Orchestrating ICTs for Promoting Students' Mathematical Proficiency at the Secondary Level in Bangladesh

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A thesis submitted in fulfillment of the requirements for the degree of
Doctor of Philosophy

Tamanna Sultana
MPhil (Mathematics), BUET, Bangladesh
MSc (Mathematics Education), University of Bristol, UK

Institute of Education and Research
University of Dhaka

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APPROVAL

Orchestrating ICTs for Promoting Students' Mathematical Proficiency at the Secondary Level in Bangladesh

PhD Researcher

……………………..

Tamanna Sultana
Registration No.: 119
Academic Session: 2020-2021

Supervisor

……………………………………..

Professor Dr. Md. Abdul Halim
Director
Institute of Education and Research
University of Dhaka

Co-Supervisor

……………………………………..

Mohammad Nure Alam Siddique
Professor
Institute of Education and Research
University of Dhaka

DECLARATION

I hereby declare that this thesis has been prepared in accordance with the University's guidelines on the presentation of a research thesis and conforms to the regulations for the degree of Doctor of Philosophy. The contents of this thesis are my own work and have not been submitted for the award of any other degree.

Signature: ……………………………………

Date: 18/04/2024

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TABLE OF CONTENTS

Approval i
Declaration ii
Acknowledgements iii
Table of Contents iv
List of Tables viii
List of Figures ix
Glossary of Abbreviations xi
Abstract xii
Chapter One: Introduction 1
1.1 Introduction 1
1.2 Mathematics Education context Bangladesh 2
1.3 Students' Performance in Mathematics: Bangladesh context 6
1.4 ICT in Education context Bangladesh 7
1.5 Problem Statement 12
1.6 Rationale of the Study 13
1.7 Purpose and Research Question 15
1.8 Significance of the Study 16
1.9 Operational Definitions 16
1.9.1 Orchestration 16
1.9.2 ICT-facilitated Teaching-Learning (TL) environment 17
1.9.3 GeoGebra 18
1.9.4 ICT-facilitated Teaching-Learning Process 19
1.10 Overview of the Dissertation 19
Chapter Two: Literature Review 20
2.1 Mathematical Proficiency (MP) 20
2.1.1 Conceptual Understanding (CU) 21
2.1.2 Procedural Fluency (PF) 21
2.1.3 Adaptive Reasoning (AR) 22
2.1.4 Strategic Competence (SC) 22

2.1.5 Productive Disposition (PD) ... 23
2.2 Tools for Learning ... 23
2.3 Teaching for Developing Mathematical Proficiency ... 24
2.4 Teaching with ICT for Developing Mathematical Proficiency ... 27
2.5 Enablers and Inhibitors to ICT Integration ... 35
2.5.1 Personal aspects ... 36
2.5.2 Pedagogical aspects ... 39
2.5.3 Institutional aspects ... 42
2.6 Underpinning Theories of the Study ... 43
2.6.1 Instrumental Orchestration ... 43
2.6.2 Forms of Instrumental Orchestrations ... 45
2.6.3 Technology Integration Panel (TIP) ... 47
2.7 Conceptual Framework of the study ... 51
Chapter Three: Methodology ... 53
3.1 Research Paradigm ... 53
3.2 Research Methodology ... 56
3.3 Research Design ... 58
3.3.1 Preliminary phase ... 59
3.3.2 Prototype phase ... 59
3.4 Instructional Unit ... 61
3.5 Data Collection Method ... 62
3.5.1 Paper-pencil test ... 65
3.5.2 Focus Group Discussions (FGD) ... 66
3.5.3 Classroom Observation ... 66
3.5.4 Semi-structured Interview ... 67
3.5.5 Questionnaire ... 68
3.6 Sampling ... 69
3.7 Data Analysis ... 69
3.7.1 Rubrics and indicators for measuring MP ... 71
3.8 Pilot Study ... 75
3.9 Trustworthiness of the Study ... 78
3.10 Ethical Considerations ... 79

Chapter Four: Data Analysis and Findings 80
4.1 Case-I 80
4.1.1 Teacher T1 80
4.1.2. Teacher T1's pedagogical considerations in an ICT-facilitated teaching-learning environment 81
4.1.3 Understanding students' level of mathematical proficiency (MP) 117
4.1.4 Factors affecting integration of ICTs in teaching-learning process 128
4.1.5 Summary of the findings 143
4.2 Case-II 145
4.2.1 Teacher T2 145
4.2.2 Teacher T2's pedagogical considerations in ICT-facilitated teaching-learning environment 145
4.2.3 Understanding students' level of mathematical proficiency (MP) 167
4.2.4 Factors affecting integration of ICTs in teaching-learning process 179
4.2.5 Summary of the findings 191
4.3 Findings of the Study by Cross Triangulation of Two Cases 192
Chapter Five: Discussions 201
5.1 RQ-1. How do teachers apply pedagogical considerations in an ICT facilitated teaching-learning environment? 201
5.1.1 Pedagogical consideration in Didactical Configuration phase 201
5.1.2 Pedagogical consideration in Exploitation Mode 204
5.2 RQ-2. Whether and how does the ICT facilitated teaching-learning process promote students' mathematical proficiencies? 208
5.2.1 Assessing students' mathematical proficiency 208
5.2.2 Effect of pedagogical approaches on students' mathematical proficiency 209
5.3 RQ-3. What are the factors that affect integration of ICT in mathematics teaching-learning process? 215
5.3.1 Teacher factors 216
5.3.2 Student factors 218
5.3.3 School context 219
5.3.4 National context 220
5.4 Developing a process framework 222

Chapter Six: Conclusion....225

6.1 Key Findings 225

RQ1: How do teachers apply pedagogical considerations in an ICT-facilitated teaching-learning environment? 225

RQ2: Whether and how does the ICT-facilitated teaching-learning process promotes students' mathematical proficiencies? 226

RQ-3. What are the factors that affect integration of ICT in mathematics teaching-learning process? 226

6.2 Contributions and Implications 227

6.2.1 Contribution to theory 227

6.1.2 Implication to policy 228

6.1.3 Implication to practice 229

6.2 Suggestions for Future Research 230

6.3 Limitations of the Study 231

6.4 Concluding remark 231

References....233

Appendices....263

Appendix A: Introductory Letter from the supervisor 263

Appendix B: Informed Consent Form 264

Appendix C: Paper-pencil test (Pre-intervention) 266

Appendix D: Paper-pencil test (Post-intervention) 272

Appendix E: Pupil Survey Questionnaire 278

Appendix F: Interview schedules and Focus Group Discussion (FGD) 280

Appendix G: Activity Task-1 (Case-I) 283

Appendix H: Activity Task-2 (Case-I) 284

Appendix I: Activity task-1 (Case-II) 285

Appendix J: Activity task-2 (Case-II) 286

Appendix K: Transcripts of a full intervention lesson 287

Appendix L: Tests of Normality (Paper-pencil test data) 292

Appendix M: Tests of Normality (Survey data) 293

Appendix N: Descriptive statistics of each indicator of the PD 294

Appendix O: Comparative test between pre & post intervention 296

LIST OF TABLES

Table 1.1: A simplified presentation of Education structure in Bangladesh 3
Table 1.2: Subject framework, time allocation for Grade 9 - 10 (General Stream) 4
Table 1.3: Textbook associated with different learning areas from pre-primary to secondary level 5
Table 2.1: Effective ICT based teaching approach 34
Table 2.2: Brief descriptions of different types of orchestrations 46
Table 3.1: Methodology matrix of the study.. 64
Table 3.2: Marks assigned for different components of MP in the paper-pencil test item............ 72
Table 3.3: Rubrics of the four strands of MP (Adapted from Lerís et al., 2017) 73
Table 3.4: Mathematical proficiency level associated with the score range 74
Table 3.5: Items associated with the indicators of PD 75
Table 3.6: Category Productive Disposition (adapted from Diknas, 2008) 75
Table 3.7: Reliability of the test items 76
Table 3.8: Modification recommended by pilot study 77
Table 4.1: Identifying critical events, transcribing and developing suitable code 81
Table 4.2: Themes emerged as effective pedagogical approaches for Case-I............................... 84
Table 4.3: Role of ICTs..116
Table 4.4: Role of students 117
Table 4.5: Descriptive statistics of the strands of MP 117
Table 4.6: Comparative statistics of CU, PF, AR and SC..120
Table 4.7: Comparative statistics for the factors of PD 122
Table 4.8: Developed themes for influencing factor of ICT integration in TL process 128
Table 4.9: Themes emerged as effective pedagogical approaches for Case-II 146
Table 4.10: Role of ICTs..167
Table 4.11: Role of students 167
Table 4.12: Descriptive statistics of the strands of MP 168
Table 4.13: Comparative statistics of CU, PF, AR and SC..172
Table 4.14: Comparative statistics for the factors of PD 173
Table 4.15: Developed themes for influencing factor of ICT integration in TL process 179
Table 4.16: Comparison between pedagogical considerations by T1 & T2.................................193
Table 4.17: Identified roles of ICTs and students while ICTs are used in TL process 195
Table 4.18: Pedagogical approaches for developing five components of MP 196
Table 4.19: Comparison between the influencing factors identified in Case-I and Case-II..........199

LIST OF FIGURES

Figure 1.1: Learning environment provided by Teachers' Portal 10
Figure 1.2: Snap shot of Teachers' portal 10
Figure 1.3: Blended Education For All (BEFA) Framework 11
Figure 2.1: Five intertwined strands of MP (Kilpatrick et al., 2001) 21
Figure 2.2: Factors affecting integration of ICT in teaching-learning process 36
Figure 2.3: Technology Acceptance Model (TAM) (Davis, 1989) 37
Figure 2.4: The TPACK Model 39
Figure 2.5: Components of Instrumental Orchestration (Trouche, 2004) 44
Figure 2.6: Framework of TIP (Li & Dawley, 2019) 47
Figure 2.7: Conceptual framework of the study 52
Figure 3.1: Process of Design experiment (Adapted from Plomp, 2007) 60
Figure 3.2: The design process of the intervention 60
Figure 3.3: Data collection process of the study 64
Figure 3.4: Sequential analytical approach for recorded data 70
Figure 4.1: Classroom layout of the teacher T1 87
Figure 4.2: Teacher assists student to operate ICT tool 89
Figure 4.3: Applying zoom in & zoom out option in GeoGebra 93
Figure 4.4: Connecting concept of function with real life 95
Figure 4.5: Students use simulation to apply their gained math knowledge in new context 97
Figure 4.6: Task for drill and practice 98
Figure 4.7: Representation of function in different form in one frame in GeoGebra 99
Figure 4.8: Students involve in peer discussion 103
Figure 4.9: Exploring parallel line using slider of GeoGebra 105
Figure 4.10: Using real-life oriented attractive picture 111
Figure 4.11: Link-screen- board 112
Figure 4.12: Discuss-the- screen orchestration 114
Figure 4.13 : Sherpa student operated laptop and explain; another student arguing his opinion 115
Figure 4.14: Graphical presentation of different math expression using GeoGebra 115
Figure 4.15: Mean scores of each strand of MP before intervention 118
Figure 4.16: Mean scores for each indicator of productive disposition before intervention 118
Figure 4.17: Mean scores of each strand of MP after the intervention 119
Figure 4.18: Mean MP score of four strands before and after intervention 121

Figure 4.19: Students' mathematical proficiency before and after intervention 123
Figure 4.20: Performed task during FGD 127
Figure 4.21: Factors affecting ICT integration related to teachers 133
Figure 4.22: Factors affecting ICT integration related to students 135
Figure 4.23: Factors affecting ICT integration related to school context 139
Figure 4.24: Factors affecting ICT integration related to national context 143
Figure 4.25: Traditional classroom Vs Lab room 147
Figure 4.26: classroom layout of the teacher T2 148
Figure 4.27: Use simulation to link mathematics with real context.. 152
Figure 4.28: Applying knowledge in the new context 154
Figure 4.29: Problem for enhancing strategic competence 155
Figure 4.30: Group leaders work directly with ICT 157
Figure 4.31: ICT provide feedback on students' work 161
Figure 4.32: Sequence of slides to teach difference forms of equation of a straight line 164
Figure 4.33: Link-screen-board 165
Figure 4.34: Discuss-the –screen orchestration 166
Figure 4.35: Mean scores of each strand of MP before intervention 168
Figure 4.36: Mean scores for each indicator of PD before intervention 169
Figure 4.37: Mean scores of each strand of MP after intervention 170
Figure 4.38: Mean scores for each indicator of PD after intervention 171
Figure 4.39: Comparative mean score of four strands of MP before and after intervention........ 172
Figure 4.40: Students' mathematical proficiency before and after intervention 174
Figure 4.41: Performed task during FGD 178
Figure 4.42: Factors affecting integration of ICT related to teachers 182
Figure 4.43: Factors affecting integration of ICT related to students 185
Figure 4.44: Factors affecting integration of ICT related to school context 188
Figure 4.45: Factors affecting integration of ICT related to national context............................. 190
Figure 4.46: Comparison between the students' MP for Case-I and Case-II.............................. 198
Figure 5.1: Proposed framework for ICT orchestration in TL process to promote students' MP 224

GLOSSARY OF ABBREVIATIONS

AR	Adaptive Reasoning
CU	Conceptual Understanding
DBE	Department of Basic Education
DFES	Department for Education and Skills
DGS	Dynamic Geometry Software
GoB	Government of Bangladesh
ICT	Information and Communication Technology
IWB	Interactive White Board
MMC	Multimedia classroom
MoE	Ministry of Education
MoPTIT	Ministry of Posts, Telecommunication and Information Technology
MP	Mathematical Proficiency
NCTB	National Curriculum and Textbook Board
NCTM	National Council of Teachers of Mathematics
NGO	Non-Government Organization
PD	Productive Disposition
PF	Procedural Fluency
SC	Strategic Competence
TL	Teaching-Learning
TPACK	Technological, Pedagogical and Content Knowledge
UNESCO	United Nations Educational, Scientific and Cultural Organization
ZPD	Zone of Proximal Development

ABSTRACT

ICT has widely been considered to have the potential to promote positive changes in the teaching and learning process. This study aims to explore how ICTs can be orchestrated in the teaching-learning practice so that students' mathematical proficiency is enhanced. Through a classroom-based intervention study, teachers' teaching practice with ICTs and students' level of mathematical proficiency were investigated. This study also identified the factors that influence integration of ICTs in the teaching-learning process.

This study employed a case study- mixed method (convergent parallel) approach where two cases were selected from the schools of Dhaka city. Each case constitutes an ICT-facilitated Grade-10 mathematics classroom, one mathematics teacher & students of that classroom and head teacher of the school. A design experiment was applied under each case. In the preliminary phase of the design experiment, tentative design principles for the intervention were developed and in the prototype phase of the design experiment, the intervention was applied. The mathematical software 'GeoGebra' was considered as the catalyst of the intervention along with the other technologies. The instructional unit for the intervention was on linear function.

Classroom observations, interviews, FGDs, paper-pencil tests and survey questionnaires were administered to collect data. The qualitative data were collected through interviews, classroom observations and FGDs while the quantitative data were collected using survey questionnaires and paper-pencil tests. To explore teachers' pedagogical considerations in an ICT-facilitated teaching-learning environment to promote students' mathematical proficiency, classroom observations, interviews (with teachers) and FGDs (with students) were conducted. Before the intervention, survey questionnaires and paper-pencil tests were administered to understand students' baseline mathematical proficiency level. After the intervention, survey questionnaires, FGDs and paper-pencil tests were conducted to understand whether students' mathematical proficiency improved or not. Finally, semi-structured interviews with teachers and head teachers of both cases were administered to

identify the factors that affect ICT integration in the teaching-learning process. The affecting factors were also identified by classroom observation. Qualitative data were analyzed by iterative analytical approach whereas quantitative data were analyzed by the descriptive statistics that include mean, median and standard deviation. A paired sample t-test and Wilcoxon signed rank test were used to compare the students' level of mathematical proficiency before and after intervention.

The study found that the teachers apply different pedagogical considerations with the help of ICTs to make the lesson effective. These pedagogical considerations are rearranging classroom amenities, ensuring technology accessibility and its appropriate usage, adopting different strategies to make the learning meaningful, offering multi-channel feedback, offering opportunity to identify error/ imprecision and engaging students through motivation. In the ICT orchestration process, ICT tools and students also perform several roles while teachers apply different types of instrumental orchestration (e.g., link-screen-board, Technical-support, Sherpa-at-work etc.). The study found that teaching approaches have a great influence on students' development of mathematical proficiency (MP). When teachers orchestrate ICTs in their teaching-learning process, students' all strands of mathematical proficiency (i.e., conceptual understanding, procedural fluency, adaptive reasoning, strategic competence and productive disposition) increase. The study also revealed that students' productive disposition increases if they learn mathematics interactively. The study found that while a variety of pedagogical considerations promote students' MP, all the pedagogical considerations do not directly enhance every strand of MP. The study also found several factors related to teachers, students, school and national context that affect ICT integration in the teaching-learning process.

Overall, the thesis has several contributions to the theories and for policy and practice. The key theoretical contributions of the thesis can be stated as: 1) identifying specific pedagogical approaches that develop each element of mathematical proficiency (MP), 2) introducing a new component "*selection of task*" in the didactical phase of the theoretical framework "instrumental orchestration" of this study, 3) specifying the role of ICTs as well as students in the ICT-enabled teaching-learning environment while teachers' intention to

promote students' MP, 4) developing a comprehensive ICT-orchestration framework to enhance students' mathematical proficiency. Further to that, several practical implications (for both policy and practice) of the findings have been discussed and also few scopes for future research have been offered.

Key words: ICT-orchestration, mathematical proficiency, ICT- facilitated Teaching-learning environment, factors, framework, resource-constrained environment, Bangladesh.

Chapter One

INTRODUCTION

1.1 Introduction

ICT has widely been considered to have the potential to promote positive changes in the teaching and learning process. Over the years, it has become an effective educational tool by promoting significant change in the teaching-learning process. Many studies demonstrate the benefits of ICT integration for teachers and students in the classroom (Das, 2019; Tinio, 2003). ICT helps teachers to create better lessons and encourages students to participate in them willingly, even if technology may also be used as a supporting tool to help teachers improve their instruction (Department for Education and Skills [DfES], 2004). Research to date indicates that ICT in conjunction with essential teaching strategies has a significant impact on students' development of higher order thinking skills (Kearney & Treagust, 2001). Laborde (2001) argued that another benefit of ICT as a tool (e.g., dynamic geometric software) is to help learners to test their conjectures instantly and modify their solutions in a non-threatening environment. Cunska and Savicka (2012) stated that ICT tools (e.g., computer,interactive board, multimedia data projector, internet etc.) have opened a new possibility in teaching-learning process. According to them, in this era of technology, traditional teaching techniques need to be shifted into new paradigm, where teaching method should be interactive, and motivate students for self-learning. While ICT has been seen to have positive influence on the quality of pedagogy, students' learning (Mumtaz, 2000), and students' motivation (Chen & Looi, 1999), its potential would be of no use if it is used only as technological possibilities rather than in service of educational needs (Cuban, 2001). Consequently, researchers argued that the focus should be on the needs for contextualized teaching and learning to drive ICT interventions, rather than on the technology itself (Khalid et al., 2023).

Development of students' mathematical proficiency has been universally accepted as one of main goals of the mathematics education (National Council of Teachers of Mathematics [NCTM], 2014). According to Kilpatrick et al. (2001), mathematical proficiency is made up of five interconnected elements, such as conceptual understanding, procedural fluency, adaptive reasoning, strategic competence, and productive disposition. Kilpatrick et al. (2001) define mathematical proficiency as having a firm grasp of the subject matter, being able to carry out procedure fluently, being able to solve problems using a variety of approaches, and demonstrating a willingness, confidence, and perseverance to solve mathematical problems. According to published research, ICTs can help students think more mathematically (Laborde, 2001) and become more confident in their capacity to solve mathematical puzzles (DfES, 2004). Researches also show that use of ICT in teaching-learning process not only develop students' mathematical procedural skill but also develop advanced mathematical proficiencies such as problem solving, reasoning, and justifying skills if it is used strategically (e.g., Gadanidis & Geiger, 2010; Pierce & Stacey, 2010; Roschelle, et al., 2010a, 2010b). Extant literature asserts that ICTs are the most powerful when used as a tool for problem-solving, conceptual development, and critical thinking in mathematics (Das, 2019). Das (2019) stated that various types of ICT tools such as graphic calculators, specialized software (e.g., GeoGebra, SymPy, Maxima), spreadsheets, and databases, etc. can be used for teaching mathematics and with the effective use of these tools, the impact of ICT in mathematics education can be maximized (Becta, 2003). As a result, educators must possess the ability to recognize the circumstances in which technology can improve students' learning (International Society for Technology in Education [ISTE], 2008). Students' mathematical concepts are developed, their attention is piqued, and their mathematical proficiency is increased when teachers effectively integrate technology in the classroom (National Council of Teachers of Mathematics [NCTM], 2011).

1.2 Mathematics Education context Bangladesh

The education system of Bangladesh is divided into three streams: general education, madrasah education and vocational education (see Table 1.1). In the general education system, five years are allocated for the primary level and seven years for the secondary level (i.e., Junior, secondary and higher secondary level). In madrasah education system, students learn about religious (Islam) knowledge along with regular education. The vocational education system starts after the Junior Secondary level and students of this stream focus on gaining technical skills by hands-on-activities.

