style of working.

An average of 83% teachers agreed that CL4STEM is compatible with their teaching. This agreement increased by 8% in the Endline. In the Endline, an average of 91% of both male and female teachers reported agreement with statements regarding CL4STEM compatibility with their existing teaching practice. There was a 1% increase for female teachers and 11% increase for male teachers from BBaseline. It is evident from the interviews and survey data that CL4STEM is perceived as being consistent with existing values and past experiences of teachers. Male teachers, early career teachers and physics teachers have shown considerable positive change in the Endline.

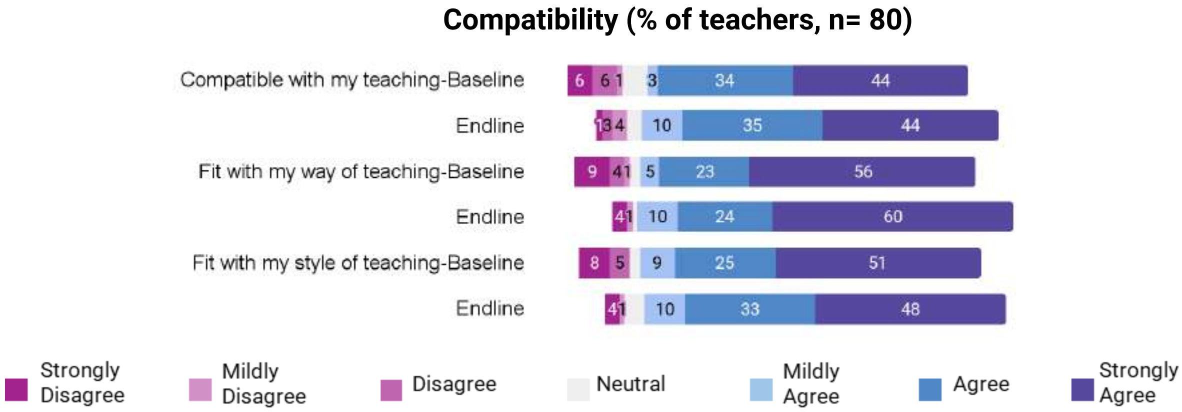


Figure 4.5. Change of Perceptions in Compatibility

4.3.4. Image

Image refers to the deployment of CL4STEM practices that can enhance the image of the teachers. Interview data indicates that participating in the project enhances the teachers' image among their colleagues as well as the image of their school. This is evident from the following response: "It has enhanced my status, yes because I know some of my friends in school used to tease me about the project at the beginning but now they respect me."(3515, Chemistry, Endline) Excerpts from the interview of a physics teacher from Baseline to Endline indicate a change in his perception of CL4STEM with regards to enhancing his image.

Baseline	Endline
"Iactually look different from my colleagues"(3302 Physics)	*"Yes it has improved the profile of the school, everywhere in my school is now like becoming an international school because of this program. We had visitors from India that came and appreciated the way we use the modules and also it has improved the way the school management is looking on how to improve the teacher education. "*

Teachers shared the digital badges received after completion of each module on CoPs and other social media platforms, showcasing their achievement (Figure 5.7).

The data shows that 7 teachers at the Baseline indicated that the project enhanced their image along with their schools'. In the Endline, the number increased to 14 teachers. These findings have implications for CL4STEM project's acceptability and scaling. Image parameter consists of three 7-point Likert questions of the survey questionnaires. Some of these questions include:

(i) Teachers in my school who are participating in CL4STEM have more prestige than the ones who do not

(ii) Teachers in my school who are participating in CL4STEM have a high profile	
(iii) Participating in CL4STEM is a status symbol in my school	

An average of 76% of teachers indicated that participating in CL4STEM gives more prestige and is a status symbol. The percentage of teachers increased slightly to 78% in the Endline. Overall, the teachers' image and status has been enhanced by participating in CL4STEM as reported by them in the interviews and survey. The change in image was especially high for early career teachers and physics teachers.

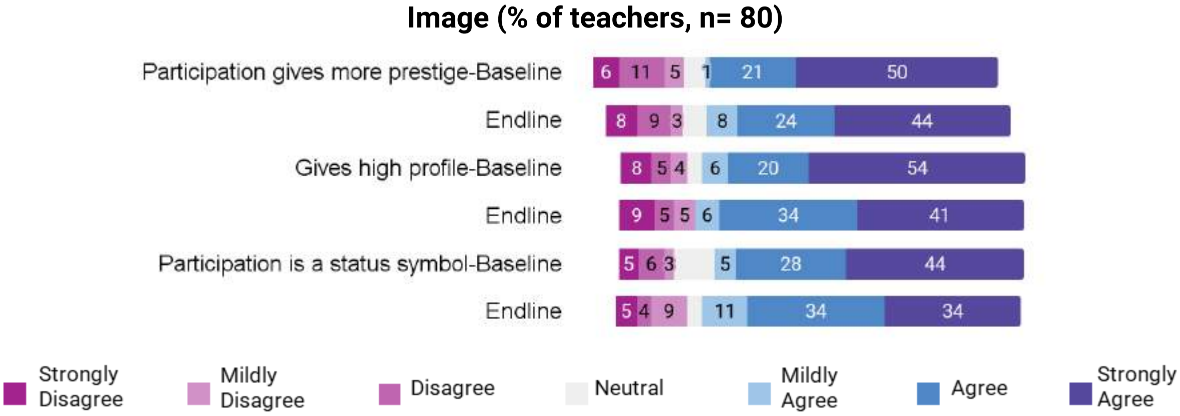


Figure 4.6. Change of Perceptions in Image

4.3.5. Ease of Use

Ease of use refers to CL4STEM practices that require a manageable physical and mental effort on the part of teachers to implement. Interview data was collected to explore teachers' perceived ease of use of the CL4STEM innovation. Ease of use could be a strong determinant of the adoption of the innovation. The findings seem to indicate that at the beginning, the participating teachers did not find the module easy to use or navigate which could be attributed to their level of proficiency with Information and Communication Technology (ICT) and other factors as indicated by this excerpt from the interview of a Physics teacher:

> "Initially, we did not find it easy but now I'm getting used to this 3rd module. I have already adopted the module"(3305, Physics, Endline).
>
> "We have some challenges with technological devices such as smartphones and computers. And sometimes you need to go online. So, we have these kinds of challenges with the availability of the internet" (3303, Physics, Midline).

Most of the respondents in the Midline and Endline perceived the module to be easy to use as indicated by this mathematics teacher's verbal excerpt: "The first module in CL4STEM open for us is algebra. And I did all the activities under it. They are very simple and straightforward" (3118, Midline, Math). There appears to be a shift in the perception of the innovation's ease of use among teachers from Baseline to Midline and Endline as indicated by the following excerpts from a physics teacher's interview:

"No task comes easy" (3316, Baseline)	*"Yes, because it's easy and the module is user/friendly"* (Midline)	*"Yes easy to be used , it makes my teaching to be easier* [sic]*" (*Endline*)*

It can be concluded from the interviews that the participating teachers find the innovation easy to use. Ease of use parameter comprised of four 7-point Likert statements in the survey and those include:

(i) CL4STEM modules are clear and easy to understand
(ii) I believe it is easy to learn new approaches to teaching by participating in CL4STEM
(iii) Overall it is easy to participate in CL4STEM
(iv) Learning to navigate the CL4STEM modules and community of practice is easy for me

In the Baseline survey, an average of 84% of teachers agree with all the four statements on ease of use, including CL4STEM modules and CoPs. This percentage increased by 8% with the average going up to 92% in the Endline. Overall, teachers considered the CL4STEM model of TPD with modules and CoP to be easy to use, even though there were initial challenges in getting familiarised with the platform. As internet access and affordability is an issue in Nigeria, the modules were made to be available offline once downloaded. This design feature will be useful while scaling the model.

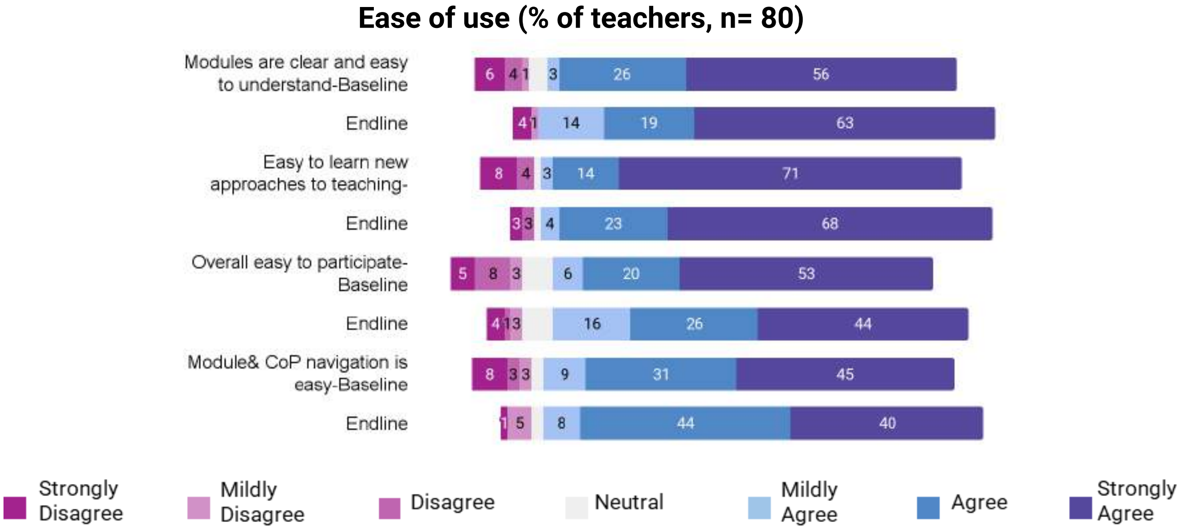


Figure 4.7. Change of Perceptions in Ease of use

4.3.6. Result Demonstrability

According to Moore and Benbasat (1991), result demonstrability means the tangibility of the results of using CL4STEM modules and CoPs, including their observability and communicability. It refers to the extent to which implementing the CL4STEM innovation produces positive outcomes or benefits or the degree to which the use of the innovation is perceived to enhance the teaching and learning of science and mathematics.

The direct effect of the project on teachers' pedagogical content knowledge could be observed in the interview data. "...as I said earlier, it improved my teaching ability and in fact the CoP allows teachers to interact with one another and share knowledge. So it makes me understand how to teach different students effectively." (3103, Math, Midline). 3 teachers indicated that they shared their knowledge with other non participating teachers. This is exemplified in the following excerpt: "CL4STEM trained me on how to carry out effective teaching. We share ideas and train some of our biology teachers on how to use the CL4STEM to impart knowledge to their students" (3702, Biology, Midline). Furthermore, teachers' perception of results demonstrability changed from Baseline to Midline, as indicated by the following responses of a physics teacher (3305, Physics):

"It is going to make me a better teacher. I'm both excited about the project. I believe it's something that I'll have a fruitful outcome. The knowledge will easily pass across to the learners." (Baseline)	*"As I share my ideas with others, I also learned from the other teachers and teacher educators, it helped me to solve my classroom problems."(Midline)*

In the survey result, demonstrability parameter contained four 7-point Likert statements These are as follows:

(i) I would have no difficulty telling others about the results of participating in CL4STEM
(ii) I believe I could communicate to others the consequences of participating in CL4STEM
(iii) The results of participating in CL4STEM are clear to me
(iv) I would have difficulty explaining why participating in CL4STEM may or may not be beneficial

From the survey, it can be observed that 79% of teachers in the Baseline agreed that the results of participating in CL4STEM are clear and easy to communicate, which increased by 3% in the Endline. There is a slight positive change in result demonstrability in the Endline survey, especially among early career teachers and teachers from federal government schools. Teachers shared instances of sharing their learnings from CL4STEM in the CoP and with their colleagues in their respective schools. This shows a positive trend in terms of result demonstrability.

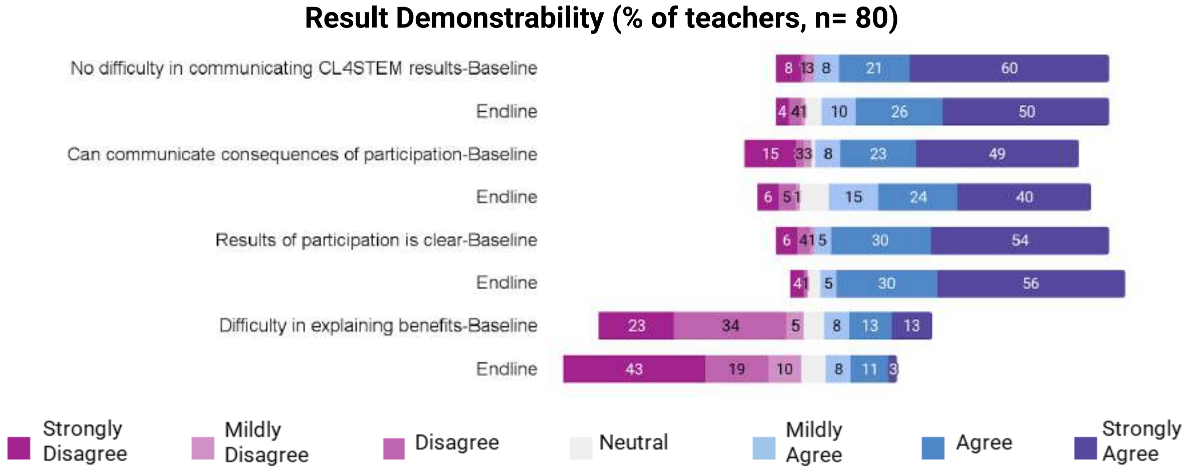


Figure 4.8. Change of Perceptions in Result Demonstrability

4.3.7. Visibility

Visibility seeks to measure the popularity of the innovation in schools. The findings on visibility appear to be mixed. Some highlighted that CL4STEM is visible in their schools while others objected to that. For example, to the question of visibility, one teacher responded that CL4STEM "...is visible in our school, because everybody knows about this CL4STEM" (3502, Chemistry, Midline), while another teacher highlighted that "...well not everyone (is aware of the project) just some of the teachers that are already in the program" (3719, Biology, Midline). In the Midline, 6 teachers highlighted that the innovation is visible in their school as indicated by the following excerpt,