According to the national curriculum 2012, mathematics is taught from the very beginning of the school and students have textbook on mathematics from Grade-1. The students of all streams (i.e., general education, madrasah education and vocational education) study mathematics as compulsory subject and mathematics curriculum is same for all those streams. Mathematics curricula at primary level are integrated which focuses on:

i) to develop students' basic skills related to language, numeracy and counting

ii) to help develop learning skills and attitudes and

iii) to help develop the habit of solving problems through scientific methods as well as to develop a scientific outlook in life.

Table 1.1: A simplified presentation of Education structure in Bangladesh

<table>
<tr><th rowspan="2">Age range</th><th rowspan="2">Grades</th><th colspan="5">Programs in different Sub-systems</th></tr>
<tr><th colspan="2">General Education</th><th colspan="2">Vocational Education</th><th>Madrasah Education</th></tr>
<tr><td></td><td>Postgraduate degrees and diplomas</td><td colspan="4">Post graduate programs</td><td></td></tr>
<tr><td>18+-</td><td>Undergraduate degrees and diplomas</td><td colspan="4">Undergraduate Programs</td><td>Kamil</td></tr>
<tr><td>16+ to 17+</td><td>Grade-11 and Grade-12</td><td rowspan="3">Secondary Education</td><td>Higher Secondary Education (HSC examination)</td><td>HSC vocational</td><td>Certificate</td><td>Alim</td></tr>
<tr><td>14+ to 15+</td><td>Grade-9 and Grade-10</td><td>Secondary Education (SSC examination)</td><td>Trades certificate/ SSC vocational</td><td>Artisan courses</td><td rowspan="2">Dakhil</td></tr>
<tr><td>11+ to 13+</td><td>Grade-6 to Grade-8</td><td colspan="3">Junior Secondary Education</td></tr>
<tr><td>6+ to 10+</td><td>Grade-1 to Grade-5</td><td colspan="4">Primary Education</td><td>Ebtedayee</td></tr>
<tr><td>3+ to 5+</td><td colspan="6">Pre-primary education</td></tr>
</table>

(Source: Bangladesh Bureau of Educational Information and Statistics [BANBEIS], 2016)

Students from Grades 6 to 8 study 'mathematics' as a compulsory subject and 100 marks are allocated for each class for that subject. Students in General Education are distributed into three streams – Science, Humanities and Business studies which start at Grade-9. Students of all these three streams study a compulsory General Mathematics where the main contents are real number, set, function (basic idea), algebraic expression, trigonometric ratio, geometry (line, angle, triangle, circle etc.), statistics, measurement etc. Additionally, Students of Science stream can study "Higher Mathematics" as an elective subject (students have to choose one between Biology and Higher Mathematics, see Table 1.2) or as an optional subject (students may or may not take one from 7 subjects). Higher Mathematics is designed to build a strong foundation of mathematics that will be beneficial for students in higher study. In fact, the applicability of higher mathematics is everywhere and it contributes huge in the development of ICT and Science. Gaining knowledge through the higher mathematics helps students to visualize real features of abstract ideas as well as to enhance their thinking skills (NCTB, 2013).

Students face a public examination after finishing year 10. This public examination which is called *Secondary School Certificate* (SSC) and it is very important to students, teachers, parents, school authorities as well as government.

Table 1.2: Subject framework, time allocation for Grade 9- 10 (General Stream)

Type	Subjects	Number
Compulsory	1. Bangla	200
	2. English	200
	3. Mathematics	100
	4. Religion and Moral Education/Hinduism & Moral Education/ Christian Religion & MoralEducation/ Buddhist Religion & Moral Education	100
	5. Information and Communication Technology	50
	6. Career Education	50
	7. Physical Education, Health Science and Sports	100
	Total	800
Group wise Subjects: Compulsory subjects for Science	8. Physics	100
	9. Chemistry	100
	10. Biology/Higher Mathematics	100
	11. Bangladesh and Global Studies	100
Optional subjects for Science (one will be chosen)	12. Biology/ Higher Mathematics/ Agriculture/ Home Science/ geography and Environment/ Arts and Crafts/ Music	100
	Grand Total	1300

(Source: National Curriculum and Textbook Board [NCTB], 2012)

However, according to the recent reformed national curriculum 2021, there are no groups or streams up-to secondary level. The curriculum is competency based and main objectives of this curriculum is to prepare a civil society who are capable to meet the challenges of 21st century. To achieve desire competencies, 10 distinct learning areas (Table 1.3) have been identified. Associating with these learning areas, students of pre-primary level study integrated subjects whereas students from primary to secondary level study several subjects (e.g., Bangla, English, Math, Science, Religion and Culture etc.). Up-to the secondary level, all students have to study mathematics as a subject. Subsequently, in upper secondary and beyond, they go for specialized areas to acquire skills and knowledge for professional preparation.

Table 1.3: Textbook associated with different learning areas from pre-primary to secondary level

Learning Areas	Pre-primary	Primary	Secondary (Grade 6-10)
Language and Communication Mathematics and Reasoning Life and Livelihood Social and Global Citizenship Environment and Climate Science and Technology Digital Technology Physical and Mental Health and Wellbeing Religion, values and Ethics Arts and Culture	Integrated subject	▪ Bangla ▪ English ▪ Mathematics ▪ Science ▪ History and Social Science ▪ Wellbeing ▪ Religion Studies ▪ Arts and Culture	Bangla English Mathematics Science History and Social Science Digital Technology Life and Livelihood Wellbeing Religion Studies Arts and Culture

(Source: National Curriculum and Textbook Board [NCTB], 2021)

The new curriculum discourages completing straight-forward textbook questions without using critical thinking skills or memorization of mathematical formulas. Instead, the study of mathematics emphasizes its nature, logical reasoning, and practical applications (NCTB, 2021). It is hoped that by learning mathematics, students would be able to use their skills in a variety of contexts (such as everyday life, social interactions, the workplace, etc.) and develop into rational, considerate citizens (NCTB, 2021). This curriculum groups the various branches of mathematics into four main categories: number and measurements, mathematical relations, shapes, and probability. It is expected that students will apply their mathematical skills and perspectives to solve problems associated with these fields. It may be mentioned that the reformed curriculum 2021 is not implemented during the course of this study.

Since, the revised curriculum 2021 was not put into practice while this study was being conducted. Therefore, the study's focus is on secondary education (Grade-9 and Grade-10) of general education.

1.3 Students' Performance in Mathematics: Bangladesh context

According to Morshed (2013), Bangladeshi students do remarkably poorly in mathematics, and comparatively few of them elect to take more advanced mathematics courses at the upper (senior) secondary level (Alam & Morgan, 2017). As, Bangladeshi students learn mathematics as compulsory subject from the primary to secondary level, it is desired that they will grow up with a good mathematical knowledge. However, in reality, students' performance in mathematics is disappointing (Kafi, 2015). In 2015, the Learning Assessment of Secondary Institutions (LASI) reported that the baseline competence of the students of secondary level in mathematics is very poor (Directorate of Secondary and Higher Education [DSHE], 2015b). Again, the Bangladesh Bureau of Educational Information and Statistics (BANBEIS) 2022 and 2021 data reports show that fewer students in Grades 6, 7, 8, 9, and 10 were enrolled in mathematics courses in both years (BANBEIS, 2023; BANBEIS, 2021). One way to gauge the caliber of secondary education in Bangladesh is through the Secondary School Certificate (SSC) exam (Hossain, 2018). According to previously published research, 24 schools were found to have all of their students fail the 2014 SSC exam, with a key contributing factor being a lack of success in math classes (BISE, 2014). Besides, it is reported that within the last 10 years, the pass rate of SSC examination was highest in 2014 which was 91.34 %. In 2022, the pass rate was 87.44% whereas in 2023, it was decreased by 7.05. The SSC examination of the year 2023, the students (of Dhaka Board) performed the lowest in 13 years and it happened due to the poor performance in mathematics and English (Siddiqui**,** 2023). In a study, Morshed (2013) reported that students of secondary level performed the lowest in mathematics subject among all the subjects and sometimes failed to exhibit the basic mathematical skills.

According to Salamet al. (2015), Govt. of Bangladesh has taken initiatives to change this scenario such as emphasizing on creative questions rather than typical set of questions within the book.

Abdullah (2023) discussed that students of secondary level perform very weak in mathematics and English and the key reason identified behind this is lack of qualified teachers on those subjects' area. As a result, the government has placed a special emphasis on teaching mathematics since it is believed that in order for students to successfully navigate the challenges of the twenty-first century, they need to possess a sufficient level of mathematical knowledge and abilities, or mathematical proficiency (Redecker & Johannessen, 2013). Under the Secondary Education Quality and Access Enhancement Project (SEQAEP) (Directorate of Secondary and Higher Education [DSHE], 2015a), highly qualified extra class teachers (ACTs) have been hired in Mathematics to increase the quality of secondary education in addition to English and Science.

Despite the efforts, students' performance in mathematics remains as a concern. Study also showed that the major portion of the Bangladeshi students of Grade-10 fail to perform a problem in different strategies (which is one of the strands of mathematical proficiency) rather they are able to identify information and to perform routine procedures according to direct instructions only (Sultana et al., 2020). To improve this situation, ICT has been found to have potential to both motivate students in mathematics (Chen & Looi, 1999) and develop their mathematics proficiency (Kilpatrick et al., 2001).

1.4 ICT in Education context Bangladesh

Considering the huge potential of ICTs, the current government of Bangladesh (GoB) has given significant emphasis to incorporate ICT in education in the National Education Policy. In the chapter one of the education policy, there are 30 distinct statements associated with the aims, objectives, goals and principles and among these statements, two are focused on application of ICT in Education:

> *12. to attach substantial importance to information and communication technology (ICT) along with Mathematics, Science and English in order to build up a digital*

Bangladesh based on knowledge-orientation and cultivation of ICT" (Ministry of Education [MoE], 2010, p. 2) and

21. extend the use of information and communication technology (ICT) instrumental in educational process at every level" (MoE, 2010, p. 2).

Besides, use of ICT has also given the highest importance in the vocational and technical education unit of the education policy to develop competent and skilled manpower. It is reported in the national education policy, "turn our students into competent manpower through vocational and technical education with emphasis on science, technology and especially on information technology" (MoE, 2010, p. 24). Compulsory introduction of ICT in vocational and technical education has emphasized in the education policy too. To capitalize the potentiality of ICT in every aspect, National ICT Policy 2018 provides several action plans (Ministry of Post, Telecommunication and Information Technology [MoPTIT], 2018). In order to realize the vision of "Digital Bangladesh" by 2021, the ICT policy aims to enhance human resources, guarantee government accountability and transparency, and create an ICT knowledge-based society. The ICT policy has made integrating ICT into education a top priority. According to the policy statement, GoB has emphasized on several aspects related to education such as:

- *Extending the reach of ICT literacy throughout the country by incorporating ICT courses in secondary education and technical & vocational education.*
- *Boosting use of ICT tools in all levels of education.*
- *Improving quality of education through ICT (e.g., more access to education and resources).*
- *Setting up computer labs with high-speed internet connections in all educational institutions.*
- *Suggesting some strategies aligned with blended learning environment.*

To achieve the vision "Digital Bangladesh" by 2021 and "Smart Bangladesh" by 2041, and to enhance the quality of education and to develop the capacity of the teachers of the country, several programs have already been implemented while many are in progress.

Developing multimedia classrooms (MMC), well equipped ICT labs, a teachers' portal, digital content, an e-platform for taking classes (Muktopaath), students' e-portal, e-Book, MMC Monitoring Application (Islam & Ferdosh, 2019) are few to mention. The government intends to incorporate ICT facilities in educational institutes all over the country. The government has decided to introduce at least one multimedia classroom in every schools and has expected to convert each classroom of every institution into a multimedia classroom (one laptop/PC, projector, internet connection) and to establish at least one laboratory with adequate computers and internet facilities in each institute (MoE, 2013). Accordingly, over 50,000 primary and secondary schools have already been equipped with multimedia facilities (United Nations Development Programme [UNDP], 2021) and most of the schools have at least one ICT lab equipped with computers and few of those having internet access too (Imon, 2017). Besides, recognizing the strength of digital platform, the GoB and NGOs are trying to integrate ICTs as an innovative approach in education (Parvin, 2013).

Even though utilizing ICT in education is prioritized more than ever, most Bangladeshi teachers utilize it for administrative tasks including making notes, updating their knowledge, maintaining administrative records, and doing routine information searches. (Khan, 2014, p.22). Concerning issue arises when subject teachers intend to practice ICT in their classrooms (John & Sutherland, 2004). Teachers and students initiate to use technology without prior knowledge or experience (Shohel & Power, 2010). Taking this into account, government of Bangladesh has started professional development programs for the subject teachers (e.g., trained teachers for developing multimedia digital content). The focus of the training programs was to develop both pedagogical knowledge and technological knowledge of the teachers for their relevant subjects (Hansson et al., 2018). More than 150,000 teachers have been trained to develop and use digital contents (mainly PowerPoint based presentation) (Islam & Ferdosh, 2019).

Teachers who got the training on developing digital contents, create contents appropriate for multimedia classrooms and share those materials through a Teacher's Portal (https://www.teachers.gov.bd/), which is a central repository for e-learning content for teachers, trainers and for all students (Sultana & Haque, 2018). Teachers' Portal gives them access to an adaptable learning environment (Figure 1.1). Teachers can, for example, use this online platform to build a new profile prior to starting school, create content, learn from their colleagues, support their professional growth, and much more (Aspire to Innovate [a2i], 2023). All levels of teachers, from general academic to madrasah and vocational instruction, can access the Teachers' Portal (Figure 1.2). Teachers from all over the nation can connect with one another and get help anytime they need it via this online platform. Every two weeks, teachers of that platform are acknowledged as best content developer, innovative teacher, best online performer etc. based on user online rating and some other criteria. Some teachers have also been approved as ICT4E (ICT for Education) District Ambassadors based on their active participation in the platform as well as in the development of teaching- learning. Another platform Muktopaath (http://www.muktopaath.gov.bd/login/auth) was developed to make teaching-learning material easily accessible for both the teachers and students. By that platform, anyone can gain knowledge by accessing free online courses and tutorials easily.

Figure 1.1: learning environment provided by Teachers' Portal

Figure 1.2: Snap shot of Teachers' portal

The Covid-19 pandemic has also forced us to introduce contemporary methods in the field of formal education, pushing the conventional educational system in the direction of an innovative, technologically-based system. During the pandemic, instructors and students had to adapt to using technology for teaching and learning, which ultimately assisted them in partially replacing the conventional pedagogical approach with a more modern one

(Gamage et al., 2022). At the same time, Bangladesh experimented with various options to deliver lessons (e.g., delivering lesson over radio, TVchannel and the internet) and the learning from that unique situation compelled the educationists to think about necessity of "Blended Education". The government has already taken initiatives to develop a comprehensive National Blended Education and Skills Master Plan, 2022-2031 which is based on Blended Education For All (BEFA) Framework (World Economic Forum, 2023). The plan is guided by some issues (Figure 1.3) such as teaching-learning practices, educational content & resources, assessments, teachers' professional development etc. According to the framework, teacher learning practices should be innovative rather than merely providing lectures. To cope up with this complex and challenging world, learners' must learn how to learn, ask questions and solve problems. The aim of the teaching-learning practice would be to prepare students for the future with 21st century skill through synchronous and asynchronous interaction (World Economic Forum, 2023).

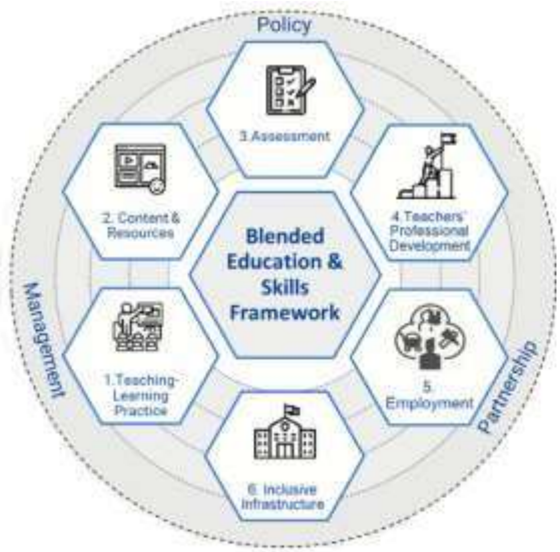


Figure 1.3: Blended Education For All (BEFA) Framework

Bearing this in mind, the ongoing national curriculum reform in Bangladesh emphasizes on experiential learning and problem-based learning (PBL) approaches in classrooms. Along with the teaching-learning approaches, it also stresses on modification of all content and resources such as teacher guides, workbooks, school-based resources, learning content etc. Besides, empowering teachers to use smartphone for students' assessment and learning purpose, continuous assessment tools are piloted in Bangladesh. In addition, face-to-face teachers' professional development (TPD) has been shifted to blended TPD which is supported by about 2,500 tech-savvy teacher ambassadors (termed as "super-teachers") who are performing as a change-agents within the teacher communities (World Economic Forum, 2023).

1.5 Problem Statement

Despite the efforts and initiatives taken by the Govt. (discussed in sections 1.3 and 1.4), research shows that no remarkable change is observed between students' performance in general classroom and that in multimedia classroom (Imon, 2017). Every year a huge number of students pass with grace marks (additional marks awarded to help the learners who were on the borderline of passing) and fail to show minimum level of math proficiency (Kafi, 2015). In a study, Salam et al. (2015) argued that Bangladeshi students lack in math proficiency levels, which is very important for developing skilled citizen in the twenty first century. According to Kafi (2015), the majority of mathematics teachers lacked sufficient understanding of contemporary teaching techniques. Traditional teacher-centered lecture-based pedagogy, which promotes rote learning and places students in a passive rather than an active and creative learning role, is still widely used in many institutions across the nation (Barua et al., 2020). Besides, teachers are still found to struggle in using the digital materials properly. They could not engage learners in activities as suggested in the instructional materials and sometimes struggled to operate those materials confidently (Ropum, 2022). Subsequently, they are found not using digital devices in their classroom teaching-learning process regularly (Khan et al., 2012).

In fact, use of ICT in Bangladesh is mostly limited to the use of scientific and ordinary calculators and presenting PowerPoint slides in mathematics classrooms (Sultana et al., 2016). Teachers are not aware of how to teach with ICT tools to develop a concept (Sultana & Khan, 2017). In a study, Sultana (2016) found that usually teachers do not use any specific mathematical software or online mathematical sites in the classroom. Instead, they make PowerPoint slides and project those slides on the large screen. She also found that most of the teachers use ICT tools to show pictures, video clips, and diagrams related to a topic to stimulate and engage students in the lesson (i.e., to develop productive disposition) rather than focusing on other components of mathematical proficiency i.e. conceptual understanding, procedural fluency, adaptive reasoning and strategic competence. While mathematical software has potential to enhance mathematical proficiency (Das, 2019), due to existing constrains such as lack of physical facilities in school, large size class, financial issue etc., teachers cannot practice various strategies with the assistance of mathematical software or web-links (Sultana, 2016). In a recent study, Kabir and Jalali (2021) found that the focus of teaching of the Bangladeshi teachers is to convey the mathematical knowledge to the students instead of making math meaningful to them and they (teachers) fail to engage students' in logical and systematic reasoning. As a result of this, students' capability of adaptive reasoning does not develop and they fail to transform real-world problem into a math problem. This may lead to lack of interest (i.e., reduce productive disposition) in mathematics among the students (Anigbo & Ekene, 2015).

The national education policy emphasizes the use of ICT in science and mathematics, but no specific approach has been suggested to be followed in order to develop students' mathematical proficiency. In addition, to the best of my knowledge, there is no literature or instructional guidelines on how ICTs can be applied in the teaching-learning process so that students' mathematical proficiency develops. Thus, teachers in Bangladesh are unaware about how to develop a concept or students' mathematical proficiency with the help of ICTs (Sultana & Khan, 2017).

1.6 Rationale of the Study

It is argued that technology is a vital tool for learning mathematics in the 21st-century and for effective mathematics learning experience, schools must ensure that all their students have access to technology (NCTM, 2011). But developing countries having enormous challenges and a unique social context different from developed countries (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2014). ICT use documented in the classrooms of developed countries may not be applicable for classrooms in developing countries because of differences in their contexts. Developing countries struggle with lack of ICT infrastructure and equipment, frequent power failure, inadequate laboratories, low ICT skills, lack of funds, substandard classrooms with large numbers of students (e.g., more than fifty students per class), shortage of qualified teachers, lack of teaching materials, very low teacher salaries, and inadequate training facilities (Khan et al., 2012). Besides these challenges, the lack of proper planning and, misalignment of policy and implementation make the situation worse (Khan et al., 2012). Consequently, the social context of such a resource-constrained environment must have impact on what and how ICTs are being used in mathematics teaching-learning process and how students' mathematical proficiency can be developed. Ernest (1989) claimed that the constraints and opportunities of the social context are so powerful that teachers adopt teaching practices according to the context even if their beliefs vary from what context offers. This reflects the importance of social contexts, which deserve special attention.