> “The CL4STEM is a very visible one, because the school is aware of it, the VP, and the principal. In fact, as of last week, we have a few visitors that came to the school. And in fact, they appreciated everything about CL4STEM. So it is very visible to students, teachers, the school authority, and even from the Federal Ministry of Education.” (3702, Biology, Midline)

The ‘visibility’ parameter contains two 7-point Likert statements in the survey. They are:

(i) In my school, one sees many teachers participating in CL4STEM
(ii) Participation in CL4STEM is not very visible in my school.

Overall, there is no change in visibility in the Endline and not much difference is observed in terms of gender as well. There is no change from Baseline to Endline survey in terms of visibility of using CL4STEM in their schools. This also reflected in the interviews. The teachers also mentioned that only mathematics and science teachers were involved, social science and language teachers did not know about CL4STEM modules.

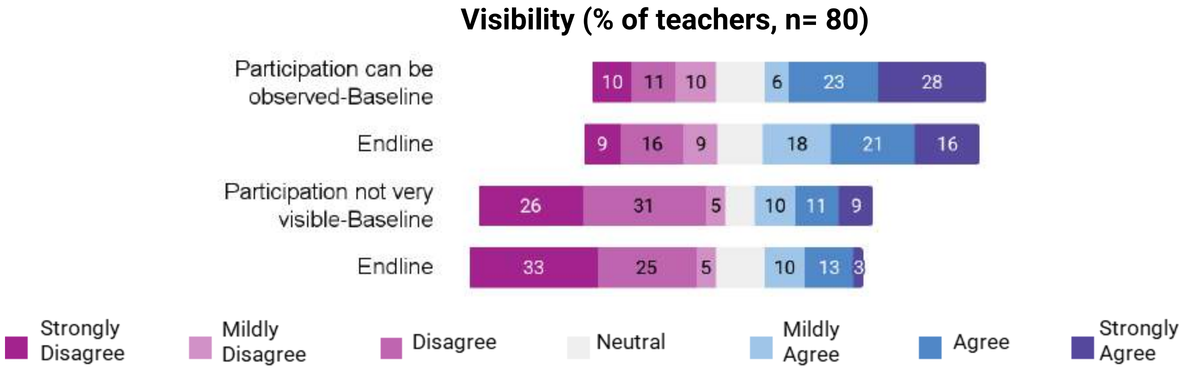


Figure 4.9. Change of Perceptions on Visibility

In the Baseline, the percentage of teachers agreeing with the statements on relative advantage, compatibility and ease of use was more than 80%. Among the seven themes in the adoption of the CL4STEM TPD model, compatibility and ease of use had the highest increase (8%) in the Endline. It was followed by relative advantage (+6%), result demonstrability (+3%) and image (+2%). Voluntariness increased by 1 percent and there was no change in visibility. There was no decrease in the overall average for any of the seven themes. When the data was segregated on gender, years of experience, school type and subjects, except for teachers from federal government schools and biology teachers, every other category of teachers demonstrated an overall positive change in the Endline.

From the analysis, it can be concluded that even at the initial stages of this innovation (as seen in the Baseline), the teachers had a high level of positive disposition towards adopting the innovation. This perception continued to be high at the Endline and had a slight positive inclination as well. This shows a positive trend in acceptance of CL4STEM innovation amongst the participating teachers.

5. Social Learning in CoPs

Social Learning in CL4STEM refers to the participants acquiring knowledge and learning from interactions with each other. 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 just observation to actively initiating conversations, sharing practice, and sharing and receiving feedback. The Communities of Practice 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 those 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.

There are few different levels of participation in CoPs (Wenger, McDermott & Snyder, 2002)[41]:

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

The researchers looked at the interaction of all participants within each subject specific CoP using social network analysis and qualitative thematic analysis. This section starts with a description of the social network analysis parameters followed by that of the qualitative analysis.

Density refers to how many interactions are happening between the participants of any group at that point in time. Maximum possible density is 1, indicating that every node in the network is connected to every other node directly. Average degree is the average number of interactions each node is participating in. Maximum degree is the maximum number of connections a node has. In this case, for example, the participant who has interacted with the most people will have the maximum degree. Table 5.1 shows the development of the Telegram based Communities of Practice during the implementation of CL4STEM modules in Nigeria.

At Baseline, all four subject CoPs for mathematics, biology, chemistry and physics, had low densities ranging between 0.07- 0.17. The Baseline time stamp was taken in June 2022, at the end

Table 5.1. Evolution of Network Density & Degree Over the Implementation of CL4STEM

	Mathematics			Biology			Chemistry			Physics		
	BL	EL	Δ	BL	EL	Δ	BL	EL	Δ	BL	EL	Δ
Density	0.11	0.28	**0.17**	0.17	0.34	**0.17**	0.07	0.2	**0.13**	0.11	0.25	**0.14**
Average Degree	3.56	8.87	**5.31**	5.16	9.93	**4.77**	2.43	7.57	**5.14**	3.46	8	**4.55**
Maximum degree	12 (T, TE)	27 (T)	**15**	16 (T)	20 (TE)	**4**	10 (T)	19 (T)	**9**	15 (TE)	21 (T)	**6**

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

[41] Wenger, E., McDermott, R., & Snyder, W. M. (2002). Seven principles for cultivating Communities of practice. *Cultivating Communities of Practice: a guide to managing knowledge*, *4*, 1-19.

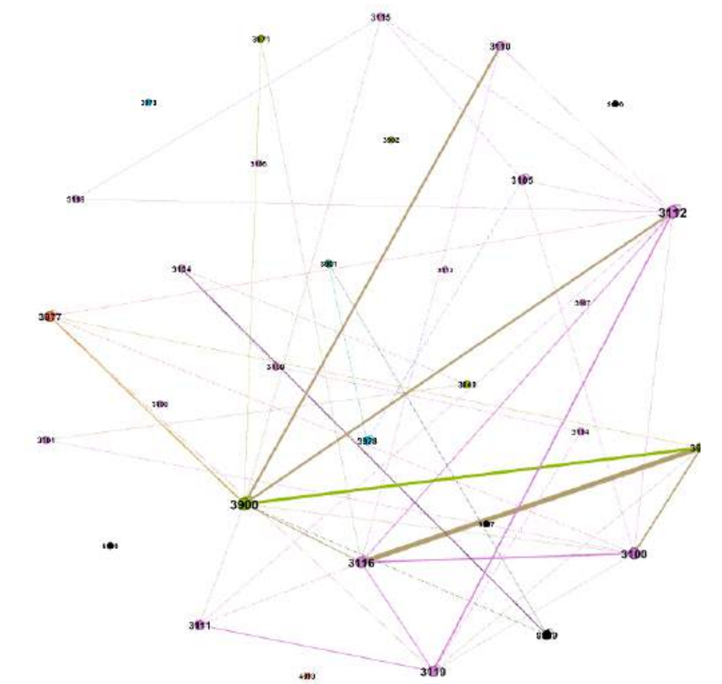
of the common module and the beginning of the subject modules. It includes all interactions that happened till June 2022. Through an orientation, teachers were familiarised with the idea and process of being part of CL4STEM but had not started subject specific professional development. This is understandable, as at the beginning of the interventions, the participants did not know each other.

Endline time stamp is from December 2022, when all three modules had been closed and teacher participation was complete. This time stamp includes all interactions from June to December 2022. The density at this period ranged from 0.2-0.34. As can be seen from the table above, density increased in all four subjects, implying that the number of interactions in each CoP increased overtime. This is not surprising, given that the teacher educators were explicitly using the CoPs to communicate with teachers and also encouraging teachers to participate in the CoPs and the modules.

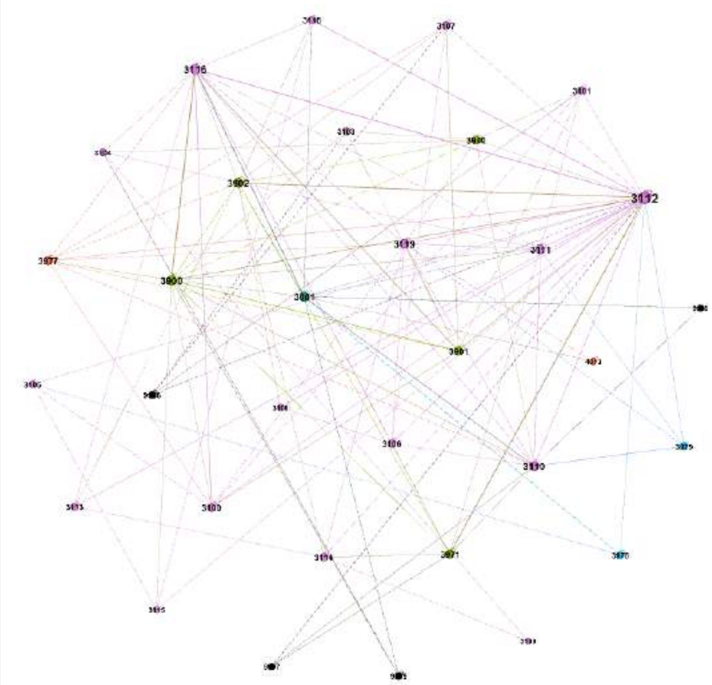
At Baseline, the average degree ranged from 2.43 in Chemistry to 5.16 in Biology, meaning that the participants in Chemistry CoP had interacted with (on average) 2 other people at the start of the subject modules. Participants in Biology CoP, however, had interacted with more than 5 people on average. 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 observed in mathematics, whereas the highest average degree was reported in Biology. At Endline, each participant in mathematics was interacting with around 8 other participants, whereas in biology, each participant was interacting with 9 other participants.

Finally, maximum degree is important to consider, as it represents the participant who has interacted with the most number of participants, meaning that they have the most relationships in the current participant group. It was expected that teacher educators would have a high maximum degree across all four subjects, because they were leading the implementation of modules, and hence they would have interacted with the maximum number of participants. However, upon analysis of data it became evident that maximum degree was shared between the teachers and teacher educators both. Thus, this small group of teachers and teacher educators formed the core of the CoP, and became the core participants. Images of each subject network evolution are shared below (Figure 6.1). These images show not only how the network evolved over time, but also how the nature of participation varied. There are some nodes, which are connected to many other nodes (meaning they have high degree), but there are also some other nodes that are not connected to any other node. These nodes are the participants who did not interact with anyone in the CoP, but were just present in the community. It is important to know that lack of interaction in the CoP did not mean that the participants did not consider the CoP as valuable. These participants would be considered as peripheral participants.