In a recent study, Sudiarta and Widana (2019) argued that ICT, if used appropriately, has a great impact on enhancing mathematical proficiency among the students. This finding reflects that introducing ICT in a classroom promotes improvement of the learning experience, if used suitably. But extant literature does not explicitly discuss which ICTs are appropriate for a mathematics classroom and how it can be taken advantage of. In addition, though Govt. of Bangladesh has given stress on incorporation of ICT for teaching mathematics, no specific guidelines (focusing on to develop students' mathematical proficiency) have been suggested for the teachers. In fact, existing literature offer limited guidelines on how and what ICT tools could be integrated to harness the potential of ICT in mathematics classrooms, specially to increase the proficiency in such a resource constrained environment like Bangladesh. As mentioned in the problem statement, teachers in Bangladesh are unaware about how to develop a concept or students' mathematical proficiency with the help of ICTs. Hence, the benefits of using ICT in the classroom needs to be clearly spelt out so that teachers are motivated and can envision how to use it in their teaching to enhance students' proficiency in mathematics. Besides, it should also be clear to the teachers how to use technology in the classroom to develop students' mathematical proficiency, since teachers' delivery quality has been found to have critical impact on students' satisfaction (Sultana & Khan, 2019). As such, given the novelty of ICT adoption in mathematics education in Bangladesh, it deserves special attention to investigate how ICTs could be incorporated in the mathematics teaching-learning process so that students' mathematical proficiency is enhanced. This study aims to address this gap in extant literature by investigating how ICTs could be orchestrated in the mathematics teaching-learning process to enhance students' mathematical proficiency in the context of a developing country like Bangladesh.

1.7 Purpose and Research Question

The purpose of the study is to explore the effective use of ICT tools with appropriate pedagogical approach to promote student's mathematical proficiency. In line with the purpose of the study, the broader research question of the proposed research is-

> *How can ICTs be orchestrated in the mathematics teaching- learning process to promote students' mathematical proficiencies in Bangladesh?*

To address the above question, the following specific research questions have been explored:

> **RQ-1.** How do teachers apply pedagogical considerations in an ICT-facilitated teaching-learning environment?
>
> **RQ-2.** Whether and how does the ICT-facilitated teaching-learning process promote students' mathematical proficiencies?
>
> **RQ-3.** What are the factors that affect integration of ICT in mathematics teaching-learning process?

Researchers argue that societal differences between developed and developing countries provide opportunities for testing, refining, and extending theoretical perspectives that have emerged from research in developed countries. In light of that, this study in the context of resource constraints can be useful for developing new theories on effective ways of using ICTs in teaching-learning to enhance students' mathematical proficiency.

1.8 Significance of the Study

The study is significant in number of ways. First, this study intends to provide a holistic guideline of how ICTs can be orchestrated in the teaching-learning process so that students' mathematical proficiency enhance. To compete with this challenging world and to become 21^{st} century's skilled citizen, proficient in mathematics is vital. Thus, findings of the study will be critical as the current government of Bangladesh aims to develop a smart Bangladesh and reform the national curriculum to meet the international standard of education. The framework developed in this study will guide the policy makers and curriculum developers for necessary reformation in school curriculum, teacher education curriculum and policy.

Findings of the study will guide the teachers what would be effective way of using ICTs in their teaching practice so that students' mathematical proficiency develop. Teachers of Bangladesh particularly will find this study beneficial as this study will help them to understand how classroom need to be organized while teaching with ICTs. Besides, the study will suggest them which and how ICTs should be applied, what should be the function of ICTs, and how student should be performed during the orchestration process of ICTs in their teaching practice. Second, this study will explore the factors which influence ICT integration in teaching-learning process. This information will be helpful for the teachers, administrators, policy maker so that they can think about necessary modification required to change the existing situation. ICT has the potentiality to develop students' proficiency. However, no study so far explore how ICT should be used in the teaching-learning process to develop students' mathematical proficiency specifically in a resource constrained environment like Bangladesh. Thus, this study will contribute to the relevant literature by developing an ICT-orchestration framework to develop students' mathematical proficiency.

1.9 Operational Definitions

1.9.1 Orchestration

The term "orchestration" is used by many scholars. According to them orchestration is the design and real-time management of multiple classroom activities, various learning processes and numerous teaching actions (Tomlinson, 1999; Gravier et al., 2006; von Inqvald, 2009). Moon (2001) expressed 'orchestration' as "the process of managing a whole learning group in such a way as to maintain progress towards the learning outcomes and improvement of practice for all" (p. 120). According to Dillenbourg et al. (2011), orchestration refers as the multi-layered actions applied by the teacher in a technology-enhanced learning environment. In this study, Orchestrating ICTs means teacher's intentional and systematic organization and use of ICT tools available in a ICT-facilitated teaching-learning environment. In the orchestration process, along with the teacher, ICT tools and students also perform vital role.

1.9.2 ICT-facilitated Teaching-Learning (TL) environment

Teaching-Learning environment is a very important variable as it affects learning outcomes. Extant literature shows that 30-60% of our learning is the result of our brain's wiring whereas 40-70% is due to the impact of environment (Langford, 1989). In line with that, Waxman and Huang (1998) argued that the learning environment has direct influence on students' cognitive and affective outcomes. In their study, Pear and Crone-Todd (2002) argued that to ensure high quality learning environment, it is necessary to create technology-based learning situation. They also emphasized on internet-based learning context. Research shows that to motivate students, to enrich learning resources, to implement learning and instructional strategies, and to assess and evaluate learning goals, technology–enhanced learning environment is very effective (Wang & Kinuthia, 2004). They argued that technology enhanced learning environment open a scope for teacher as well as learners to experience an innovative teaching-learning practice. With the assistance of technology, the learning tasks, learning activities can be presented in such a way that learner becomes curious to learn and achieve better mathematical understanding. Besides, in this environment, it is possible to enrich learning resources by the use of technology which is quite unlikely to be accessed in a traditional classroom environment. With the use of technology, it is possible to provide learners with clear guidance, instant feedback, and immediate satisfaction on their learning efforts. Computer programs and software especially offer learning with formative and constructive feedback which enhance the learning progress (Wang & Kinuthia, 2004). According to Feng and Hannafin (2005), technology- enhanced learning environments are “technology-based learning and instruction systems through which students acquire skills or knowledge, usually with the help of teachers or facilitators, learning support tools, and technological resources” (p. 5).

In this study, the classroom environment is considered as technologically enhanced. For technologically enhanced classroom environments, several literature use the term ICT-enabled, ICT-enriched, ICT-enhanced, ICT-mediated classroom environment etc. (Dong & Newman, 2018; Kurt, 2014; Lim et al, 2005; Wang & Kinuthia, 2004). I use the term ICT-facilitated classroom environment for this study. In this environment, teachers and students can use computer (s) and computer-based tools. The teacher’s instructional strategies and task design should be suitable for technology-facilitated classroom environment setting. Students perform in the classroom with the guidance of a teacher, learning support tools, and technological resources. The teachers project the computer screen on the board or projector screen. Different types of mathematical software specially the dynamic mathematics software (i.e. GeoGebra) along with the other ICT tools are used by the teachers as well as students for deeper understanding of the mathematical problems. Besides, teachers can use additional instructional material/tools (i.e. concrete material, objects etc.) in connection with technology in this environment. In such an environment, teaching and learning practices are composed of all the moments in which those instructional tools are used and not used.

1.9.3 GeoGebra

GeoGebra is a free dynamic mathematical software that integrates geometry and algebraic feature in a connected way (Hohenwarter & Fuchs, 2004). In this study, along with other ICT tools, the GeoGebra software is used. The GeoGebra software has been chosen for several considerations. Firstly, this software is fairly complete tool and user friendly. Secondly, it is free and can be used without an internet connection. Thirdly, it has the potentiality to increase students’ mathematical understanding by providing visualization of multiple representations. Besides, it offers student centered learning and fosters students’ active participation (Preiner, 2008; Zulnaidi et al., 2020). It also has positive effects on students' motivation and increases students' interest towards the course (Zengin, 2017). As one of the major intentions of this study is to promote students' mathematical proficiency, evidence supports that GeoGebra has the ability to facilitate it.

1.9.4 ICT-facilitated Teaching-Learning Process

Teaching-learning process is the combination of several actions where the teachers evaluate learning needs, set specific learning objectives, construct teaching-learning strategies, execute the plan of work and assess the outcomes of the instruction. (Holz-Clause, 2015). In another study, Mora-Cruz et al. (2022) expressed that teaching-learning process is a relationship between teacher and students by which it is intended to transmit knowledge in a certain area. In this study, ICT-facilitated teaching-learning process refers to the pedagogical approaches that teachers applied with the assisted of technology (where necessary). In this process, teachers may act as an instructor or facilitator based on the requirements of the class to develop students' mathematical proficiency.

1.10 Overview of the Dissertation

This dissertation is organized into six chapters. The following chapter (Chapter two) provides a review of the relevant literature including the theories considered and the conceptual framework developed for this study. The subsequent chapters (Chapter Three to Five) represent the methodology, findings and discussions in line with the research objectives. Finally, the conclusion in chapter six focuses on the contributions made to the existing literature, practical implications of the findings the study and also sheds light on the future scopes for future research.

Chapter Two

LITERATURE REVIEW

Given the objectives of this study, this chapter reviews the relevant literature on mathematical proficiency, tools for learning, teaching for developing mathematical proficiency, teaching with ICTs for developing mathematical proficiency, enablers and inhibitors to ICT integration. Based on the underpinning theory and literature reviewed, a conceptual framework for this study is presented at the last section of this chapter.

2.1 Mathematical Proficiency (MP)

The world in the 21st century is changing fast due to the continuous advancement of technology. It would not be an exaggeration to say that all such advancements are somewhat connected to mathematics. Mathematics is no more perceived as subject for basic computations rather mathematics knowledge is considered as one of the key catalysts of such advancement. According to Redecker and Johannessen (2013), to cope up with this 21st century's world, students have to be prepared with sufficient mathematical skills and competencies i.e. Mathematical Proficiency (MP). Extant literature showed that mathematical proficiency offers several benefits. Mathematical proficiency improves problem-solving skills, which are essential for any career and personal decision-making (Valencia-Márquez , 2022). Besides, it promotes critical thinking and logical reasoning abilities, enables individuals to comprehend complex concepts and arrive at optimal solutions (Baroody, 1993). In line with that, Sumartini (2015) argued, mathematical proficiency develops the ability to convey information in different form (e.g., oral, written, diagram, map etc.) and helps to make well informed decisions.

Kilpatrick et al. (2001) stated that mathematical proficiency consists of five intertwined components- conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. These five strands of MP have been illustrated in Figure 2.1 and explained below.

2.1.1 Conceptual Understanding (CU)

Conceptual understanding is one of mathematical abilities that enables students to organize their knowledge. According to Kilpatrick et al. (2001), CU is an understanding of mathematical ideas as an integrated and functional system that helps students to learn new knowledge by connecting those ideas with what they already know. Similarly, Kenedi et al. (2019) argued that mathematical understanding does not only mean the knowledge about unrelated concepts, but also the ability to explain the relationship among them. Thus, students with CU could organize their knowledge as well as explain them as a coherent system. Kilpatrick et al. (2001) stated that students with CU are able to apply and adapt acquired mathematical ideas to explain new mathematical concepts. This ability helps them to expand their knowledge and perform better in new situations. They claimed that students will be able to use several mathematical representations and communicate their ideas if they have conceptual understanding.

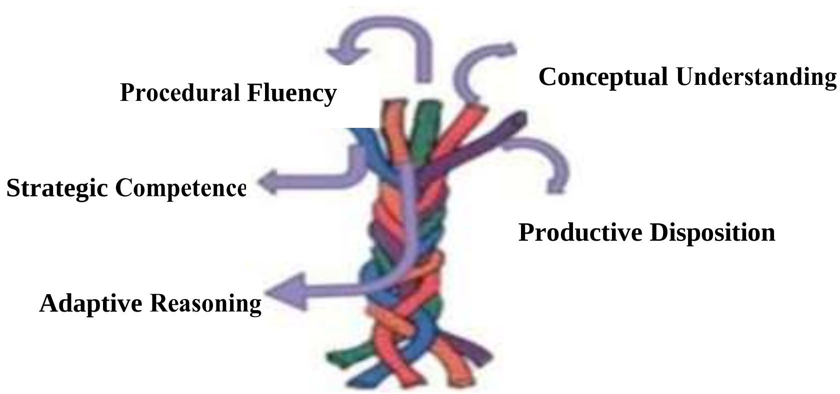


Figure 2.1: Five intertwined strands of MP (Kilpatrick et al., 2001)

2.1.2 Procedural Fluency (PF)

To ensure students' mathematical development, attaining fluency in mathematical procedure is vital. Procedural fluency deals with knowledge of procedures, appropriate time and way to use them (NCTM, 2014). It also refers as the skill of carrying out the procedures flexibly, accurately, and efficiently (Kilpatrick et al., 2001). Students with procedural fluency not only know about the procedures but also know when and how to use the procedure correctly. They also know the information required to perform the procedure effectively and accurately. Moreover, students with PF can use the algorithm flexibly which means that they are able to manipulate the procedure to reach the right solution. Procedural fluency involves both the remembering and thinking process. Thinking process is vital as it will support students' CU based on procedures (Hiebert, 1999). While remembering helps students to recall the procedures, thinking process assists them to choose the appropriate procedure to solve a problem. Besides, students with PF are able to create their own procedures through thinking process (Bahr & Garcia, 2008).

2.1.3 Adaptive Reasoning (AR)

Adaptive reasoning is the capability to think logically, to estimate the answer with proper justification and to judge mathematical truth (Milgram, 2007). Students with adaptive reasoning skills, able to estimate, support their claims with arguments or proof, and draw inferences (Kilpatrick et al., 2001). In a study, Marasabessy (2021) claimed that students' logical thinking ability will be formed by involving in non-routine tasks. In this situation students make connections between concepts and context by their logical thinking capability. Besides, reflective thinking skills (e.g. the ability to explain, the ability to justify) are also generated by logical thinking. Students' ability of adaptive reasoning is vital as it helps them to cope-up with real-life situation (Marasabessy, 2021).

2.1.4 Strategic Competence (SC)

Another mathematical competence which is necessary to solve mathematical problems is strategic competence. The strategic competence is defined by the National Research Council (NRC) as the "ability to formulate, represent, and solve mathematical problems" (NRC, 2001, p. 116). This competency guides students to apply the efficient strategies to find the solution of a problem. Moreover, while solving a problem, students who possess strategic competence track development and create backup plans in case the tactics used turn out to be less successful than anticipated (Ostler, 2011). The ability to comprehend and articulate mathematical issues verbally, to choose the best formulae, methodologies, and/or techniques for problem-solving, and to assess the accuracy of the problems that have been solved- all these aspects are considered as strategic competency. According to Kilpatrick et al. (2001) students with strategic competence can formulate the problem and represent it mathematically, either in numerical, symbolic, verbal, or graphical form.

2.1.5 Productive Disposition (PD)

The habitual inclination to view mathematics as meaningful and valuable, coupled with a belief in persistence and one's own abilities, is known as a productive disposition (Kilpatrick et al., 2001). In a study, Siegfried (2012) stated that productive disposition refers as the tendency to see mathematics as a sense-making endeavor, useful, and worthwhile. They also claimed that students with productive disposition believe that with appropriate effort and experience, one can learn mathematics. Moreover, they believe on their self-efficacy which means they are confident in their knowledge and ability, mathematical habits of mind; mathematical integrity and academic risk-taking; persistence; positive goals and motivation. Extant literature showed that teachers are the essential element of productive disposition as they play a critical role to encourage studentsto uphold positive attitude toward mathematics. Teacher's attitude, teaching strategies as well teaching practice must have great influence on students to develop productivedisposition (Woodward et al., 2018).

2.2 Tools for Learning

Research showed that tools are essential for teaching-learning context as these enable both the teachers and students to fully express themselves (Sutherland et al., 2004; Noss & Hoyles, 1996). The notion of mediation between subject-specific information and learning, scaffolding by different tools in a learner's ZPD is emphasized by the Vygotskian approach (Bakhurst, 2023). While printed text book is an immensely powerful tool in traditional teaching-learning approach, digital technologies are currently being added as an influential tool to mediate between learners and knowledge (Lugalia, 2015). With paper-pencil, printed text book and sociocultural interaction that occur in the classroom teaching-learning environment, computer has become an important tool. According to Noss and Hoyles (1996), the focus of using the computer tools in teaching- learning is to make-meaning in mathematics lessons rather than computer itself. They expected, "the computer will open new windows on the construction of meaning forged at the intersection of pupils' activities, teachers' practices and the permeable boundaries of mathematical knowledge" (p.2). They also added that, by "offering a screen on which students can express their aspirations and ideas, the computer can make explicit what is implicit" (p.5). Research showed that the provision of diversity and alternative teaching- learning styles can raise students' interest and motivate them to engage in learning process (Harel & Papert, 1991). Computer aided teaching-learning environment allow such a diversified teaching-learning style. Specifically, different types of software permit pupils to control activity, learn from instant feedback, see connection, observe pattern, explore data, work with dynamic images and more instances to reflect on results (Becta, 2008). Harel and Papert (1991) stated that "Computers cannot produce 'good learning' but children can do 'good' learning with computers" (p.41).

2.3 Teaching for Developing Mathematical Proficiency

To enhance mathematical proficiency of students, focus needs to be given on how the strands of MP discussed above could be developed in students. Extant literature showed different strategies for developing students' math proficiency. In a study Davis (2018) argued that while teaching mathematics, if teaching approach focuses on rote memorization and procedures only, students will acquire procedural knowledge rather than concepts. Smith et al. (2018) claimed that for developing students' conceptual understanding about mathematics, teachers have to create an environment so that students get involve in the discussions. According to Department of Basic Education (DBE, 2018), to do that teachers should allow learners to answer the question with a 'yes' or a 'no'. This commitment will uphold the learners' interest in the discussion and then ask them to provide the explanation behind their answer. The focus of the discussion should be reasoning rather than simply asking the answer. Since use of mathematical language and explanation of students' own ideas behind their mathematical work are two vital aspects to build students' conceptual understanding, teachers should provide the opportunity to the learners to speak mathematically and explain their answer with proper justifications (DBE, 2018). However, teacher should explore students' misconceptions and use them as building blocks for deeper mathematical understanding (Anthony & Walshaw, 2009).

Again, procedural fluency of students is developed not only by practice but also on a solid basic mathematical concept. While teachers' intention is to develop students' procedural fluency, they need to provide several types of examples from different angles (Foster, 2018). It is an effective way to develop quick recall of basic bonds in the Foundation Phase. This technique will help the learners "to use rapid recall when necessary, to carry out strategic calculating, when working with bigger numbers and to develop their ability to think strategically when doing mathematical calculations" (DBE, 2018, p. 28).

To grasp the deeper mathematical understanding and become proficient, it is vital to develop students' ability to find out the most efficient approach to do calculations and the technique they desire to use. Teachers, by encouraging learners to try different approaches to do a problem and to apply variety of ways to check the solutions of their work, can help students develop that ability (DBE, 2018). In addition, teachers need to provide variation of problems and several methods to solve those problems. By doing that, students will become comfortable to deal with non-routine problems with variety of strategies. This will strengthen students' strategic competence as well as procedural fluency skills. In a study, Ozdemir and Pape (2012) stated about four supporting activities to develop students' strategic competence. These supporting activities are- "the nature of tasks and activities, practices supporting understanding, practices supporting strategic knowledge and skills, and practices supporting motivation" (p.160). According to them the task should be intentionally planned so that students can develop their understanding by involving in collaborative work in small group. To support students' understanding, teacher should provide detailed explanations with multiple methods and the concepts need to be connected with real-life situation. They also stated that teachers need to invite the students to engage in problem solving activities group-wise where "students exercised strategic competence by analyzing the task (e.g., rereading, under-lining, and using context clues), selecting, adapting, and implementing strategies, as well as comparing and contrasting each other's strategies" (Ozdemir & Pape, 2012, p.161). They claimed that teachers need to acknowledge students' understanding and ideas, since motivation is vital to persist in problem solving. In addition, teachers need to highlight the strategies used by the students to solve problems, so that they are encouraged to perform the task by their own techniques.

Assessment is vital to evaluate students' progress (Suurtamm, 2018). While mathematical proficiency is the cohesive blend of conceptual understanding, strategical competence, procedural fluency, adaptive reasoning, and productive disposition, it is commonly observed that the broader focus of assessment is on procedural fluency (Kilpatrick & Swafford, 2002). Kilpatrick and Swafford (2002) mention "[m]ost current math tests, whether standardized achievement tests or classroom quizzes, address only a fraction of math proficiency- usually just the computing strand and simple parts of the understanding and applying strands" (p.32). In line with that Burkhardt (2007) argued, while assessing students' progress in mathematics, focus is often given on procedure rather than learning with proper understanding, logic and strategy. In a study, Groth (2017) reported that it is a common perception among the people that mathematics education is only about procedures and formulas. He claimed that a group of people perceive, "mathematical proficiency mainly in terms of procedure skill" (p. 104). Extant literature showed that to become skilled in mathematics, repetition and reproduction of procedures is not adequate (Schoenfeld, 2007). He argued that though practicing a task repeatedly may lead students to become proficient on that task, students may not be able to deal with a slightly different problem or procedure, if they do not grasp the idea that underlies the procedure. Thus, while assessing students' progress in mathematics, "[a]ssess valued aspects of mathematical proficiency, not just its separate components" (Burkhardt, 2007, p. 79). According to Burkhardt (2007), mathematical proficiencies cannot be appropriately assessed through traditional testing measures (e.g. multiple-choice tests) rather it should consider student's entire performance instead of isolated aspects of students' work. Similar findings are reported by Suurtamm et al., (2016) where they reported that classroom assessment should encourage the use of variety of assessment techniques, tools, and formats. They also discussed that it is necessary to provide timely and regular basis formative feedback and involve students in the assessment process. In a study, Anthony and Walshaw (2009) claimed that to make students' thought visible and to support students' learning, effective teachers use a range of assessment practices. For example, by observing students while they work and by talking with them, teachers can measure students' understanding, see what strategies they prefer, and listen to the language they use. Based on these information, teachers can decide what examples and explanations they should use for discussion in the class. Besides, during the question-answer session, teachers should create the environment as such that students have to respond by thinking critically and with proper justification (Anthony & Walshaw, 2009). They argued that such kind of initiatives ultimately promote students' adaptive reasoning ability. They also argued that when students struggle to deal with a problem, effective teachers support them rather than providing full solutions. They encourage students to search for more information, try another method, or discuss the problem with peers, reflect on their own learning.

To engage people in any sorts of work, motivation is vital. According to Broussard and Garrison (2004), motivation is "the attribute that moves us to do or not to do something" (p. 106). Thus, motivation and engagement are both crucial for the teaching and learning environment. Research showed that students would not have benefited if the instructions are simply provided rather than motivating them (Fried & Konza, 2013; Kim & Kamil, 2002). In the similar vein, Haji et al. (2019) stated that students do not perform well if they are not interested/motivated to learn. They reported that beside focusing on developing math concepts and skill, teachers need to give emphasis to develop students' positive attitude towards mathematics (productive disposition). Extant literature showed that students are motivated to learn while they learn math linking with their practical life (Özkaya & Yetim, 2017) and work in collaborative or cooperative learning environment Lai (2011). According to Anthony and Walshaw (2009), teachers need to motivate students to get involved in student–student and student–teacher dialogue, self-evaluation process.

2.4 Teaching with ICT for Developing Mathematical Proficiency

Effective mathematics instruction should prioritize understanding over rote memorization of solutions. Allowing students to breeze through problems without encountering obstacles may hinder their ability to persevere while they face difficulties. Consequently, creating a learning environment that presents realistic challenges is essential. Swan (2008) proposed that introducing challenging/non-routine problems can cultivate such an environment. Lugalia et al.’s (2015) study demonstrated the significant role of ICT, when used appropriately, in fostering mathematical resilience among students. Resilience instills in students the qualities necessary to tackle challenges, embrace curiosity, and actively engage in mathematical learning (Lee & Johnston-Wilder, 2014). Granberg and Olsson (2015) emphasized that, to maximize the benefits of using Dynamic Geometry Software (DGS) like Cabri and Geometer's Sketchpad, students should engage with moderately challenging tasks that promote the exploration of geometric relationships (Erbas & Yenmez, 2011) and the planning and evaluation of interactions (Hollebrands, 2007).

Similarly, Brousseau and Warfield (2020) advocated for creating opportunities for students to participate in discussions, share their current understanding, and create cognitive dissonance by confronting learners with inconsistencies and surprises. They also maintained that teaching is more effective when misconceptions are identified, challenged, and rectified. Similarly, Parhizgar (2022) highlighted about the importance of exploring students’ misconception and suggested problem-posing as a good approach to point out the misconception. Fuglestad (1997) and Yadav (2015) agreed with this notion, suggesting that various computer software, such as word processors, spreadsheets, and graphics, can be utilized to present challenging tasks and address students’ misconceptions related to mathematical and scientific concepts.

Research demonstrated the potential of dynamic software and apps like Geogebra and Desmose to enhance learners’ conceptual understanding (DBE, 2018). These tools are well recognized for their ability to reinforce mathematical concepts, improve visualization, and rectify misconceptions. By interactively engaging with the software, learners can uncover relationships, formulate conjectures, and test their hypotheses. Static calculation and graphing tools provide opportunities for accurate and efficient calculations and constructions. This frees up learners to focus on developing mathematical concepts rather than being bogged down by tedious calculations and constructions. As a result, ICT enables the exploration of real-world problems that demand complex calculations. It's crucial to note that calculators should not be used if the lesson's purpose is to grasp or practice calculations (procedural skills development). The use of ICT in the mathematics classroom should align with the lesson's objectives (DBE, 2018).

Research also delved into the area of representational fluency, suggesting that technology supports students' ability to learn and compare multiple representations of mathematical concepts (Gunpinar & Pape, 2018). Multiple representations offer learners diverse entry points for mathematical engagement and numerous connections for knowledge construction. Mathematical technologies, with their multiple representations and command options, empower teachers to implement and support tasks with moderate or high cognitive demand (Hwang et al., 2007). For instance, tasks proposed by Doorman and Drijvers (2011), and Jane-Jane Lo and Kratky (2012) exemplify open-ended and/or challenging tasks that capitalize on the affordances and constraints of mathematical technologies. These tasks lack a prescribed solution path, allowing students to forge their own paths, utilize their understanding, and construct arguments leading to a solution. In essence, teachers should integrate mathematical tasks that encourage students to employ technology as learning tools to generate multiple representations and explore connections between them.

Extant literature (e.g., Bramald et al., 2000; Pedersen et al. 2021) showed that ICT offers a diverse range of methods for representing mathematical concepts. ICT-equipped classrooms facilitate the creation and sharing of mathematical representations between teachers and students. Graphical software, for instance, allows for real-time modifications to graphs by manipulating formulas. Teachers can utilize this software to present examples and counter-examples simultaneously, explaining the reasons behind their differences.

Ogwel (2008) contended that ICT environments "offer multiple mathematical representations that enhance the generality of mathematical concepts and provide opportunities for counter-examples, unlike paper-and-pencil environments" (p. 2). Similarly, Wolfram (2010) explained that ICT-mediated teaching-learning environments empower students to solve problems governed by the same principles but with varied levels of difficulty. Therefore, teachers should explore the “computer as an open-ended tool” to allow students to tackle both simpler and more challenging problems, fostering their conceptual understanding (Wolfram, 2010, p.9).

Effective teaching and learning hinged on teachers’ comprehensive understanding of their students’ progress and the ability to differentiate instruction accordingly. Given the unique learning styles and abilities of each individual, providing task materials tailored to students’ achievements can significantly enhance the learning process. Research indicated that ICT environments play a pivotal role in facilitating differentiated instruction (Cunska & Savicka, 2012; Karatza, 2019). Cunska and Savicka (2012) observed that:

> *The use of ICT in lessons helps teachers make the educational process more individualized and differentiated due to the interactive dialogue between a student and a computer at a pace and location suitable for the student. (p.1486)*

Teachers can design and assign differentiated worksheets or checklists based on students’ levels to guide them through the same learning task. ICT-based learning management systems can further enhance the process of supporting students according to their specific requirements (Lim & Chai, 2004).

Manipulatives (both concrete and virtual) play a crucial role in mathematics instruction by making concepts more accessible and understandable for students. Existing literature emphasized the importance of integrating virtual manipulatives to enhance student engagement in lessons and promote the development of deeper connections to mathematical concepts (Moyer et al., 2002; Reiten, 2018). They also highlighted the value of virtual manipulatives in providing immediate feedback and enabling students to self-correct in a non-threatening environment. However, in their study, Burns and Hamm (2011) revealed that while both virtual and concrete manipulatives individually strengthen mathematical understanding, the most effective approach involves the combined use of both manipulatives.

Effective feedback is another essential component of mathematics education. Timely and appropriate feedback helps students recognize the importance of their work and demonstrates that their efforts are valued. Students should receive feedback in such a way that acknowledges their strengths and identifies areas for improvement. ICT-enabled classrooms provide a platform for students to receive feedback from both teachers and computers. Additionally, ICT-based feedback can guide students towards making generalizations based on experimental evidence (Department for Education and Employment [DfEE], 1999). When feedback is delivered using ICT, teachers can encourage students to reflect on their observations, evaluate the evidence, make predictions, and explain their conclusions (Lim and Chai, 2004).

The above literature emphasizes the need for student-centered learning approaches that prioritize active participation over passive knowledge transmission. In large class environments, ensuring active engagement and individualized attention for each student can pose challenges. The integration of multimedia resources, such as computers, audiovisual devices, internet access, and CD/DVD-equipped classrooms, can promote individual ICT engagement in large classes by providing students with opportunities to individually interact with a computer at the front of the classroom. Additionally, teachers can utilize wireless slates, keyboards, mice, or tablet PCs that can be circulated among students. In this teaching approach, the teacher's role transforms from a mere knowledge transmitter to a more interactive facilitator, guiding students through demonstrations, explanations, questions, discussions, predictions, and interpretations of the displayed content while inviting individual students to interact with the computer (DfEE, 1999). Furthermore, projecting computer screens or graphical calculator displays onto whiteboards using projectors or overhead projectors allows teachers to introduce new concepts and guide students in practicing or reinforcing previously learned mathematical concepts. Beauchamp and Kennewell (2010) recommended the use of interactive whiteboards (IWBs) for whole-class instruction, as they enable teachers to present lessons through slideshows, text, and preloaded web pages. Teachers can leverage IWBs to dynamically incorporate various resources based on students' needs and responses. Consequently, the effects of IWBs are often comparable to those of individual computer usage in terms of student engagement and learning outcomes.

It has been noted that promoting active engagement for all students, group work effectively encourages collaboration and problem-solving among peers. Despite the widespread recommendation of collaborative learning approaches, such as group activities, for actively engaging students in lessons (Laal & Ghodsi, 2012), Wegerif (2010) expressed concerns about the use of group work in ICT-enabled classrooms. He argued that while students perform a task group-wise with the help of computer, it is a bit challenging for the teachers to observe students' interactions within groups, raising the possibility that some students may not participate meaningfully in discussions. Wegerif advocated for a dialogic approach, suggesting that dialogue facilitates the exploration of students' thoughts, engagement with their developing ideas, and the resolution of misunderstandings. By engaging in extended classroom dialogues, students can contribute their perspectives, examine the limitations of their own understanding, and practice utilizing language as a tool for thinking and learning. Wegerif (2010) stated:

> *Dialogic is about holding different perspectives together in tension, which inevitably leads to the challenge and competition between ideas, fostering critical thinking, and the spontaneous generation of new ideas and insights, nurturing creative thinking. (p. 23-24)*

The introduction of ICT into mathematics classrooms should not diminish the role of the teacher. Effective student engagement hinges on the teacher's skillful orchestration of ICT. Drijvers (2015) asserted that the integration of technology in mathematics education is not a solution that minimizes the importance of the teacher. Instead, the teacher must orchestrate learning, for instance by synthesizing the outcomes of technology-rich activities, highlighting useful tool techniques, and connecting the experiences within the technological environment to traditional paper-and-pencil skills or other mathematical activities.

When students engage directly with computers, teachers must take a more proactive approach to ensure that they maximize the benefits of the computer's feedback. Unintentional use of ICT, characterized by simply clicking buttons without understanding and connecting concepts to the computer's output, results in ineffective learning. To verify students' comprehension, teachers should encourage them to focus on the presented information and pose questions such as "Why did that happen?" or "What would happen if...?" (DfES, 2003).

While students are actively utilizing ICT tools for their studies, teachers must ensure that all students have a thorough understanding of the tools' operation (Lim and Chai, 2004). They argued that students who are unsure about the tool's operation and benefits are less likely to engage with ICT. They further asserted that students who understand "how to use the ICT tools were more likely to be motivated and engaged in the learning process" (p. 12)

Despite the documented potential of ICT, the importance of traditional tools like paper and pencil and blackboards should not be diminished. As part of ICT-facilitated teaching and learning environments, teachers should encourage the parallel use of paper and pencil alongside ICT tools (DfES, 2003) and also seamlessly integrate the technological environment, such as projected screens, with conventional contexts like paper, books, and blackboards (Drijvers et al., 2010). In a study, Koyuncu et al. (2014) highlighted the advantages of developing proficiency in both paper-and-pencil skills and ICT tools. Sultana et al. (2016) similarly concluded that the incorporation of ICT into the classroom should not lead to the abandonment of traditional tools like paper and pencil.

For a considerable period, the focus in mathematics education has primarily been on developing procedural knowledge, while neglecting the importance of conceptual development. However, recent research suggests that rote memorization alone is insufficient for fostering mathematical proficiency. A more effective approach involves nurturing students' conceptual understanding of mathematical concepts (Balka et al., 2009). According to Al-Mutawah et al. (2019):

> *Students demonstrate conceptual understanding in mathematics when they provide evidence that they can recognize, label, and generate examples of concepts; use and interrelate models, diagrams, manipulatives, and varied representations of concepts. (p.259)*

When students actively construct new knowledge by connecting it to their existing understanding and apply it to solve problems in novel scenarios, their conceptual understanding of mathematics deepens (Balka et al., 2009). Additionally, students who learn through conceptual understanding tend to solve problems more effectively and with fewer errors (NRC, 2001). Since developing conceptual understanding is essential for achieving mathematical proficiency, teachers must employ appropriate pedagogical strategies to facilitate this process.

In a study, Sultana and Khan (2017) identified eleven principles which have been considered as ICT-based effective approaches for teaching-learning mathematics (Table 2.1). They claimed that providing challenging tasks, encourage to involve in creative reasoning, exploring misconceptions, providing counter examples, using manipulatives and treating ICT as an open-ended tool are effective teaching approaches which directly involve enriching students' conceptual development.

Table 2.1: Effective ICT based teaching approach

The Eleven Principles	
Principle 1	Assigning challenging task
Principle 2	Engaging into creative reasoning
Principle 3	Identifying misconceptions
Principle 4	Differentiating students
Principle 5	Treating ICT as an open-ended tool
Principle 6	Providing counter-examples
Principle 7	Using both concrete and virtual manipulative
Principle 8	Appropriate feedback in different aspects
Principle 9	Involving students in classroom dialog
Principle 10	Familiarizing ICT tools
Principle 11	Integrating paper and pencil with ICT

Source: Sultana and Khan (2017)

On the other hand, while several approaches using ICT could be applied to develop conceptual understanding, approaches to increase students' engagement and motivating them in the lesson cannot be ignored as they are crucial for concept development as well. Motivation and engagement are closely related to each other. If students are motivated to learn, they would be willing to engage into the lesson. Research showed that when students learn with a degree of attention, curiosity, interest, confident and passion, it means that they are engaged in the learning process and consequently students' motivation level (productive disposition) is enhanced (Filgona et al., 2020).

According to Lai (2011), to foster motivation and engagement, teachers need to take initiatives to provide autonomy to students by allowing them to be involved in collaborative or cooperative learning approaches. He also stated that teachers need to explore a supportive environment according to the target of the lesson. Research showed that when teaching materials are presented via technology (e.g. computer media), students are more interested to learn and willing to get engaged into the lessons (Halidi et al. 2015, Made, 2011). In a study, García-Valcárcel et al. (2014) claimed that when students learn in collaboration with the help of ICTs, they can hold attention and feel motivated to learn. Research also showed that when students learn mathematics connecting with everyday life, their productive disposition develop (Özkaya & Yetim, 2017) and ICT helps learner to visualize mathematics in real world context (DBE, 2018).

2.5 Enablers and Inhibitors to ICT Integration

Extant literature showed that some characteristics or attributes need to be considered while integrating ICT in mathematics teaching-learning process (Ismail, 2020; Lawrence & Tar, 2018; Turgut & Aslan, 2021). Turgut and Aslan (2021) identified five factors (students, educational material, infrastructure, management, and teachers) that influence ICT integration in teaching whereas Sokku and Anwar (2019) claimed about four distinct aspects such as personal factors, school factors, pedagogical factors and technological barriers which have impact on ICT integration.

According to Crisan et al. (2007), integration of ICT into teaching depends on both the contextual and personal nature. They stated that teachers' learning about ICT and its incorporation in their practice are influenced by school context, institutional characteristics, institutional key persons, availability and accessibility of resources, teachers' ICT skills and ICT professional development (Figure 2.2).

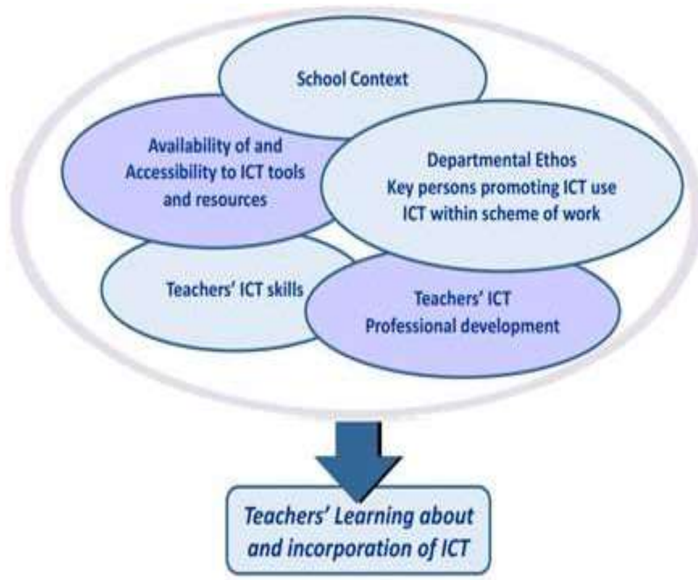


Figure 2.2: Factors affecting integration of ICT in teaching-learning process (Crisan et al., 2007)

As several literature discussed the enablers and inhibitors of ICT integration in the mathematics teaching-learning process from different perspectives, the review literature have been discussed below under three aspects- personal, pedagogical and institutional, which are inter-linked to each other.

2.5.1 Personal aspects

Existing Literature showed that, teachers' teaching practice is influenced by their attitude. For instance, Kaleli-Yilmaz (2015) claimed in his study that teachers' attitudes towards ICT affect their use of ICT in the classroom. They argued that the teacher who hold the negative attitude towards ICT, are less confident and less skilled about technology, as a result they are less willing to accept and adapt with technology and try to avoid use of ICT in their teaching practice. Whereas the scenario is totally reverse for the teachers who possess the positive attitudes (Harrison & Rainer, 1992, Mundy, 2021). As such, if teachers intend to integrate ICT in their teaching practice, it is necessary to hold positive attitude towards ICT.

In a recent study, Sokku and Anwar (2019) stated that ICT integration is directly linked with not only the teachers' attitude, but also their perception regarding ICT. They reported that the teachers who have positive perception about the effectiveness of ICT in learning and consider learning with ICT is interesting, they are interested to use ICTs in their teaching practice. Davis (1989) claimed that teachers' intention to use ICT in their practice depends on their attitude towards ICT. They also argued that teachers show positive attitude towards use of ICT if they perceive it is easier to use and effective for the students. Afshari et al. (2009) argued that when teachers become comfortable about ICT and well-informed about its implications, their positive attitudes to ICT will develop. Again the majority of research on ICT integration reported that teachers view on technology depends on how people evaluate the role that ICTs play in education (Fives & Buehl, 2012; Zinger et al., 2017). Extant literature showed that not only teachers but also students' interest towards technology also influence ICT integration in TL process. In a study, Deryakulu et al., (2008) claimed that students' interest to learn with technology influence the incorporation of ICT in teaching. In addition, several researchers (Cope & Ward, 2019; Parker et al., 2008) stated that the effectiveness of ICT supported teaching to some extent depends on how students perceive about the importance of ICT for their learning. In a recent study, Lin and Muenks (2023) argued that students' mind-set about technology is somewhat shaped by their family members' perception about technology.

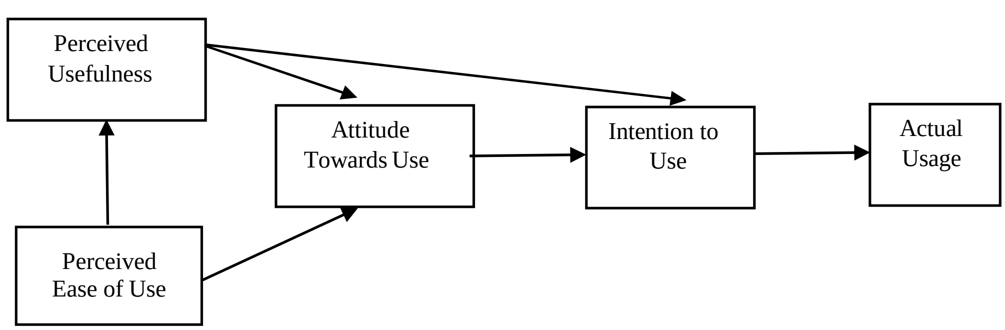


Figure 2.3: Technology Acceptance Model (TAM) (Davis, 1989)

While teacher's perception seems to be a significant predictor for technology integration (Miranda & Russell, 2011; Ottenbreit-Leftwich et al. 2010), it sometimes may constrain teachers to integrate ICTs. For instance, one teacher may feel direct instruction would be the most effective way of instruction rather than the open nature of (some) technological solutions (Donnelly et al. 2011). In another study, Hennessy et al. (2005) found that teachers use technology only when they perceive it will enhance learning compared to other approaches. In an experiment, Cedillo and Kieran (2003) initially found that despite strong mathematical knowledge, most experienced teachers did not show positive attitudes regarding teaching with technology as they believed that incorporation of ICT in teaching would not benefit students. But over the time, those teachers showed their positive views about use of ICT in teaching and changed their practice noticeably as they have seen the positive impact of ICT on their students.