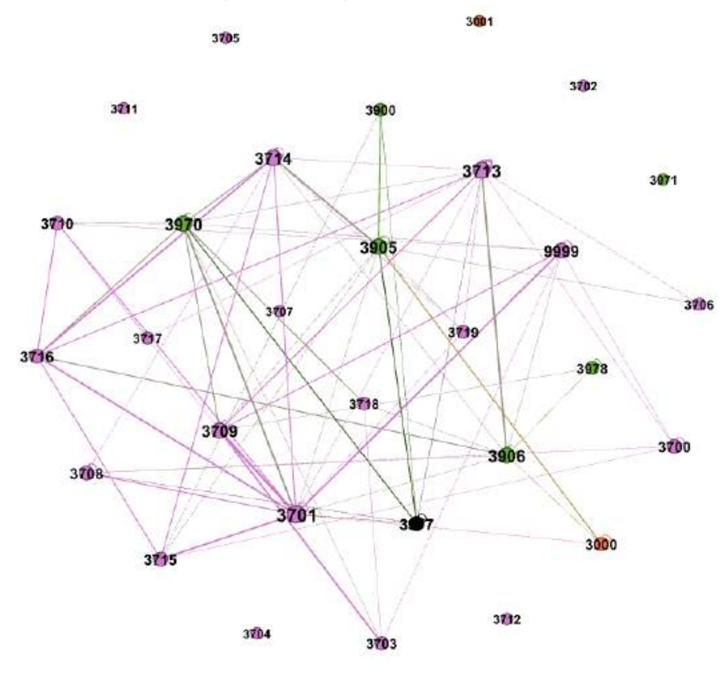
Mathematics : Density=0.12, June 2022



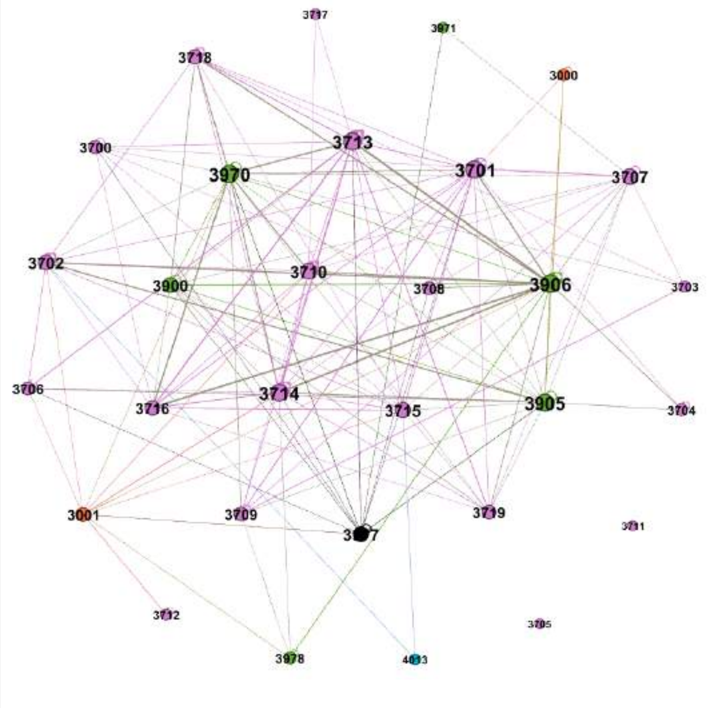
Density= 0.29, December 2022



Biology : Density= 0.17, June 2022



Density= 0.34, December 2022



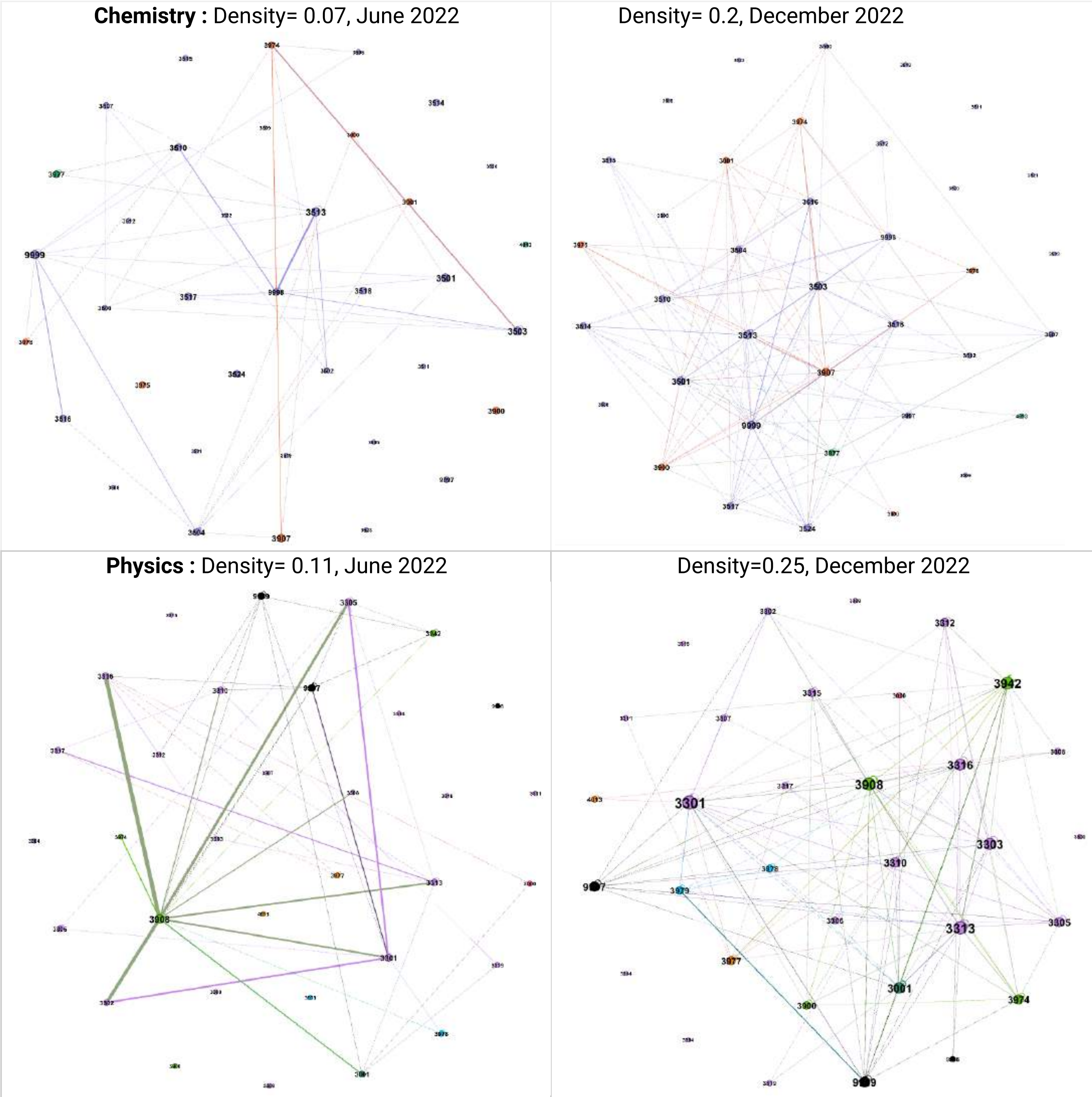


Figure 5.1. Social Network Analysis of CoPs

From a qualitative analysis perspective, all subject CoPs showed some common types of interactions. These interactions are explained below and associated screen grabs of the chats are shared here as well. Four main types of interactions were seen across all subjects:

1. Teachers sharing practice
2. Reminders
3. Support and feedback
4. Appreciation

1. Teachers sharing practice: In Nigeria, teachers across subjects were sharing lesson plans, photos, and videos of lesson plan implementation from their schools, as seen in the pictures below (Figure 5.2). This created a platform for the teachers to not only showcase their lessons, but also for teacher educators to provide feedback to the teachers on these lesson plans.

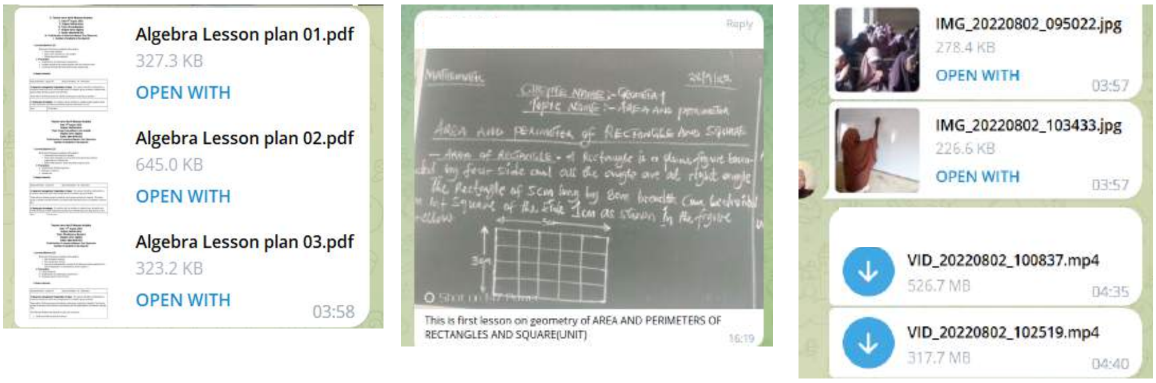


Figure 5.2. Examples from CoP on Teachers Sharing their Practice.