Schiller (2003) claimed that personal characteristics such as age, gender, educational level and experience, experience with technology and attitude towards technology has a great effect on integration of ICT in teaching practice. Several literature showed that gender has an effect on ICT integration in teaching. Research revealed that male teachers' use ICT in their teaching practice more than that of female (Gebhardt et al. 2019; Volman & van Eck, 2001; Wilson et al., 2015). The dominating factors identified behind this scenario is limited access to technology, lack of technological skill, and interest among female teachers (Volman & van Eck, 2001). Research also identified teachers' teaching experience (Gorder, 2008; Lawrence & Tar, 2018) is another influencing factor to use technology in classroom. Studies showed that experienced teachers tend to be more hesitant about using technology in their classrooms than their younger counterparts (Jones, 2017; Mertala, 2019). This reluctance stems from various factors, such as anxiety about technology use, a perceived loss of control over the teaching environment, hardware and software limitations, inadequate technical support, the time-consuming nature of acquiring and maintaining ICT proficiency, and the challenge of selecting appropriate technology for the classroom setting. In contrast, younger teachers are more open to accept new teaching approaches andactively participate in training workshops. Moreover, teachers generally believe that using technology in the classroom requires more time and effort than traditional teaching methods, and they express concern about the potential loss of privacy and personal control associated with excessive technology use (Aminu & Samah, 2019; Ramírez-Rueda et al., 2021; Tang et al., 2021).

2.5.2 Pedagogical aspects

Research consistently underscores the critical role of teachers in determining the effectiveness of ICT integration in classrooms (Sutherland et al., 2009). However, this is by no means a straightforward task. Effective integration necessitates a fundamental shift at the personal level, encompassing teachers' belief systems (Webb & Cox, 2004), skills (Foster, 2014), and knowledge levels (Alexander, 2008) to harness the affordances of ICTs for the benefit of student learning. In a study, Turgut and Aslan (2021) claimed that teachers' competency about technology, ICT competence of students' have a dominating effect on ICT integration in teaching-learning process. The Technological, Pedagogical, and Content Knowledge (TPACK) framework serves as a model for developing teachers' knowledge for ICT integration in education (Mishra & Koehler, 2006). The TPACK frame is shown in Figure 2.4.

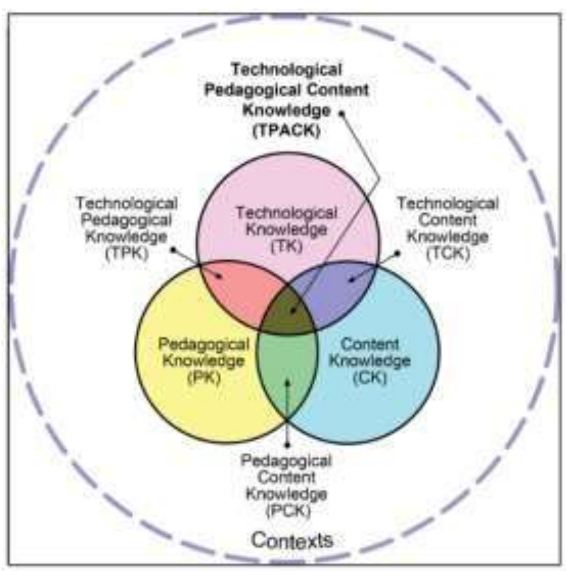


Figure 2.4: The TPACK Model (Mishra & Koehler, 2006)

According to Jones (2017) despite the availability of sheer existence of ICT facilities in the classroom, the class will not be an effective one due to the lack of teachers' preparedness to integrate ICT into teaching. Gikundi (2016) also identified teachers' preparation influence use of ICT in their teaching practice. In addition, teachers' self-efficacy and competency about ICT are two major predictors of integration of ICT in their practice (Buabeng-Andoh, 2019). Research showed that teachers who possess negative or neutral attitude towards the ICT integration in their practice, the major portion of them cannot make "informed decision" due to their limited knowledge and skill about ICT (Al-Oteawi, 2002, p.253). Extant literature depicted that teachers with stronger technological pedagogical content knowledge (TPACK), are more willingly to work with technology in their classroom (Aminu & Samah, 2019; Tang et al., 2021).

Though existing literature illustrated about the importance of trainings to develop teachers' professional development (Brinkerhoff, 2006; Mwendwa, 2017; Sokku & Anwar, 2019; Turgut & Aslan, 2021), Li et al. (2019) stated that it (training) is not the prime solution for effective integration of ICT in the classroom. They suggested that training program should be focused on use of ICT in the pedagogical aspect rather than technical issues and technical support. Existing literature revealed that professional training program will be an excellent program if it helps teachers to shift their traditional teaching practice into a new paradigm and implement technology appropriately (Brinkerhoff, 2006; Li et al. 2019). In a study Davis (2018) argued about the importance of proper training for professional development. He claimed that though the mathematics curriculum of Ghana emphasizes on problem solving approach for teaching, the teachers usually focus on procedure and rote memorization due to the lack of appropriate training.

Hsu's (2010) study highlighted the importance of comprehensive teacher training for successful ICT integration in classroom instruction. While professional development programs are widely recognized as tools for enhancing teachers' ICT proficiency (Serin, 2015), Cox and Marshall (2007) argued in a study that teachers' training program should not only emphasize the development of teachers' skill with ICT and support teachers to choose and utilize appropriate ICT tools in their classrooms, rather it also needs "to challenge teachers' fundamental beliefs about how to teach their subject and how specific

ICT resources can enhance and fundamentally change the way in which their students learn" (p.68). Thus, it is essential to address any underlying perceptions that hinder ICT adoption during both initial and ongoing training. For instance, research has shown that teachers may resist change due to factors such as insufficient training, low self-esteem, and frustrations (Hartman et al., 2019).

The lack of consistent professional development opportunities has been addressed in various publications (Faizi, 2018), with suggestions that teacher training is often focused on using technology merely as a tool for delivering subject matter. Further research suggested that employing technology facilitators or digital media consultants could provide valuable input for shaping teachers' beliefs about appropriate ICT integration (Mwendwa,2017). Teachers' professional development programs play a critical role in providing pre-service and in-service teachers with the necessary training, support, and up-to-date technological skills (Lasky, 2005). These programs must serve as catalysts for transforming teachers' perspectives and ensuring that technology integration is an integral part of classroom teaching.

Existing literature showed that along with the necessary competencies for technology integration, teachers must possess and maintain a comprehensive understanding of the curriculum (Mwendwa, 2017). In case of ICT integration supported curriculum, Tay et al.(2013) suggested that schemes of work with ICT should be clearly specified in the curriculum plans. The key themes emerged from the study of Ghavifekr and Rosdy (2015), indicating the multifaceted benefits of technology in classroom teaching, encompassing academic performance, generic skills, socioemotional skills, societal preparation, metacognition, and creative development. These key themes underscore the promise of effective technology integration in classroom teaching, provided that comprehensive planning and strategies are established and implemented within the school curriculum (Ghavifekr & Rosdy, 2015). To effectively implement such a plan, it is crucial to develop a technology framework that aligns with the overall vision and strategic direction of the teacher education program (Tang et al., 2021).

2.5.3 *Institutional aspects*

Existing literature demonstrated that the successful implementation of ICT in classroom teaching hinges on school support, including the provision of up-to-date infrastructure, and dedicated support staff during the application phase (Mwendwa, 2017). In a study, Lawrence and Tar (2018) claimed that accessibility of technology is one of the dominating issues for applying technology in the teaching practice. Besides, technical support for teachers is also identified as a vital component for ICT integration in teaching. They revealed that if teachers do not get the proper technical supports, they become frustrated and as a result they become reluctant to use ICT. Similar findings are reported in several literature where adequate classroom access to technology, a supportive technology philosophy, technical support, as well as the reliability of technology infrastructure are found more likely influencing factors to integrate ICT into their teaching practices (Aminu & Samah, 2019; Ramírez-Rueda et al., 2021; Tang et al., 2021). Furthermore, teacher workload (Min, 2019), time allocated for teaching, are reliable factors influencing technology use in the classroom (Ramírez-Rueda et al., 2021; Vannatta & Fordham, 2004). Recently, Turgut and Aslan, (2021) identified some of the challenging factors such as shortage of available ICT resources, educational materials, insufficient technical supports, lack of effective training for professional development and unsupportive attitude of school authorities which hinder ICT incorporation in education.

In addition, various levels of leadership, including principal, administrative, and technology leadership, play a crucial role in the successful integration of ICT in schools (Razak, 2019). Zinger et al. (2017) found that schools with higher socio economic status tend to adopt technology more readily due to teachers' confidence in students' access to ICT at home, enabling them to complete technology-based homework assignments without difficulty. The pedagogical culture of the school can also shape teachers' attitudes towards the types and frequency of technology use in the classroom. In a study, a teacher instructed her students on logging out of online sites and discussed appropriate online sharing process. She also aligned the school's motto, " Be safe, be kind, be responsible," with online behavior. This study demonstrated that teachers were more inclined to adopt technologicalpractices when a clear school motto was in place (Mertala, 2019).

2.6 Underpinning Theories of the Study

This section discusses two theories (i.e., *instrumental orchestration framework* and *technology integration panel*) adopted in this study to find out the effective pedagogical approaches for orchestrating ICTs.

2.6.1 Instrumental Orchestration

The ‘instrumental orchestration’ (Trouche, 2004; 2005) framework represents the extension of ‘instrumental approach’ (Artigue, 2002). The focus of the approach “is on the process of ‘instrumental genesis’ in which tool and person co-evolve so that what starts as a crude ‘artifact’ becomes a functional ‘instrument’ and the person who starts as a naive operator becomes a proficient user” (Ruthven, 2014, p. 7).

On the other hand, instrumental orchestration is a teacher’s purposeful and systematic arrangement and employment of the various educational resources and tools available in a learning environment, specifically designed for a particular mathematical task. The objective of instrumental orchestration is to foster students’ instrumental genesis, a process of developing and refining their understanding of mathematical concepts through the use of artifacts (Trouche, 2004). According to Trouche’s (2004) framework (Figure 2.5), instrumental orchestration comprises two key components: a didactic configuration, which outlines the overall structure and flow of the lesson, and an exploitation mode, which focuses on the specific interactions and manipulations of artifacts by the teacher and students.

2.6.1.1 Didactical Configuration

A didactical configuration is the planning of the teaching setting and the artifacts (tools) involved in it. Teacher may plan the didactical configuration prior to the beginning of a lesson or during the lesson but before performing the instrumental orchestration. Didactical configuration consists of layout of artifacts and configuration of classroom (Trouche, 2004).

For the component *layout of artifacts*, the teacher chooses the artifact(s) for the students and plans for arrange them in the classroom while *configuration of classroom*, including the placement of student desks, the utilization or non-utilization of a digital projector, and other general classroom elements that can influence the learning environment. In a study, Kratky (2016) stated about *students' arrangement* which means whether the students will work individually, in pairs, in a group or a whole class setting in the didactical configuration phase. In this study, I considered three elements *selection of artifacts*, *classroom setup* and *students' arrangement* in the didactical configuration phase.

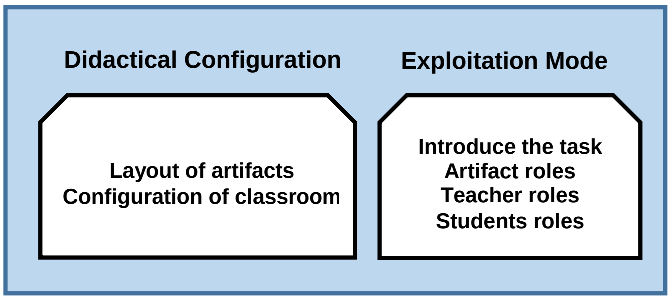


Figure 2.5: Components of Instrumental Orchestration (Trouche, 2004)

2.6.1.2 Exploitation Mode

An exploitation mode represents the teacher's deliberate plan for employing a didactic arrangement to fulfill their pedagogical goals (Trouche, 2004). It involves teachers' decisions about task introduction and execution, the roles of the artifacts (tools), and the development of students' knowledge and techniques. Drijvers et al. (2010) highlighted that during this phase, the teacher's role is to craft instructions that effectively guide students' conceptual and technical understanding while they interact with the artifacts. According to Kratky (2016), in the exploitation mode, teachers plan for leveraging their selected didactical configuration in line with their goals for the orchestration. He argued that during this mode of orchestration, teachers may demonstrate a specific artifact technique, create a link between work done with the assistance of both the artifact and paper-pencil, initiate a discussion and create scopes for the students to present their work with the artifact. Similar opinion is found in the study by Ratnayake et al. (2023) where they discussed that during the exploitation mode, the didactical configurations are organized into a plan. Thus, this mode provides the plan of how the configurations should be played to fulfill the teacher's expectations and goals. In a study, Drijvers et al. (2010) argued that exploitation mode is the way the teacher decides to achieve the didactical configuration (rearrangement of classroom setup) to get the benefit of his/her didactical goals. According to them, didactical configuration is that phase of instrumental orchestration where teachers have to think about the arrangement prior to the lesson and usually do not change during the teaching, whereas exploitation mode is flexible in nature. In addition, they showed in their study that while teacher arranges classroom setup for whole class discussion with one PC, he may decide to operate the PC by himself and project the screen on the front of the wall, so that students can involve in classroom discussion.

2.6.2 Forms of Instrumental Orchestrations

Extant literature showed that teachers apply certain techniques with the aid of technical tools to guide students for using tools and learning (Kendal & Stacey, 2002;). Rather than extensive discussions, literature showed the types of instrumental orchestration that the teachers use in their practice (Değerli & Uygan, 2023; Erfjord, 2011; Kratky, 2013). Drijvers and colleagues (2010, 2013) identified various forms of instrumental orchestrations for whole class setting as well as small-group setting. They provide a guideline on how the teacher as well as students will perform during the orchestration process.

Drijvers and colleagues (2010) categorized five forms of instrumental orchestrations named as *Technical demo, Explain-the –screen, Link-screen-board, Discuss-the –screen and Spot-and-show*. In 2013, they talked about the orchestration *Guide-and-explain* which has similar features to *Explain-the–screen* and *Discuss-the –screen.* They also added two new form of orchestration *Board-instruction* and *Technical-support* with the prior orchestration type. Besides, Drijvers (2012) stated *Work- and- walk-by* and *Discuss-tech-without-it*, two new category of orchestration. *Sherpa-at-work* and *Not-use-tech* are two other forms of orchestration proposed by Tabach in 2011. Tabach also proposed a new orchestration from *Monitor-and-guide* in his study in 2013. The scholars provide guideline on how the teacher as well as students will perform during the orchestration process (considering both the whole class setting and small group setting) in their studies. The brief descriptions of all the types of orchestrations illustrated in the literature are given in the Table 2.2 below.

Table 2.2: Brief descriptions of different types of orchestrations

Type of Orchestration	Description	References
Technical-demo	When teacher demonstrates something or provide lecture directly with the artifacts. Teacher leads and projects his/her screen though both the teacher and students may have access to the artifacts.	Drijvers et al. (2010)
Explain-the –screen	Totally leaded by the teacher. Teacher explains all about what is projected on the screen rather than opening scopes for conversation.	
Link-screen-board	Teachers use both the projected screen and board-work at the same time. The main intention of this type of orchestration is to establish the connections between what happens in the technological environment and how to represent it in the other setting.	
Discuss-the –screen	When teacher invites students to share their ideas or thought about the images that is projected on the screen and encourages collaboration so that students can make connections, raise questions and build their ideas as a group.	
Spot-and-show	During preparation of lesson, teacher accesses artifacts of students work and selects work(s) which is novel and relevant to use in the class. Teacher project the image of the student's work and open scope for discussion.	
Guide-and-explain	Teacher performs as an instructor and guide students to work in a small group with the help of artifacts. Teacher explains the images of the projected screen and may ask questions for the students to verify their understanding.	Drijvers et al. (2013)
Technical-support	Teacher assists students to overcome technical problems such as access, login, power etc.	
Board-instruction	In spite of availability of technical facilities in the classroom, teacher conducted class by traditional approach by using only the black board.	

Work- and- walk-by	Students perform individually. Teacher provide feedback by walking or sitting with students. If necessary, teacher uses board to explain the answer of the questions ask by the students.	Drijvers (2012)
Discuss-tech-without-it	At the beginning of the lesson discussion on technology is held without using the technology.	
Sherpa-at-work	Teacher invites a student to work as Sherpa who present project and explain his/her work with the help of artifact. Rest of the students follow the presentation and may ask questions or contribute to the discussion.	Tabach (2011)
Not-use-tech	There is an environment where teacher provides instructional explanations without using technology	
Monitor-and-guide	Such an environment where teachers answer technical questions of the students and describe the operations on the screen and in some cases, send messages remotely to students who have problems through classroom management software.	Tabach (2013)

2.6.3 Technology Integration Panel (TIP)

The Technology Integration Panel (TIP) proposed by Li and Dawley (2019), acknowledged the multifaceted nature of teaching and learning with technology while providing a clear framework to guide educators in their journey towards achieving their goals. Unlike conventional rubrics that oversimplify technology integration by equating it with either

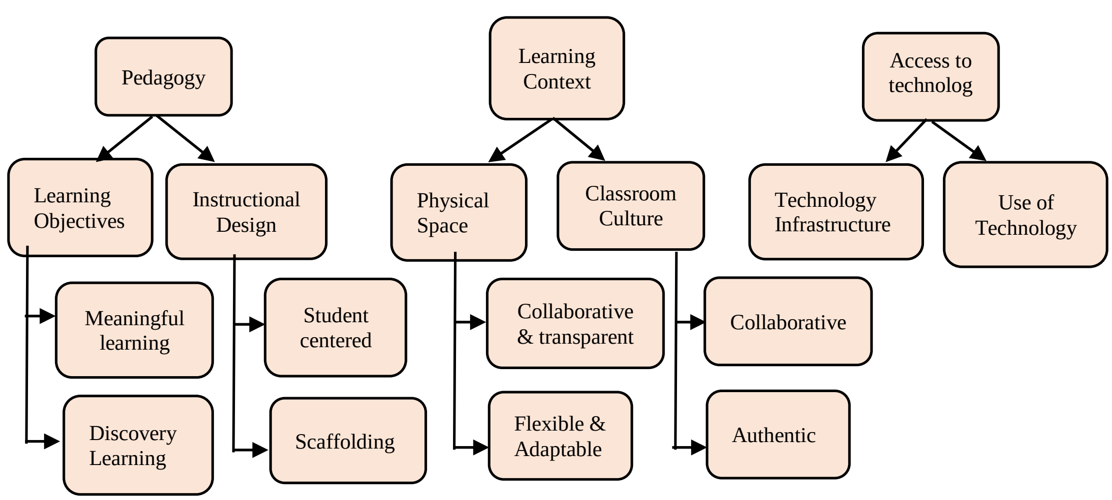


Figure 2.6: Framework of TIP (Li & Dawley, 2019)

learning or teaching, TIP adopts a three-dimensional approach that encompasses pedagogy, learning context, and technology use (Li & Dawley, 2019). They argued that these continua recognize the dynamic nature of the classroom environment and allow for a nuanced understanding of how technology can enhance student-centered learning. Research identified that each continuum encompasses key components that contribute to effective technology integration (John & Sutherland, 2004; Weaver, 2006). By acknowledging the diversity of learning environments, content areas, and student needs, TIP avoids prescribing a single, uniform approach to technology integration. Instead, it empowers educators to determine what best practice looks like for their specific circumstances.

2.6.3.1 Pedagogy

Learning objectives serve as roadmaps for teachers guiding their instructional strategies. Traditional classrooms often prioritize rote learning, which emphasize memorization and practice without fostering a deeper understanding of concepts (Kurtz, 2019). However, meaningful learning, championed by Ausubel (2000), encouraged the construction of knowledge connections, leading to a comprehensive understanding of concepts and their relevance to existing knowledge. This approach necessitates teachers designing instruction that aligns with students' personal experiences, enabling them to apply knowledge meaningfully in new situations rather than merely recalling facts free of context. Ausubel (2000) further advocated for discovery learning, replacing the passive reception of information with active exploration and inquiry. Students engage in the process of discovering new knowledge, identifying underlying concepts, and solving problems. This approach cultivates high-order thinking skills, including analysis, evaluation, and synthesis, fostering a deeper and more meaningful learning experience.

Instructional design refers to the systematics procedures that utilizes pedagogical research and practice to achieve desired learning outcomes of the students (Li & Dawley, 2019; Seel et al., 2017). According to them, it is the process of analyzing learning needs and address those needs by applying different pedagogical approaches such as teacher-centered, student-centered, or a combination of both. They argued that in a student-centered learning environment, students engage enthusiastically, link learning experiences to the intrinsic interests of them and involve in knowledge construction by seeking out new information, Besides, in that environment, knowledge is collaboratively created by teachers and students whereas in a teacher-centered learning environment, knowledge is directly transmitted by the teacher. Extant literature showed that the introduction of educational technology in classrooms led to a shift of teaching-leaning process towards 21st-century learning (UGWU & Nnaekwe, 2019) and a student-centered ICT supported instructional approach is more effective to prepare students for the 21st-century's skilled learners (Hsu, 2010).

2.6.3.2 Learning Context

Physical space of a classroom plays a crucial role in determining whether learning objectives can be effectively achieved and whether student-centered instructional design can be implemented successfully. Extant literature (Imms et al. 2017; Li & Dawley, 2019; van Merrienboer et al., 2017) have identified some key design features that contribute to an optimal alignment between pedagogy and the physical learning environment: i) flexible and adaptable learning features which recommended that furniture should be movable or that learning space can be reorganized according to the learning need. Moreover, lighting arrangement should be adjustable to support varied activities for learning, ii) collaborative and transparent spaces that promote interaction between students-students and teacher-students. This feature also encourages students to engage in collaboration iii) observation learning suggested for easily visible and accessible tools and resources for the learners. Besides, Li and Dawley (2019) stated that convenient and reliable Wi-Fi access to support technology integration, and an overall supportive learning environment that fosters the seamless integration of educational technology with pedagogical approaches.

Classroom culture encompasses the interwoven environmental, institutional, and practical aspects of school life that permeate every classroom and every lesson, shaping the teaching and learning experiences (Li & Dawley, 2019). Existing literature identified a constellation of factors that collectively influence classroom culture (Glover & Miller, 2007; Lozano, 2017). These factors include interactions among student-to-students, teacher-student; learning approaches supportive of pair, collaboration, and group-work; the choice and integration of educational technology, the selection and implement of diverse instructional materials. They also argued that some external influencing factors such as examination requirements, teachers' understanding of cognitive process, teaching-learning supported tools as a central component of classroom activities. The interplay of these factors shapes classroom culture, giving rise to a spectrum that ranges from independent/conventional, characterized by traditional methods such as lectures, storytelling, and the use of analogies, where learning is viewed as the passive reception of knowledge, to interactive, characterized by a variety of engaging actions, collaborative and inquiry-based learning.

2.6.3.3 Access and Use of Technology

Access and use of technology delves into the extent to which technology is available in the classroom, the proficiency of both students and teachers in using available technology,and the frequency of technology utilization (Li & Dawley, 2019). They reported in their study that evaluating technology usage involves determining whether both students and teachers have engaged with technology during TL practice in the classroom and identifying the types of technology utilized. Research showed that students who are more proficient in technology, can perform well in mathematics and better availability of technology in the school, shows students' academic performance is higher (Sze Ming Loh, 2023). In a recent study, Ali et al. (2020) identified that teachers' competency level of technology and appropriate integration of technology in their practice has a great impact on students' achievement.

In summary, this chapter reviewed the existing literature on mathematical proficiency (MP), the effective teaching-learning strategies offered in the literature for developing MP, teaching with ICTs focusing on the development of MP and also the enabling and inhibiting factors for ICT orchestration in teaching-learning process. Extant literature showed that ICT has the potential to develop students' conceptual understanding and procedural fluency (Laswadi, 2016), ability to enhance students' strategic competence (Gunpinar & Pape, 2018) and reasoning skill (Granberg& Olsson, 2015). To develop students' resilience on mathematics and to make the learning interesting, ICT plays a vital role (Lugalia et al., 2015). Literature suggests that ICT has a great impact on developing students' MP (Sudiarta & Widana, 2019) and its success depends on how skillfully teacher orchestrates ICTs in their practice (Drijvers, 2015). Most of the existing literature discuss the potential of ICTs to develop students' ability on individual strand of mathematical proficiency discretely and thus offers limited guidelines on what and how ICT tools could be orchestrated to harness the potential of ICT in mathematics classrooms, especially to increase the mathematical proficiency in such a resource constrained environment like Bangladesh. Drawing on the theoretical frameworks discussed in this chapter, "Instrumental Orchestration framework" and "Technology Integration Panel framework", this study attempts to bridge this gap in the extant literature on how to orchestrate ICTs in teaching-learning process so that students' mathematical proficiency develops in a resource constrained setting.

2.7 Conceptual Framework of the study

The conceptual framework that guided this study had been developed (Figure 2.7) based on the theoretical frameworks (e.g. instrumental orchestration framework, TIP framework) and the reviewed literature. To explore the phenomena, this research draws on the theoretical concept 'instrumental orchestration' (Trouche 2004; 2005) and TIP framework linked with the concept of mathematical proficiency (Kilpatrick et al., 2001). Instrumental orchestration (align with the TIP framework) as a theoretical lens allowed me to explore how teachers manage and apply ICTs in their practice in a ICT-facilitated teaching-learning environment. This theoretical concept also facilitated me to understand whether and how students' mathematical proficiencies can be developed through interaction of constrained resource and different ICTs, since this lens is considered as a means of analyzing technology-facilitated teaching and learning in mathematics.

This framework enabled me to explore the developmental processes of how different ICTs can be orchestrated in the mathematics classroom so that students can learn mathematics skillfully with proper understanding and overcome affective barriers of learning mathematics, thus become mathematically proficient. In this process the socialized form of knowledge emerges, by orchestrating activities and disparate ICTs across the class.

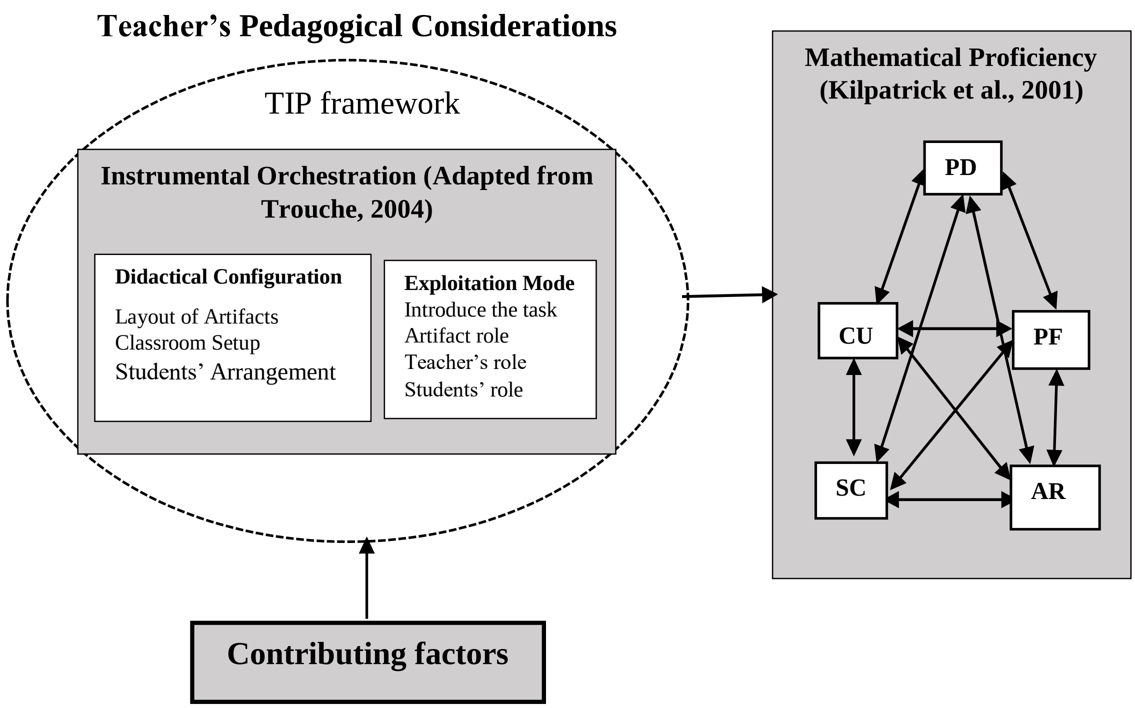


Figure 2.7: Conceptual framework of the study

Chapter Three

METHODOLOGY

The main objective of this study was to explore the effective pedagogical approach with the aid of ICTs for promoting students' mathematical proficiency. In line with that purpose, the following research questions were formulated.

RQ-1. How do teachers apply pedagogical considerations in an ICT-facilitated teaching-learning environment?

RQ-2. Whether and how does the ICT-facilitated teaching-learning process promote students' mathematical proficiencies?

RQ-3. What are the factors that affect integration of ICT in mathematics teaching-learning process?

To obtain the answer of the research questions, a design experiment was administered under two cases. Two mathematics teachers (one from each case) were the participants of the design experiment process. Design experiment adopted an intervention containing the phases- *planning, enacting* and *analyzing instruction* in an ICT-facilitated learning environment. The teachers used mathematical software GeoGebra along with the other ICT tools and prepared the supportive materials by keeping in mind to develop students' mathematical proficiency. This chapter elaborately discusses my research stance, research methods and justifications of the methods employed in this study. It includes ten sections namely research paradigm, research methodology, research design, instructional unit, data collection method, sampling, data analysis, pilot study, trustworthiness and ethical considerations.

3.1 Research Paradigm

Research philosophy adopted in a study indicates how the researcher views the world and peels away the layers of the research strategy and methods appropriate for that particular study based on the assumptions of the philosophy chosen (Saunders, Lewis & Thornhill, 2009). Saunders, Lewis and Thornhill (2009) also argued that which philosophical position is "better" for a study is largely depended on the research question(s) the researcher is seeking to answer. Hence, taking a philosophical stance in relation to the purpose and nature of this study was the first step for me. According to Saunders, Lewis and Thornhill (2009) the philosophical position a researcher can take are positivism, realism, interpretivism and pragmatism. Positivism is the philosophical stance which claims that whatever exists is rigid, singular and objective and can be confirmed by robust observation, experiments, and logical evidence while realism is the philosophical view that assumes that external world exists independent of human mind **(**Khanna, 2019**).** Besides, Interpretivism paradigm is based on the assumption that social reality is not singular or objective, but it is rather shaped by human experiences and social context. Under this paradigm, research aims to understand the meanings and interpretations that people assign to their experiences, whereas pragmatism paradigm offers an experience based, action-oriented framework whereby the purpose of research is to help address the issues of dealing with how people experience and come to know the world in a practical sense (Goldkuhl, 2012). The epistemological stance of pragmatists is that the knowledge is not an absolute *copy* of reality rather it is the construction of knowledge (Goldkuhl, 2012).

Given the purpose and nature of the research questions stated in the previous section, interpretivism was the likely choice for this research. This paradigm enabled me to get deep insights of the effective pedagogies applied by the teachers in an ICT-facilitated learning environment to promote students' MP rather than being capable to test hypotheses or existing theories. Giving a focus on the epistemological (i.e., how the researcher knows what he knows) perspective, it also discussed the ontological (i.e., how the researcher views the world) assumptions of the chosen paradigm since Goldkuhl (2012) argued that "ontology and epistemology are intertwined in interpretivism because knowledge (understanding, meanings) is so essential in the ontological assumptions of the constitution of the world" (p. 6). To understand and explore the deep insights of the teaching practice with ICTs towards developing students' MP and issues and challenges associated with ICT integration in mathematics Teaching-learning process, I intended to adopt a stance that allow me to get close to the participants of such experience. Adopting interpretivism as a paradigm, I got the opportunity to enter into the close view of ICT-facilitated classroom environment, mathematics teacher and students who are experiencing teaching-learning with that environment. In addition, my own experience and background also added subjectivity to the interpretation of the reality. This kind of close association with the object under investigation is ontologically supported by interpretivism while such subjective understanding of the reality is the core epistemological stance of interpretivists (Easterby-Smith et al., 2008; Creswell, 2009).

To learn the details of the phenomena and the reality behind the phenomena, exterior stand point demanded by positivism was not applicable here rather it needed to view from inside. Researchers (Goldkuhl, 2012; Morse, 1991 cited in Creswell, 2009) argued that qualitative inquiry which enables the researchers to understand the meaning actors give to the phenomena within the social setting is often associated with interpretivism. Hence, epistemological assumptions of interpretivism allowed the researcher to choose in-depth qualitative inquiry through intensive interaction with the actors and understanding their meaning subjectively. In this study, to fulfill the purpose of the study, qualitative data was the most dominating, however, to address a part of the research question more preciously, quantitative data was considered. According to Bhattacherjee (2019), though interpretive research tends to depend mostly on qualitative data, quantitative data may add more precision and clearer understanding of the phenomenon of interest. Again, this study aimed to obtain knowledge that can be used to develop theoretical framework of ICT orchestration to enhance MP which is an inductive approach unlike starting with a theory or hypothesis to test as in positivism. Furthermore, my direct observation towards participants in real setting would enable me to look into the details of the phenomena under observation. Creswell (2007) argued, "The longer researchers stay in the *field* or get to know the participants, the more they *know what they know* from firsthand information" (p. 18). So, for getting deep insights of ICT orchestration to develop students' MP, there was no other better alternative than extensive and thorough interaction with the participants (teacher and students) involved in the ICT-facilitated TL environment. Nandhakumar and Jones (1997) in a study favor this context for interactions and argued that such interactions "…may also help to reduce or evade barriers to disclosure and provide immediate experience of local meanings, dominant perceptions or tacit knowledge and non-verbal communication" (p. 112). Thus, unless the researcher takes an interpretivist's stance, he would not be able to interact with the participants and could not understand the subjective reality of their motives, actions and intentions. That is why, Easterby-Smith et al. (2008) stated that interpretivism has its own strengths as it has the capability to look at how changes happen in course of time, how people adjust to new issues and ideas as they emerge, and to contribute to the development of new theories.

3.2 Research Methodology

The methodological strategy I intended to employ for this research was case study as it is congruent with the interpretivist's stance. Yin (2009) claimed in his study that through case study, a researcher can understand the holistic and meaningful features of a complex real-life phenomenon. According to Creswell (2012), to get an in-depth picture, a few individuals or a few cases should be considered. He also argued that though the number of cases may be varied from 1 or 2 to 30 or 40, while reporting about each individual, a large number of cases can become unmanageable and lead to superficial perspectives. Though Shen (2010) acknowledged some concerns about case study due to the researcher's biasness and ungeneralizable nature, Flyvbjerg (2011) claimed that subjectivity and bias are fair criticisms of all types of research. Yin (2009) suggested multiple cases would be better for generalizing theories and should be used to develop replication and make the findings of the study more convincing and reliable. Thus, a multiple case study approach had been adopted in this study since such type of approach enabled me to answer not only 'what' but also 'how' type questions (Baxter & Jack, 2015).

Again, to address all the research questions, both the quantitative and qualitative approach i.e. the mixed method approach had been adopted. Case study experts have recommended integrating qualitative and quantitative research in investigating the case (Yin, 2014). Though an individual research strategy might have different strengths and weaknesses, a mixed research design provides more robust and thoughtful understanding of a research problem than either qualitative or quantitative data alone (Plano Clark & Creswell, 2015).

There are different sorts of mixed methods design, each of them has their own strength (Rubin & Babbie, 2019). Three research designs (e.g. convergent parallel mixed method, explanatory sequential mixed method and exploratory sequential mixed method) for mixed research approach were discussed by Barnes (2019) and Creswell (2014). The *convergent parallel mixed method* collects data (both the qualitative and quantitative) parallelly whereas the *explanatory sequential mixed method* and *exploratory sequential mixed method* collect data sequentially, sequencing from quantitative to qualitative and qualitative to quantitative respectively. Barnes (2019) argued in his study that *convergent parallel mixed method* can be further designed in two forms (the concurrent triangulation design and concurrent nested design). When researchers want to validate the data collected by one method (either qualitative or quantitative) with the other method, they use *concurrent triangulation design.* On the other hand, concurrent nested design is used when one method (either qualitative or quantitative) is considered as prime and the other one is used for different purpose (Barnes, 2019). As the main goal of this study was to explore the effective pedagogical approaches in an ICT-facilitated environment, qualitative method (data come from classroom observations, interview of teachers and head teachers, FGDs with students) were prioritized in this study. The quantitative data (data from paper-pencil test and survey questionnaire) were mainly used to understand whether students' MP enhance due to the use of ICTs in the TL process. Since, the overall findings were mostly focused on the qualitative information, the *concurrent nested design* mixed method had been applied for this study.

Case study research has a long tradition of collecting both qualitative and quantitative data to gain a more complete understanding of the case (Stake, 1995; Yin, 2014). Guetterman and Fetters (2018) argued about combination of case study and mixed method, and termed as *mixed method case study research* (MMCSR) which has two distinct approaches: 1) case study-mixed methods research (CS-MMR) and 2) mixed methods-case study research (MM-CSR). They stated that in a case study-mixed method design (CS-MM), researchers employ a "parent" case study design and uses mixed methods by collecting, analyzing, and integrating qualitative and quantitative data whereas in mixed method-case study (MM-CS), mixed method is the "parent" design that includes a nested case study design.

According to Yin (2014), a mixed methods case study may able to address extensive or more complex research questions rather than case studies alone.

Thus, for this study, I employed a *case study-mixed method research approach* (Guetterman & Fetters, 2018) where mixed method is specified as *convergent parallel (concurrent nested design) mixed methods* (Guetterman & Mitchell, 2016). Two cases were considered (one case was chosen from Govt. school and the other one from private school), in which ICT-facilitated classroom, math teacher & students of that classroom and head teacher were the unit of analysis. The following diagram illustrate the unit of analysis for this study.

Case I

- ICT-facilitated Grade-10 classroom in a Govt. school of Dhaka city
- Mathematics teacher of that classroom
- 30 students of that classroom
- Head teacher of that school

Case II

- ICT-facilitated Grade-10 classroom in a non-Govt. school of Dhaka city
- Mathematics teacher of that classroom
- 30 students of that classroom
- Head teacher of that school

3.3 Research Design

The study intended to provide a clear idea on practical problems involved in mathematics education in a resource constraint context and develop new theories on effective way of using ICTs in an ICT-facilitated teaching-learning environment to enhance students' mathematics proficiency for that context. To fulfil the intention, an intervention was designed for the mathematics teacher in an ICT-facilitated classroom environment and the students of that class. A cyclic approach of design, evaluation, and revision phases were applied in the intervention process (McKenney et al., 2006). The aim of the design process was to understand teachers' mathematical practice while conducting class with ICTs and improve the instructional sequence (if required) to enhance students' mathematical proficiencies. Cobb et al. (2009) and Zawojewski et al. (2008) suggested for the use of design experiment to understand teachers' knowledge and expertise in the classroom teaching and to explore teachers' teaching practice in their actual classroom contexts (Karpuzcu, 2017). Besides, design experiment is recommended for investigating the uses of ICTs in the educational perspectives (Reeves, 2006). Thus, design experiment was applied under the two cases, to explore secondary mathematics teachers' practice with ICTs in a ICT-facilitated real classroom setting.

Design experiment is operated through phases and cycles. Though various studies named the phases differently (Cobb & Gravemeijer, 2014; Plomp, 2007), three phases (e.g. preliminary phase, prototype phase, and assessment) are commonly known (Plomp, 2007). For this study, I applied the design experiment (Figure 3.1) adapted from the model proposed by Plomp (2007). A brief overview of the preliminary phase and the prototype phase are discussed in the subsequent sections.

3.3.1 Preliminary phase

In the preliminary phase, several literatures were reviewed, consulted with experts (expert in both mathematics and ICT) and teachers (math teacher of each case), and analyzed practical context (e.g., feasibility of teaching with ICT such as physical facilities, availability of resources etc. of each case). This phase led to the development of tentative design principles for intervention sessions.

3.3.1.1 Design principle for conducting the intervention sessions

To develop the instructional sequence and overall planning for the prototype phase, realistic mathematics education (RME) guided us (both the teachers and me) to support students' learning (Gravemeijer et al., 2003). Along with the objectives of the study, the following principles were considered to conduct the intervention sessions.

- Topic should be introduced with realistic setting
- At least two components of mathematical proficiency should be addressed through the teaching in each session.
- Where required/possible, teachers should provide the scope to the students to directly use ICTs in the classroom.

3.3.2 Prototype phase

The prototype phase is the iterative design phase where the intervention was conducted.

The intervention was applied to understand how teacher used ICTs in that real context to promote students' mathematical proficiency. Besides, students' mathematical proficiencies were monitored through the intervention. The mathematical software (GeoGebra) were considered as catalysts for the intervention, with traditional resources and new technologies.

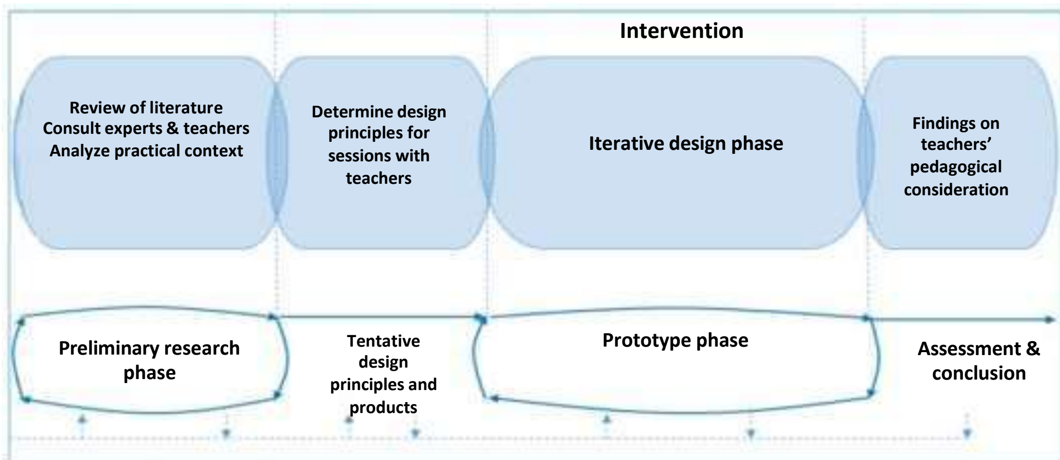


Figure 3.1: Process of Design experiment (Adapted from Plomp, 2007)

Intervention was conducted through a cyclic approach of design evaluation, and revision (McKenney et al., 2006). The design process of the intervention is shown in Figure 3.2.