2. Reminders: Teacher educators and subject leaders often shared reminders in the CoPs for the teachers to keep making progress in the implementation of modules. These were either in the form of general messages to the whole community, or through direct tagging of particular teachers. Teacher educators also used multiple types of reminders to engage the teachers. An example of this is seen in Figure 5.3, where the teacher educator was using polls to gauge participation in the module, and also subtly encouraging the teachers to continue participating.

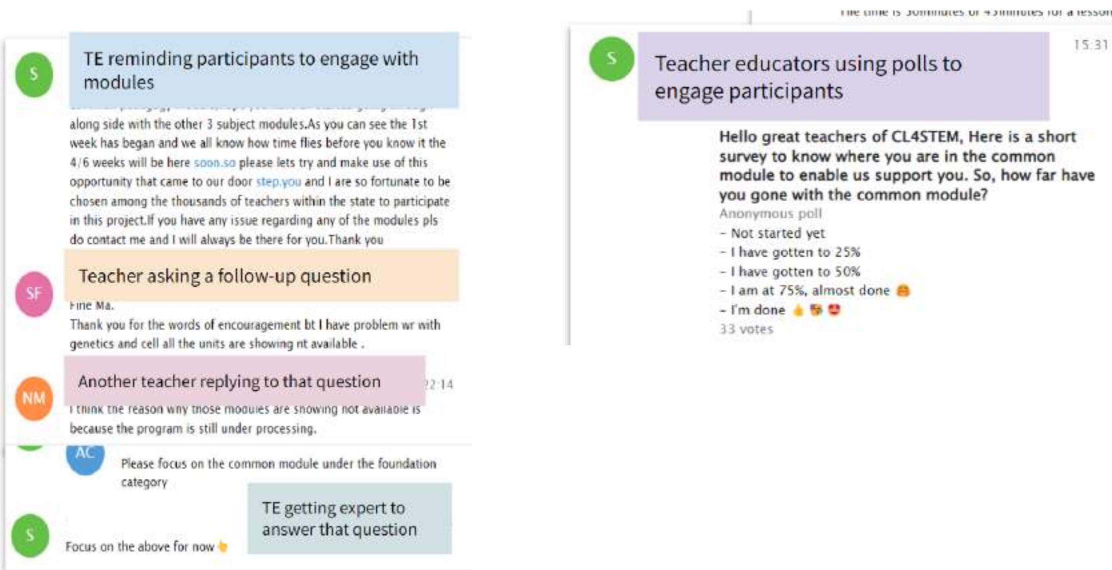


Figure 5.3. Examples of Teacher Educators Using Reminders to Encourage Participation.

3. Support and feedback: Teachers and teacher educators both shared supportive messages. Teachers would ask questions, such as “How to access Geogebra?” or ask questions about

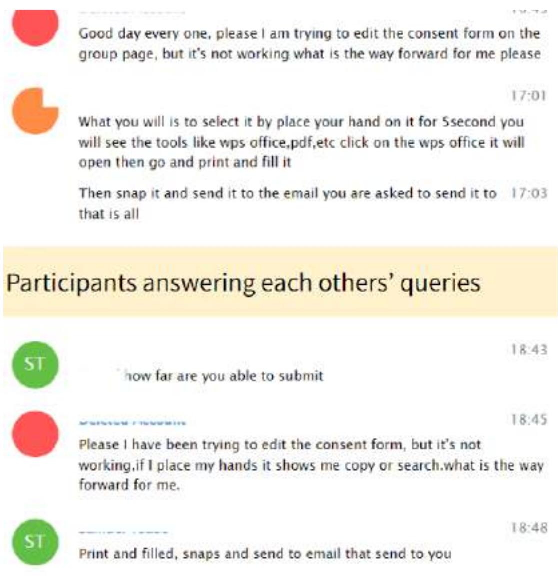


Figure 5.4. Examples of Teachers Supporting Each Other

accessing the Moodle based modules. Teacher educators would also share resources and feedback on the CoPs. An example of this peer support is shown in Figure 5.4.

In the images shared below, two examples have been presented. In Figure 5.5, a mathematics teacher can be observed asking questions about using Geogebra, and is being advised by the teacher educator on how he should proceed. A teacher shared the same sentiment in one of the interviews, as seen in the following quote: "I post mine for people to criticize.Nobody is harsh in responding. They respond in a way that makes one realise the mistake and correct it" (3101, Midline).