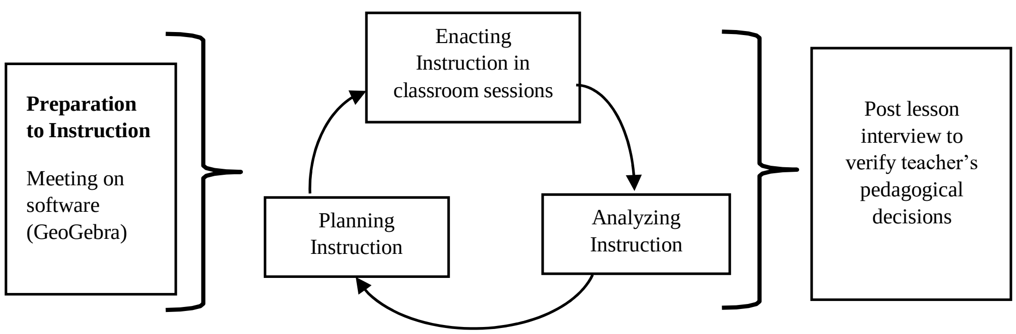


Figure 3.2: The design process of the intervention

The design process of the intervention was implemented uniformly for both cases. Under each case, in this design process, the planning stage is the session for determining the instructional goals; selecting task, designing and developing ICT supported materials & activity sheets, structure of classroom action and students' roles, while enacting session is the actual instructional sequence in the classroom. During planning the sessions, I clearly explained to the teacher about the main goal of my research study and that the teacher needs to focus on teaching with ICT to achieve students' mathematical proficiency. To design the instructional materials for the enacting sessions, I and the teacher worked as a team. For six classes, sequential instructional materials/activities associated with technology were developed where teacher has the priority to take the decisions and responsible to execute them in his/her teaching practice. As a researcher, my primary aim was to investigate what should be the teacher's role, students' role, what are the contributions of technology/ICT tools, which technologies/ICT tools should be used by students, how the teacher should use technologies/ICT tools to enhance students' mathematical proficiency. The teacher's implementation of instructions was analyzed last stage of this mini cycle and suggested for further improvement for the next class (if required). After completing each mini cycle, post-lesson interviews were conducted to evaluate the instruction and investigate teacher's mathematical practices. Prior to the cyclic approach of the intervention, I arranged several meetings with the teacher to let him/ her know about the usefulness, properties and different functional options of GeoGebra software and how GeoGebra could be used for teaching specially for teaching slope, linear function and graph of linear functions. Moreover, I provided some of the pre-prepared GeoGebra materials resource link (e.g., https://www.geogebra.org/m/GMvvpwrm#material/Vs5Wy4qw) to the teacher so that he/she can get idea to develop the GeoGebra supported instructional materials for the intervention sessions. Then teacher planned his/her lessons and developed instructional materials with the support of ICT tools (e.g. power point presentation, GeoGebra software). I also assisted teacher to develop the materials when he/she asked for my help. After completing mini-cycle six times, post interview with the teacher was conducted. Carrying out the whole process of the study, I conducted an analysis to describe and explain the data on teacher's pedagogical considerations in an ICT-facilitated teaching-learning environment.

3.4 Instructional Unit

In this study, I considered a particular learning topics of algebra (e.g. function, linear equation) to investigate the teachers' pedagogical considerations and students' learning in an ICT-facilitated teaching-learning environment. As GeoGebra along with other ICT tools, is a major teaching-learning instrument in this study, I chose the aforementioned topics since these topics could be taught very effectively using such tools (Reezan, 2013). Moreover, these topics are essential area of learning for the secondary level students. Given the vast scope of function and linear equation, I only considered the following sub-topics for this study.

- Basic concepts of function and linear function
- Slope and graphs of linear equation
- Linear equation in real-life

In both schools, these same topics were covered throughout the intervention.

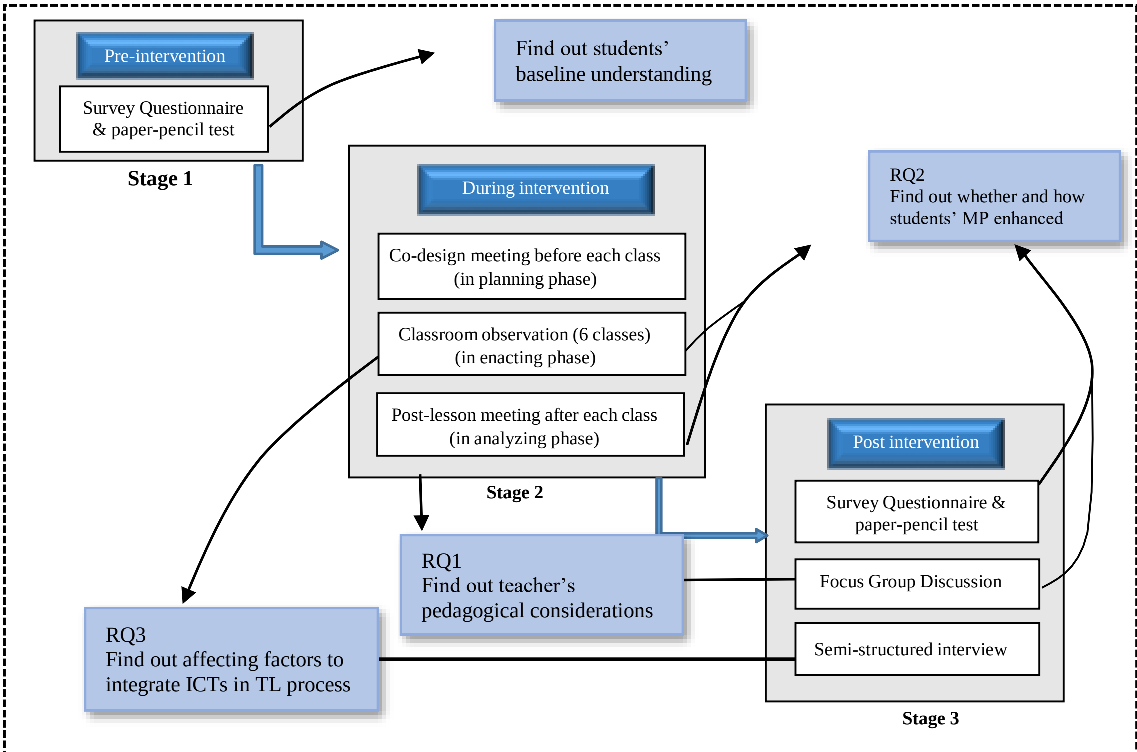
3.5 Data Collection Method

This study adopted a multiple case-study which consisted of two cases. Both of the cases were chosen from the schools of Dhaka city. One of the cases was selected from government secondary schools whereas the other was from the non-government secondary schools. The selection of schools in different forms allowed me to explore how ICTs are being used in schools in different contexts, how students and teacher of different contexts perform in ICT-mediated classroom settings, how attitudes of different groups of people vary, and what would be appropriate uses of ICT in each particular context. Besides to some extent, selection of cases was depended on the mathematics teacher as teacher was the crucial factor of this research. I looked for the secondary school teacher (both from the Govt. and no-Govt. school) who had the experience to teach mathematics with the help of ICT tools and approached two teachers from Govt. schools and three teachers from non-Govt. schools. Among them one teacher from Govt. school and one teacher from non-Govt. school were given their consent to participate in the research willingly.

The whole process of data collection (pilot study and main study) was done from September, 2022 to March, 2023. The piloting of this study was done in September, 2022 whereas the data for the main study were collected from November, 2022 to March, 2023. During this time, several meetings were arranged with teachers to orient them with the software GeoGebra as well as planning for enacting sessions of the intervention. Besides, experts' and teachers' opinion were taken to decide the tentative instructional design principles for the intervention. The total of 6 classes under each case were observed during intervention. The duration of each class were 50 minutes and the post-lesson interview session after each class was for about 1 hour.

Data were collected in 3 stages. Figure 3.3 shows the data collection process at a glance where all three stages were applied for each case and after collecting field data from the two cases, the similarities and dissimilarities among these were identified. In each case, data were collected through classroom observations, semi-structured interviews, focus group discussion, structured survey questionnaires and paper-pencil tests. The qualitative data were collected through semi-structured interviews, focus group discussions and classroom observations whereas the quantitative data were collected through survey questionnaire and paper-pencil test.

Before the intervention, a survey questionnaire and a paper-pencil test were administered to know the baseline understanding about students' mathematical proficiency. To explore how ICT is being used in mathematics classroom, classroom observations (i.e., actors' non-verbal cues, surrounding environment in the classroom, student- teacher interactions), and semi-structured interviews (post-lesson interviews) of the teacher of that class were conducted. Besides, paper-pencil test, survey questionnaire and FGD were done to know whether students' MP developed or not. In addition, data come from classroom observation, semi-structured interviews (post-lesson interviews) and FGD guided me to find out how students' MP developed in ICT-facilitated TL environment. To explore influencing factors for ICT integration in TL process, teachers' practice in mathematics classroom was observed and semi-structured interviews were conducted with head teachers (for two cases) and teachers. Semi-structured interviews allowed me to get deep insight from the participants of the phenomena being investigated, to interact with them and facilitated me to fine-tune my inquiry based on respondents' answer during the interview process and helped me to seek new information about and new angles on the topic being investigated (Kvale, 1996). The questions of the interview were mainly open-ended in nature and developed from existing literature on mathematical proficiency, mathematics resilience, mathematics education, usage of ICT in mathematics education, and adjusted based on a pilot study, if required. Besides, all interviews and observed classes were recorded (audio and video record respectively) and field notes were taken wherever required during the observation.



Under each case

Figure 3.3: Data collection process of the study

Table 3.1 below shows the research questions of this study and the data type, source of data, number of respondents, sampling techniques and instrument used for the respective questions in the study.

Table 3.1: Methodology of the study

Research Questions	Type of data	Source of data	No. of respondents	Sampling techniques	Instrument
How do teachers apply pedagogical considerations in an ICT-facilitated teaching-learning environment?	Qualitative	Math class of Grade-10		Purposive sampling	Classroom observation (2×6=12)
		Math teacher of Grade-10	2 (1 from each school)		Post lesson interview (2×6=12)
		Students of Grade-10	16 (8 from each school)		Focus Group Discussion (2×1=2)

Whether and how does the ICT-facilitated teaching-learning process promote students' mathematical proficiencies?	Quantitative	Students of Grade-10	60 (30 from each school)	Stratified random sampling	Survey questionnaire Paper-pencil test
	Qualitative	Students of Grade-10	16 (8 from each school)		Focus Group Discussion (2×1=2)
		Math class of Grade-10		Purposive sampling	Classroom observation (2×6=12)
		Math teacher of Grade-10	2 (1 from each school)		Post lesson interview (2×6=12)
What are the factors that affect integration of ICT in mathematics teaching-learning process?	Qualitative	Math class of Grade-10		Purposive sampling	Classroom observation (2×6=12)
		Math teacher of Grade-10	2 (1 from each school)		Semi-structured interview (2×1=2)
		Head teacher	2		Semi-structured interview (2×1=2)

3.5.1 Paper-pencil test

Research showed that paper-pencil test is the best technique to measure students' learning (Hoyles et al,1994). Though paper-pencil test is a promising approach for testing students' understanding, to a large extent its' success depends on the text items. Closed test item such as multiple choice items provide directly the right and wrong answer, which does not give a clear picture about students' overall understanding (e.g. reasoning ability, strategic competencies etc.). Furthermore, the inclusion of alternatives in closed item formats could influence responses and may led to guess the correct answer by comparing given alternatives (Hill et al., 2008). According to Baumert et al., (2010), these loopholes can be mitigated by using open-ended items. Thus, for this study, I used both the closed and open-ended test items as per the necessity. I administered paper-pencil test before and after the intervention. The test items of before intervention (Appendix C) and the test items of after intervention (Appendix D) were similar but not same. The total of 5 items (each item consists of at least 2 sub items) were administered in each paper-pencil test. All the test items were set based on the indicators (proposed by Kilpatrick et al., 2001 & Milgram, 2007) of the four attributes (conceptual understanding, procedural fluency, adaptive reasoning and strategic competence) of mathematical proficiency.

3.5.2 Focus Group Discussions (FGD)

Research showed that for getting in-depth information, focus group discussion (FGD) is certainly valuable (bell, 2005). Mareschal and Delaney (2019) stated that FGD is very effective research instrument if the researcher's intention is to understand the changes take place in students after an intervention. Moreover, they argued that to triangulate the outcome of a survey, FGD is a better option to understand how and why certain trends have been observed in a survey. Bryman (2016) stated that an individual may respond in a particular manner during a focus group, however, while he/she listens to the other response, she or he can modify her/his opinion, can think more about the issue. Thus, focus group discussions may have the high potential to elicit a diverse range of viewpoints on a particular issue due to these possibilities (Bryman, 2016).

In this study, I conducted two FGDs in total (one in each case) and each FGD contains 8 students. The main concern of conducting FGD was to get more information about students' understanding about mathematical concept, procedural, reasoning and strategic ability as well as students' attitude towards mathematics (productive disposition) after experiencing classes using ICTs. I started the discussion sessions by greeting students and asking their permission to record (audio) the discussions. The major queries of the discussions were to know the learning experience of the students in the new classroom situations (6 classes) where ICT tools were used to enhance their proficiency. I asked some questions (Appendix F) in line with the research questions of the study so that students response would be in track. I also provided them a contextualized problem and asked them to solve it by discussing with each other. The main intention of this part was to know students' conceptual understanding about math, their procedural and reasoning skill, as well as their ability to solve problem in different ways and also get the essence of how they response while performing a task in a group. Beside, while students debate to each other, more probing questions were upraised. Though in some cases students disagree to each other, most of the cases, they agreed with each other's opinions.

3.5.3 Classroom Observation

According to Bell (1987), observations enable to get a kind of data which is quite impossible to get from other approaches or techniques. He argued that observation technique is the effective one to determine whether individuals act as they claim or behave in the manner they claim to behave. In this study, I observed Grade-10 class six times (in each case). While observing the classes, both descriptive and reflective field notes were taken. According to Creswell (2012), "Descriptive field notes record a description of the events, activities, and people (e.g., what happened). Reflective field notes record personal thoughts that researchers have that relate to their insights, hunches, or broad ideas or themes that emerge during the observation" (p. 217). While observing the classes, I played the role of a non-participant observer, so that the respondents could be comfortable in their own space. Throughout the observation of classes, I tried to explore how teachers applied pedagogical consideration in an ICT-facilitated teaching-learning environment and how they faced challenges during the classes. Besides, students' responses were taken into consideration while observing the classes. Due to the explorative nature of the study, I did not use any pre-determined themes for observing the class. Some elements of observation schedule such as classroom culture, physical space, access to technology, teacher's and students' dealing with technology, teacher's instruction, teacher's feedback in response to students' questions, students' participation and response in the classes were identified from the literature (the major part is guided by TIP framework) to justify the research problem.

3.5.4 Semi-structured Interview

Semi-structured interview is very common, widely used effective research technique. When the researchers intend to understand the unique perspective of participant instead of a generalized understanding of a phenomenon, among the different data collection methods, semi-structured interview is the preferred one (McGrath et al., 2019). According to Bryman (2016), while conducting semi-structured interviews, the researchers may have a list of guided questions for the interview, however, the interviewee has a lot of flexibility in how they respond. According to Creswell, "In qualitative research, you ask open-ended questions so that the participants can best voice their experiences unconstrained by any perspectives of the researcher or past research findings" (2012, p. 218).

In this study, I aimed to know how ICT could be introduced in the teaching-learning process to promote students' mathematical proficiency. Another focus was to identify the factors affecting the teaching-learning process in an ICT-facilitated environment. Through the semi-structured interviews, I tried to explore those issues. Semi-structured interviews of teacher were conducted after each of the class (i.e. 6 post lesson interviews) and also at the end of the six classes. Thus, total of 7 semi-structured interview were administered for the teacher in each case. Besides, head teachers' opinions were also collected through semi-structured interview. The duration of each interview was about 50 minutes to 1 hour. I made a set of open-ended questions so that the interviewees could express their opinion in right track to get the answer of my research problem. During the interview session, I also supplemented some probing questions to get in-depth scenario of the situation. For the respondent's convenience, interview questions (Appendix F) and survey questionnaire (Appendix E) were prepared into Bangla so that the interviewees could response in Bangla.

3.5.5 Questionnaire

One of the research instruments to conduct a survey is *questionnaire* which is a set of questions to ask the participants in the survey with some supporting information (McGilvray, 2021). The questions are used to gather data from the target audience whereas supporting information is used to provide a clear context and background of the study, encourage participants to complete the survey by proper instructions. Questionnaire may be consisted of open-ended questions, closed-ended questions, as well as combination of both, based on the goal of the research. Denscombe (2010) argued that to collect facts and opinion directly from a large group of people (30 or more respondents), questionnaire is a cost-effective method. A uniform, structured questionnaire was developed for collecting quantitative data from the students through survey method to explore their productive disposition (PD) on mathematics (PD is students' feelings to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's efficacy) (Kilpatrick et al., 2001). According to Bell (2005), a well-structured questionnaire helps to get acceptable information and also to deal with data at the analysis and interpretation stage easily.

In this study, this instrument contains 12 items (Appendix E), asked on a five-point Likert scale ranging from “Strongly agree” to “Strongly disagree”, which indicate some specific issues such as students seem mathematics as- a) useful and worthwhile, b) sense-making endeavor and while doing mathematical problems, students show- c) enthusiasm, persistence, confidence, curiosity and cooperation. The collected data allowed me to comprehend the participating students’ productive disposition towards mathematics.

3.6 Sampling

In this study, purposive sample technique and stratified random sample technique were used for sample collection as these sampling techniques were found appropriate in the current research context. The data were collected from ICT-facilitated mathematics classrooms of two schools (one Govt. school and other non-Govt. school) at the secondary level in Dhaka city. From each school, head teacher, thirty students of Grade-10 and the mathematics teacher of Grade-10 class were considered as sample. In Bangladesh, secondary level refers to Grade-9 and Grade-10, whereas Grade- 6 to Grade-8 refer as junior secondary level and Grade-12 is in higher secondary level. As the study focuses on secondary level and the topics (which was selected as those can be effectively taught by the software GeoGebra) covered for the intervention are suitable for Grade-10 students, students of Grade-10 were considered for this study. To ensure all levels (based on academic performance) of students’ representations, the total number of students were divided in three strata and then 10 students were chosen randomly from each strata. The classes of Grade-10 (with 30 students) from each school were observed six times and one Focus Group Discussion (FGD) consisting of eight students of that class was conducted in each school. The selection of schools in different forms allowed me to explore how ICT is being used in the mathematics classroom in different contexts, what would be the appropriate ICT in that particular context, how mathematical skills and attitude of different group of people vary and what would be the possible solutions for promoting students’ mathematical proficiencies. In addition, mathematics and ICT experts’ opinion were taken in the preliminary phase of the design experiment.

3.7 Data Analysis

The quantitative data were analyzed by the descriptive statistics (Tavakol & Dennick, 2011). Descriptive statistics (mean and SD) were used to measure the average score of every individual strands of the MP. Besides, inferential statistics- paired sample t-test (for parametric statistics) and Wilcoxon signed rank test (for non-parametric statistics) were also used to compare the pre and post test score. By examining students' responses to individual test item of the survey questionnaires, I tried to explore the extent at which students' productive disposition in mathematics enhanced due to ICT-enabled teaching-learning environment. Besides, students' responses on each question of the paper-pencil test were analyzed to examine whether the four aspects of math proficiency (that is to see whether their mathematical understanding, reasoning and fluency capability as well as ability to formulate math and doing math in different strategies) of students enhanced or not after the intervention.

Qualitative data were analyzed following analytical approach used by Powell et al. (2003). It is an iterative process to look at the empirical data within and across the contexts (Govt. school and non-Govt. school) and relate them to the theoretical framework that informed data collection. The qualitative data were collected from classroom observations, interviews and FGDs (Before, during and after intervention). By analyzing recorded video data overall classroom environment (i.e., students' mathematical understanding, teacher's and students' dealing with ICT in the teaching-learning process etc.) were identified. To analyze the recorded (both the audio and video) data, seven sequential interacting phases- "viewing (in case of video record) and listening (in case of audio record) attentively the data"; "describing the data"; "identifying critical events"; "transcribing", "coding"; "constructing themes"; "composing narrative" were followed.