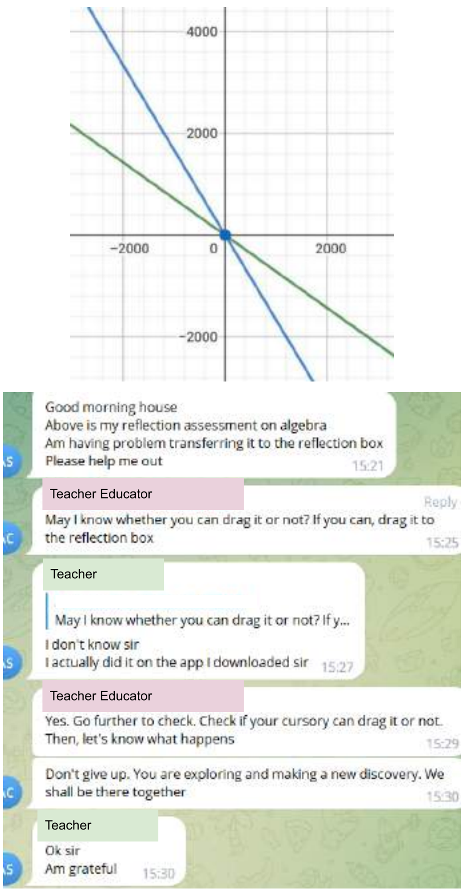


Figure 5.5. A Math Teacher & Teacher Educator Discussing Geogebra

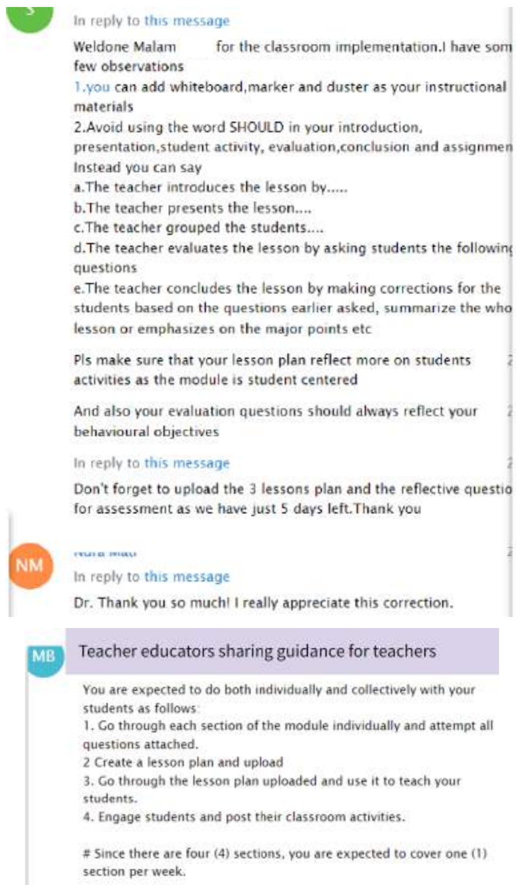


Figure 5.6. Teacher Educators Sharing their Feedback for Teachers

4. Appreciation: Teacher educators and other leaders engaged in public appreciation of participants in these CoPs, thereby encouraging others to participate. Examples of both the teacher educator being appreciated by the country project leader, and teachers being appreciated by the teacher leaders were seen in the Biology CoP. Other CoPs also had examples of teachers being appreciated by the teacher educators. The teachers showed their appreciation and pride by sharing the digital badges that they were awarded upon successfully completing the modules.

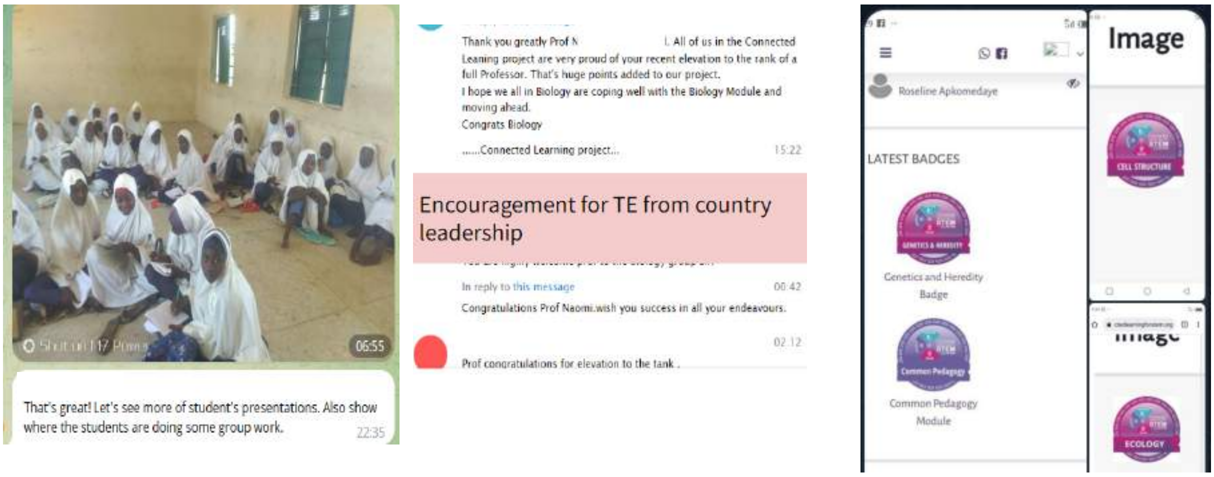


Figure 5.7. Teacher Educators' Appreciation & Teachers Sharing Digital Badges in CoP

Thus, these online groups served as communities where teachers and teacher educators were able to engage in an authentic manner, working with new tools and technologies, discussing their practice, learning from each other, and sharing their achievements.

6. Summary and Way Forward

The CL4STEM Teacher Professional Development (TPD) model adopted from CLIx was aimed at bringing change in high school teachers' Pedagogical Content Knowledge (PCK) for higher order teaching with equity and inclusion. The two major components of the TPD model are the online modules and CoPs. A conceptual framework with 10 themes was used to analyse teachers' change in knowledge, attitude and practice. As the modules were practice-based, teachers were able to experience the use of suggested strategies and also reflect on their practice. The lesson planning and reflective assignments had elements of the framework which scaffolded teachers practice and reflection along the themes in the framework.

The findings of the study with regards to teachers' instructional practices indicated a shift from traditional classroom practices to the instructional practices embedded in the CL4STEM modules. The teachers' KAP towards engaging their students in classroom practices was enhanced. Collaboration or group work was observed to be a prominent instructional practice employed by the teachers. The students were engaged in exchange of ideas among themselves and with the teachers to address equity and inclusion.

The collaborative classroom environment during the CL4STEM activities encouraged the children to construct arguments, ask questions, justify their claims, criticise each other, and make decisions. These activities could potentially enhance higher order thinking skills. The positive impact of the project with regards to instructional practices provides a very strong basis for further scaling of the project. From the data, it can be seen that amongst the 10 themes, there is an observable change in seven themes. The highlights of the changes are summarised in the table below.

Table 6.1. Summary of KAP impact

Themes	Change	Nature of change
Knowledge of Subject Matter	No	No observable change
Nature of Science /Mathematics	No	No observable change. Teacher training institutions do not seem to emphasize this
Instructional Strategies	Yes	Change from teacher centric strategies to use of hands-on materials & activities from CL4STEM modules
Students' Misconceptions & Conceptual Difficulties	Yes	Use of multiple representations & group work to address learning difficulties. Many were able to identify misconceptions. Few planned strategies & resources to address them.
Representation of the Content	Yes	Use of a variety of resources from modules & compared them with their earlier use of chalk and talk. Drop in use of only textbooks & increase in use of hands-on activities, adapting locally available materials, charts, models, ICT resources and videos.
Context for Learning	Yes	Adapt appropriate local materials, hands-on-activities & group work to address lack of material resources.
Curriculum knowledge	No	No observable change.
Equity and Inclusion	Yes	Collaborative learning in groups. More use of multiple representations.
Classroom Management	Yes	Grouping to manage large classrooms during activities.
Assessment	Yes	Increase in formative and diagnostic assessment strategies .

An important component of the CL4STEM TPD model is the social learning space, the online CoP on Telegram. Social network analysis was used to study the change in density of the interactions on CoPs. The density of all the four subject groups increased over the period of implementation and teacher educators have played the role of facilitators in the CoP conversations. The conversations largely consisted of teachers sharing their classroom practices as photographs and videos, reminders, support, feedback and appreciation from teacher educators. The CoP was well-appreciated by the participating teachers. The interactions among the teachers and between the teachers and teacher-educators was enriching and meaningful. The CoP was well accepted by the participating teachers and they showed positive satisfaction towards them as some even admitted that it was amazing, interesting and educational. The CoP model is cost effective and provides teachers the opportunity to exchange ideas and learn from each other. The level of teachers' engagement and their display of satisfaction shows that the Telegram groups have served as a professional social learning space for teachers and teacher educators. This would have a positive impact in scaling.

The largest percentage (53%) of teachers were at the stage 4 of Levels of Use (Hall, Dirksen & George, 2006)[42] at the Endline, revealing a trend towards higher order of engagement. The reasons the teachers gave for their choice of Level of Use were an expression of positive perception towards the CL4STEM TPD model. Teachers mentioned that they find the modules easy to access and understand. They expressed that they are more capable to employ CL4STEM teaching strategies like organising group work, engaging students in activities, and using UDL principles for ensuring equity and inclusiveness in teaching. The teachers mentioned that they also use these strategies to teach other topics in the curriculum.

80% of participating teachers have selected sophisticated Stages of Concerns (George, Hall & Stiegelbauer, 2006)[43] and it indicates a nuanced understanding of the CL4STEM model of professional development. The reasons given by the teachers for their various choices of Stages of Concern were high workload, high student teacher ratio, lack of ICT facility and internet and misalignment of the module with the school calendar.

Innovation diffusion study on teachers' perception towards CL4STEM revealed that even in the Baseline survey, teachers had a high positive perception towards the innovation. More than 80% of the teachers were in agreement with three out of seven themes - relative advantage, compatibility, and ease of use. There was no decrease in overall average for any of the seven themes from Baseline to Endline. This shows an overall positive trend towards CL4STEM innovation adoption.

The teachers' perceived CL4STEM innovation to be consistent with their instructional experiences in the classroom within the Nigerian socio-cultural context. Even though CL4STEM is an innovative project in this population, the innovation and teachers' everyday classroom experience coexist without conflict. This indicates that scaling this project in this population could be successful with little or no difficulty. The data from both quantitative and qualitative analysis shows that teachers perceive the CL4STEM innovation to create a conducive learning environment that is engaging and learner-centred, making it better than their traditional classroom practices. This perceived relative advantage of the project will probably enhance its scaling to other regions or subjects within Nigeria.

[42] 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

[43] 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

Table 6.2 Summary of Change in Teachers' Perception

Themes	Perceptions	Nature of change
Voluntariness	Marginally negative	Even though teachers were not compelled to join, school heads had a greater role in selecting teachers for professional development interventions.
Relative Advantage	Positive	Baseline agreement was 88% and there was a 6% increase in the Endline. Teachers perceived the CL4STEM model as more advantageous than the existing ones.
Compatibility	Positive	83% of teachers agreed CL4STEM is compatible with their teaching in Baseline and it increased by 8% in the Endline. CL4STEM was perceived to be consistent with existing values and past experiences of teachers.
Image	Marginally Positive	76% of teachers indicated that participating in CL4STEM was prestigious and it became a status symbol. It slightly increased to 78% in the Endline.
Ease of Use	Positive	At Baseline, 84% of teachers agreed that CL4STEM modules and CoPs were easy to use and it increased to 92% in the Endline. There were initial challenges in getting familiarised with the platform. As internet access and affordability was an issue in Nigeria, the modules were made to be available offline, once downloaded.
Results Demonstrability	Marginally Positive	79% of teachers agreed that the results of participating in CL4STEM are clear and easy to communicate in the BBaseline and it increased by 3% in the Endline. Teachers shared instances of sharing their learnings from CL4STEM in CoP and with their colleagues in their schools
Visibility	Neutral	There was no change. Only mathematics and science teachers are involved while social science and language don't know about CL4STEM modules.

The adoption of an innovation is sometimes determined by its perceived ease of use as highlighted by the Technology Acceptance Model. The participating teachers perceive the CL4STEM project to be quite easy to use. The data from the interviews of the participating teachers indicated that the modules were easy to navigate and user-friendly. The ease of use of the CL4STEM modules would have a positive impact in the scaling of this project in Nigeria.

From the situation analysis report that was written in the beginning of the project it can be seen that several government policies, programs, and interventions promote gender equity in the accessibility of education in Nigeria. However, literature has pointed out a high rate of gender inequality. Women are grossly underrepresented in terms of enrollment, participation, and achievement in science, technology, and mathematics at all levels of education in Nigeria (Abdullahi, Abubakar, Abubakar, & Aliyu, 2019). This was reflected in the CL4STEM intervention as well. There were fewer female teacher educators and teachers compared to male participants, especially in mathematics. There were more women among biology teachers and teacher educators. Female participation was low in research and implementation teams. So, while scaling the project, efforts have to be made to make participation more gender inclusive.

Nigeria is currently facing issues relating to internal insecurity which are destroying households and destabilizing institutions. This has prompted many parents in the affected areas to withdraw their children from schools, especially female students, resulting in an increase in the number of out-of-school children (UNESCO, 2014). With female students dropping out of school, the gender disparity in education widens. As a result of these issues, the CL4STEM intervention in the conflict zones also faced challenges.

As the innovation involved online OER modules and mobile phone messenger applications for CoP, it required teachers to have access to a smartphone. Even when the teachers had access to smartphones, the quality and specifications were not adequate in some cases for navigating modules and CoPs smoothly. This affected the participation and performance of these teachers. Due to the high expenses associated with the internet, the project had to support teachers and schools with internet packs. Moodle was chosen as the working platform as it enabled navigating modules offline. This feature was well appreciated by teachers as they could refer to the modules whenever they wanted without the internet. There was a slow start by the participants and this could be attributed to the poor proficiency in the use of digital devices. Consequently, in subsequent scaling, time and resources should be committed to training the participants on the basics of the use of digital devices. In addition to this, while scaling up the requirements of smartphones and the minimum technical features required have to be made clear to teachers, while providing appropriate support for smoother implementation.

Educational stakeholders were engaged with the project from the beginning. The launch of the project was very successful and attracted critical stakeholders such as the Ministry of Education, professional organisations like the Science Teachers Association of Nigeria (STAN), Mathematics Association of Nigeria (MAN), and the Nigerian Union of Teachers (NUT). Other educational stakeholders include the Nigerian Educational and Research Council (NERDC) and the Science and Technical School Board among others. The project was well publicised among the stakeholders.

The school heads and heads of departments had a greater role to play in the implementation of the project. They played a crucial role in allotting time for teachers to participate and offering support in gathering instructional resources. The participating teachers received support from university faculties and researchers creating a sense of curiosity in all the teachers in the schools. Therefore, while scaling the innovation, it would be good to get all the mathematics and science teachers of a school, along with the heads of departments. This could even result in a local school-level Community of Practice and could become a subject of discussion in the staff rooms and school meetings, as demonstrated by the data from perception surveys.

In recent years, there has been advocacy on the need and urgency for the improvement of secondary school STEM instruction through addressing the instructional inadequacies in science and mathematics. CL4STEM focused on capacity building for science and mathematics teachers towards Higher Order Thinking and Equity and Inclusion. The study has successfully achieved its objectives and the findings have several implications for scaling with regard to classroom instructional practices, teachers' perception, research methodology and Teacher Professional Development (TPD).

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