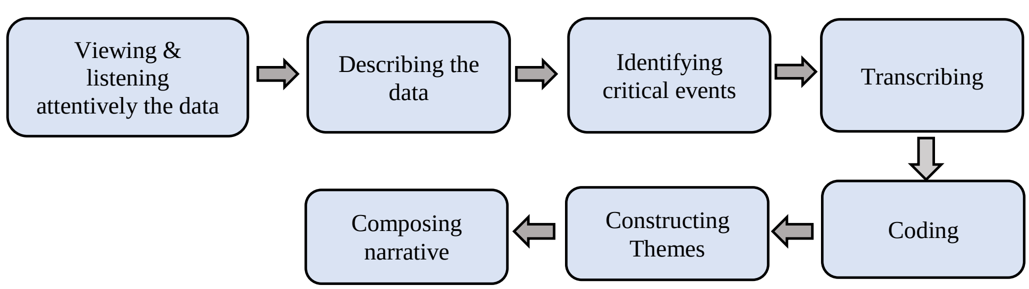


Figure 3.4: Sequential analytical approach for recorded data

To become familiar with the content of the video and audio data, I watched and listened the recording several times. Then the time-coded descriptions (in case of video recorded data) had done as it allowed me to locate quickly particular vignettes and episodes (Powell et al., 2003). Subsequently, significant moments or critical events (Maher, 2002) aligned with the research questions were identified from the recording. Some portion of the recoded data which consist the critical event were transcribed. According to Atkinson and Heritage (1984), transcripts should be "necessarily selective" (p. 12). After repetitive close observation within and across the data set for each case, I concentrated on the content of the critical events to identify the suitable codes for selected pedagogical approaches from teacher's classroom practice. I observed the pattern in the identified codes and grouped the similar patterns into six themes (Miles & Huberman, 1994): r*earranging classroom amenities, ensuring technology accessibility and its appropriate usage, adopting different strategies to make the learning meaningful, offering multi-channel feedback, offering opportunity to identify error/ imprecision, engaging students through motivation* (discussed in the next chapter). These six themes collectively stated the pedagogical considerations while teacher taught mathematics in an ICT-facilitated environment. During the analysis, data collected from different sources (audio, video recording, field notes) were triangulated to overcome the possible biases in interpretations. Finally, a narrative of how the ICT can be integrated to develop students' mathematical proficiency in a resource constrained environment were conducted followed by a proposed framework.

3.7.1 Rubrics and indicators for measuring MP

Students' mathematical proficiency was measured by analyzing data which come from paper-pencil test, survey and FGD. To measure the four strands (CU, PF, AR and SC) of mathematical proficiency, the paper-pencil test items were analyzed considering the rubrics adapted from Lerís et al. (2017) whereas the seven indicators associated with productive disposition (adapted from Kilpatrick et al., 2001; Lestari & Yudhanegara, 2015) and the category of productive disposition (adapted from Diknas, 2008) were used to analyze survey data. The descriptive statistics for both the Pre-post paper-pencil test and Pre-post survey data (n = 30) were analyzed using IBM SPSS and Excel 2016. The parametric tests were used to analyze the data under normal distribution. A paired sample t-test were conducted to determine if a significant change exists between the pre and post paper-pencil test, whereas a Wilcoxon signed rank test was executed for the pre and post survey data as the data was ordinal and not normally distributed. The details of rubrics for measuring the level of all strands of MP are discussed below.

3.7.1.1 Rubrics of four strands of mathematical proficiency (CU, PF, AR and SC)

To measure the students' ability of the four components of mathematical proficiency (conceptual understanding, procedural fluency, adaptive reasoning and strategic competence), a paper-pencil test comprising of five different questions (each question has sub items) was conducted. The question paper was prepared in such a way that students' ability on the four components of mathematical proficiency (MP) could be measured throughout the test. Though all the components of the MP are interlinked, some indicators (adapted from Kilpatrick et al., 2001; Laswadi et al., 2016, Lestari & Yudhanegara, 2015) were set for each component of the MP. To determine students' proficiency about conceptual understanding (CU), their "*ability to connect mathematical concept in another setting" (e.g., in a real life situation)* and their *"ability to represent math in various ways"* were considered as indicators, whereas the indicators "*ability to select the appropriate procedures"* and "*ability to apply the procedures correctly"* were chosen for measuring students' mathematical procedural fluency (PF). Students' *"ability to estimate answer with proper justification"* and "*ability to draw conclusion with proper explanation"* were considered as the two indicators for understanding their ability of adaptive reasoning (AR).

Table 3.2: Marks assigned for different components of MP in the paper-pencil test item

Proficiency cluster	Number of items	Marks
Conceptual understanding	2 (Q- 1c, Q-2)	10
Procedural fluency	2(Q-3b, Q-5)	10
Adaptive reasoning	3(Q-1a,1b, Q-4a, 4b)	10
Strategic Competence	2(Q-3a, 3c, Q-4c)	10
Total Marks		**40**

The rest of the components- strategic (SC) competence were measured by two other indicators “*ability to formulate, represent, and solve mathematical problems”* and “*ability to solve a problem in various ways/strategies”*. A total of 10 marks was assigned for each component (for details please see Table 3.2). The data collected from the paper-pencil test were analyzed considering the rubrics (Table 3.3) adapted from Lerís et al. (2017).

Table 3.3: Rubrics of the four strands of MP (Adapted from Lerís et al., 2017)

Four strands of MP	Indicator (Kilpatrick et al., 2001; Milgram, 2007)	Excellent	Good	Moderate	Poor
Conceptual Understanding	Ability to connect math concept to another one math concept / setting	Correct and complete	Correct and incomplete	Less complete	Incorrect/ not perform
	Ability to represent math in various ways	Correct and complete	Correct and incomplete	Less complete	Incorrect
Procedural Fluency	Ability to select the appropriate procedures	Correct and complete	Correct and incomplete	Less complete	Incorrect
	Ability to apply the procedures correctly	Correct and complete	Correct and incomplete	Less complete	Incorrect
Adaptive Reasoning	Ability to estimate the answer with proper justification	Correct and complete	Correct and incomplete	Less complete	Incorrect
	Ability to explain and draw conclusion	Correct and complete	Correct and incomplete	Managed to write the conclusion	Incorrect
Strategic Competence	Ability to formulate, represent, and solve mathematical problems	Correct and complete	Correct and incomplete	Less correct (some miscalculation)	Incorrect
	Ability to solve a problem in various ways/strategies	Correct and complete	Correct and incomplete	Less correct (some miscalculation)	Incorrect

As the marks of each component in the paper-pencil test was 10, to ensure the equal interval length for the four proficiency levels, the range for the intervals were chosen 2.5 (for details please see Table 3.4).

Table 3.4: Mathematical proficiency level associated with the score range

Proficiency level	Range of scores
Excellent	> 7.5 to10
Good	> 5.0 to 7.5
Moderate	> 2.5 to 5
Poor	0 to 2.5

3.7.1.2 Rubrics for measuring Productive Disposition (PD)

The rest of the strands of the mathematical proficiency named productive disposition (PD) was measured by conducting survey questionnaire. Students' productive disposition (PD) was measured by 7 distinct indicators (i.e., useful and worthwhile, sense-making endeavor, enthusiasm, persistence, confidence, curiosity and cooperation).

Among the 12 items of thesurvey questionnaire, different items were representative of the different indicators such as1 item (*Mathematics is essential for my future*) relating to useful and worthwhile, 3 items (*Having a solid knowledge of Mathematics helps me understand more complex topics in my field*, *I can make sense of what we do in math*, *I think that making mistakes is necessaryto get good at Mathematics*) relating to sense-making endeavor, 1 item (*I feel interest to do mathematics*) relating to enthusiasm, 3 items (*I can keep attention in times of doing mathematics, I do not stop to work on math problem even I struggle with that problem, I can learn any sorts of mathematics if I give the appropriate effort*) relating to persistence, 2 items (*I am confident to my ability of math skill to help my peers*, *I feel confident about trying different ways when solving math problem*) relating to confidence, 1 item (*I am curious to know the meaning of contextual math problems and how to solve them*) for curiosity and 1 item (*I like sharing math ideas and solve problem by discussing with my peers*) for cooperation (shown in Table 3.5).

Table 3.5: Items associated with the indicators of PD

	Indicators (Kilpatrick et al., 2001; Lestari & Yudhanegara, 2015)	**Items**
Productive Disposition	Useful and worthwhile	Item-1
	Sense-making endeavor	Item-2, Item-5, Item-11
	Enthusiasm	Item-3
	Persistence	Item-4, Item-6, Item-12
	Confidence	Item-7, Item-8
	Curiosity	Item-9
	Cooperation	Item-10

For the convenience of the interpretation of the survey data, the range scores of Likert scale was considered with the interval length of 1.8 and specified the proficiency level corresponding to the scoring range (please see Table 3.6) adapted from Diknas (2008).

Table 3.6: Category Productive Disposition (adapted from Diknas, 2008)

	Value	**Range**	**Proficiency level**
Strongly Agree	5	4.21-5.00	Very high
Agree	4	3.41-4.20	High
Neutral	3	2.61-3.40	Medium
Disagree	2	1.81-2.60	Low
Strongly Disagree	1	1.00-1.80	Very low

3.8 Pilot Study

Pilot study has been done in a non-Govt. school of Dhaka city. The school had all sorts of facilities that I needed to conduct this research study. The principal of the school was very cooperative and provided every kind of supports when required. The teacher who voluntarily agreed to participant in the pilot study, had teaching experience for almost 25 years. During his in-service period, he received Govt., non-Govt. and in-house trainings to improve his professional skills. Since for this study, an ICT-facilitated classroom was needed, the teacher chose the classroom which had Interactive White Board (IWB). The teacher conducted two classes with the 20 students of Grade-10 (all students who received higher mathematics as a subject of choice). Pilot study was done in the month of September, 2022. As GeoGebra software was chosen for this study, I setup three meetings (each meeting hold for approximate 50 minutes) with the teacher to familiarize him about the function of GeoGebra and provide the supportive materials. Before starting each class, the teacher shared with me his overall planning for the class. For further analysis of the teacher's classroom teaching with ICTs, the classes were video recorded taking the permission of the teacher. While the teacher was conducting the class, I observed the class, operated the video recording and took notes when necessary. Survey, FGD and paper-pencil test were conducted of the students and semi-structured interviews were conducted for the teacher and the principal of the school, to test the validity and reliability of the research instruments. To test the reliability of the survey questionnaire, the item analysis technique- "a reliability analysis" (Rezigalla, 2022) was carried out during the piloting phase. There are several reliability tests (e.g., split-half reliability test, Kuder-richardson reliability test and Cronbach Alpha) to measure the internal consistency of the test items. While Kuder-richardson reliability test handles dichotomously scored item and split-half reliability test is usually used to test the reliability of large number of items (split into two parts), Cronbach's alpha is the most used internal consistency measure which is generally founded as the mean of all possible split-half coefficients (Hajjar, 2018). Since, the number of items in the survey questionnaire of this study is low and the items are in five point Likert scale, Cronbach Alpha was the most suitable one to test the reliability of the items.

To measure students' productive disposition about mathematics, questionnaire was developed with 5 point Likert scale comprising 12 items. The Cronbach's alpha test showed an acceptable reliability value of α=0.842 (Table 3.7) for the questionnaire. All items appeared to be worthy of retention, as deleting any item would result into decrease in the alpha value. Consequently, all the 12 items were considered in the main study.

Table 3.7: Reliability of the test items

Reliability Statistics	
Cronbach's Alpha	No. of Items
0.842	12

Based on the analysis of the data collected from pilot study, some modifications were found necessary and were done accordingly for the main study (shown in Table 3.8).

Table 3.8: Modification recommended by pilot study

Pilot study	Modifications needed for the main study
Expected: Video record and field notes can be used to give a clear picture of the teacher's practices with ICTs. ***Reality:*** It was really tough to take field notes and video record by myself as both of the activities were not possible to do at a time, in some cases valuable data were not recorded with only one video recorder.	2 video recorders with supporting stands need to be considered During observing the classes, note taking should be only done by myself and post-lesson interviews should be conducted based on the field notes.
Expected: Teacher will use GeoGebra to conceptualize the meaning of function, slope, graphs. ***Reality:*** Teacher used the GeoGebra to show how to write the function, plot the graphs for different situations.	During the meeting session, the properties of GeoGebra and its' use to teach function, slope, graphs should be spelled out clearly.
Expected: Teacher will create the scope for the students so that they can directly use ICT tools. ***Reality:*** Teacher used the IWB by himself and students just observed and listened to teacher's instructions. However, students rarely use IWB (e.g. turn on / turn off the board)	Before enactment, in the planning session, teacher should be informed about possible involvement of the students with the ICTs.
Expected: Students' MP can be identified from the FGD. ***Reality:*** The questions of FGD provided very limited resources to understand students' MP.	Questions for FGD should be improved.

Based on the identified modification required for the main study, I have finalized my research tools and planning so that I can smoothly collect necessary data for my research study.

3.9 Trustworthiness of the Study

For the trustworthiness of this study, the criteria proposed by Bakker and van Eerde's (2015) (which is based on the guiding principle of Miles & Huberman,1994) were considered. Various techniques which were applied to seek the trustworthiness of the study are discussed below.

In a research, the quality of data collected and arguments reflect its internal validity or credibility issue (Bakker & van Eerde, 2015). To maintain the internal validity of this study, I considered several techniques. I used several data sources and data gathering methods for data triangulation. Besides, I used response validation technique (checked the transcriptions of the data by the participant teachers) to validate the data as well. External validity which is also known as transferability denotes the generalizability of the results (Bakker & van Eerde, 2015). In this study, under each case, I attempted to provide detail descriptions of the situation so that it represents a clear and enthusiastic picture. According to Yin (1994), one of the strengths of case studies is that it allows readers to get a robust experience by providing rigorous and rich descriptions of the phenomena. Besides, the way I presented the result of the study could assist other researchers to adopt them for their own contexts which ultimately tend to the result more generalize (Gravemeijer & Cobb, 2001). Though, the limiting effects of sample selection and the setting were the threats to generalizability, my prolonged engagement in the research setting with keen and persistent observation, note-taking, interview may improve the finding's validity as well as increasethe generality of the result (Kvale, 1996). In addition, a "Tools validation workshop" was organized where the participants were the experts in the relevant field of this study and the experts' opinions were taken for further corrections and modifications. To confirm the validity of the instruments, the developed tools were piloted in a school. Reliability or dependability refers to the consistency of the study findings. It relates to how consistent the results are across different versions of the same instrument or in different conditions. Data triangulation (the use of several data sources such as audio recorded and video recorded data from teacher, students and head teacher) was done to address this issue in this study. Besides, Cronbach alpha was applied to test the reliability of the quantitative data.

3.10 Ethical Considerations

I provided "introductory letter" from my supervisor (see Appendix A) to the principals of the schools for taking their permission and approval to conduct the research at their school. In addition, a letter of consent (see Appendix B) was provided to the participants. The consent letter addressed all the ethical issues associated with participants and shortly described what was expected from participants. Before starting the data collection process, issues of anonymity was discussed with the participants and I ensured them that their name will be kept anonymous. For maintaining confidentiality, I termed the participant as T (in case of teacher) and S (in case of student) instead of their name. I have labelled teachers as T1, T2 and the students Si_C1 and Si_C2, (i=1, 2,…30) for Case-I and Case-II respectively. In order to preserve individuals' right to private opinions, whilst recognizing that these may conflict with their school's policy, I confirmed to all the participants that their institutional details will be omitted. Moreover, the participants were informed that they had the right to withdraw from the research process at any stage (before, during, or after interview). As digital audio and video recorder were used for recording the interviews and classroom observations respectively, permission were sought to use the recorder.

Chapter Four

DATA ANALYSIS AND FINDINGS

This chapter shows the analysis and findings of the data collected for this study and is organized in three sections. In first two sections, two cases are described separately where the demographic characteristics of the participant teachers, teachers' pedagogical considerations in an ICT-facilitated TL environment, the factors affecting ICT integration in TL process and the level of students' MP are presented. Finally, by comparing two cases for commonalities and differences, a narrative was developed to offer an insight on how the teachers apply pedagogical considerations in an ICT-facilitated environment to promote students' MP and how the factors influenced ICT integration in TL process.

4.1 Case-I

4.1.1 Teacher T1

In this study, the participant teacher in Case-I is named as T1 to keep anonymity. The teacher T1 is a male teacher and is working in a Government (Govt.) boys school in Dhaka city. He graduated in mathematics from Dhaka University and completed his Master's degree from the same university in Applied Mathematics. During his BSc(Hons), he learnt C++, Fortran, Mathematica software along with the other mathematics courses. He has experience of teaching mathematics of secondary and higher secondary students for almost 17 years. He has been serving his current school for about 7 years. Due to his professional obligations and personal interest, he completed BEd from Govt. teachers training college, Dhaka and he took several training programs from home (CPD, ILC, ICT training, PBM etc.) and abroad (ICT training, India). Through those trainings, he enhanced his capacity on pedagogy, ICT skills and capability to prepare digital contents for improving teaching quality. Besides, he attended in-house trainings on developing questions using google form, creative question development and so on. He performed as a trainer in the in-house training as well. He has the experience to conduct class with the help of ICTs. T1 possesses a great interest on technology and is willing to participant voluntarily in this study. Though the teacher has some practical experiences about some mathematical software, he did not use GeoGebra software earlier. Among six classes, the teacher used GeoGebra (along with the PowerPoint presentation) software in every classes except the last class. In this study, T1 took all his classes in the ICT lab room (20 computers were available for students) where most of the students have the facility to work with computer in one-to-one basis. However, in every class teacher did not allow students to operate their computer individually rather he welcomed students to directly use his (T1) laptop so that it provides an essence of what should be the scenario while conducing class in a multimedia facilitated traditional classroom.

4.1.2. Teacher T1's pedagogical considerations in an ICT-facilitated teaching-learning environment

4.1.2.1 Developing themes for teachers' pedagogical considerations

The analysis shows that the teacher T1's pedagogical considerations in an ICT-facilitated Teaching-Learning (TL) environment can be described collectively by six themes emerged. By analyzing the data collected from Case-I through video, field notes, post-lesson interviews and FGD of students, a total of 29 pedagogical approaches have been identified and coded. The sample of the code selection process (based on the analysis framework discussed in chapter three in section 3.7) from the snapshot of 10 minutes' video data is shown in Table 4.1. By observing the patterns of the approaches, approaches of similar patterns are grouped into themes. As such, six themes emerged through the analysis (Table 4.2).

Table 4.1: Identifying critical events, transcribing and developing suitable code

Time	10:04 to 10:14
Descriptions	The teacher entered the class and exchanged greetings with the students. The teacher looked around the whole class and made some students change their seats. After that, he asked if anyone had any problem of understanding the functions we had learned about in the previous class. When students ensured the teachers that they have no confusion about the concepts of function, then the teacher went to his laptop and showed a slide on the projection screen.

	The teacher stood in the middle of the class and asked students to look at the screen attentively and think intensely which option or options are not considered as a function from the prior knowledge about the function. The students looked attentively at the slides and their facial expressions seemed that they tried to link the options with their gained knowledge in the previous class. Some students were also discussing with their friends sitting nearby. Teacher called a student S11_C1 randomly to come in front of the screen and asked which option he (S11_C1) felt to be correct. When the student answered, the teacher asked him to stand there and asked another student S7_C1 if he thought his friend's answer was right or wrong. When S7_C1 gave his opinion, the teacher wanted to know the reason behind he had chosen the option. The teacher asked the whole class if anyone wants to challenge his opinion. The students speak together that they are with their friend's opinion, the teacher asked S7_C1 to use teacher's laptop and to move the mouse to click on the correct option on the laptop screen. When S7_C1 clicked on his chosen option, "answer is correct" appeared on the projected screen and everyone clapped together. The teacher asked randomly some students to stand up and explain why the other options are functions. Students explained their understanding to the whole class. The teacher tried to determine whether the students were able to identify all the reasons behind to perform the function. The teacher asked the other students if anyone has anything new to add or remove in one's answer. Students were giving their opinions. Both teachers and students were seemed to enjoy the class and they were very lively. The students who looked a bit shy or inactive in the class, the teacher often asked those students.
Critical events	At the start of this episode, teacher's intention was to check students' prior knowledge about the function which they have learned in the previous class. During the episode, teacher was involving students to think critically and arguing one's opinion by the others. The teacher also welcomes a student to directly use the ICT tools. This event was critical since it pointed the key ideas to explore students' understanding on math concept and involved students in adaptive reasoning. This event illustrated that the students seek to understand and explain reasons on the options shown on the slide are function or not. In addition, at the end of this episode, students realized all the possible reasons of when a problem is considered as a function.
Transcribed data	**T1:** Look at the screen. What have you seen? **Students:** 4 diagrams **T1:** Yes, now you have to identify which diagram(s) are not represent function. Think for a while. **T1:** S11_C1, tell us which option(s) do you think? **S11_C1:** Option one i.e. this one, sir. **T1:** why? **S11_C1:** because, to be a function, every input must have an output, here one input has no output. Which is not possible. **T1:** Do you think any other option will be? **S11_C1:** Um. I am not sure, sir. **T1:** S7_C1, tell us S11_C1's answer is correct or not?

	S7_C1: No sir. I think S11_C1 is partially correct. The 4th diagram is also not a function. So the correct option will be this one. **T1:** Explain us, why. **S7_C1:** To be a function, every input must have exactly one output. But here, one input has two output i.e a and c, which is not true for function. **T1:** Students, what do you think? **Students:** S7_C1 is correct. **T1:** Ok, S7_C1, use this mouse and click on the option (in the laptop) which one you think correct. **S7_C1:** ok, sir. ("Anwer is correct" showed on the projected screen) **T1:** A big round of applause for S7_C1. (All clap for S7_C1) **T1:** who can tell us about the 2nd and 3rd diagram? Raise your hand. (all most every student raises their hand) **T1:** S23_C1, stand up. Tell us about 2nd diagram. **S23_C1:** it is function. **T1:** why? **S23_C1:** for every input there are exactly one output. **T1:** look at 'c', is it associated with any input? **S23_C1:** no sir. **T1:** then, still is it a function? **S23_C1:** yes sir, to be a function each input must be associated with exactly one output. Here 'c' is not input and every input has one output. So it is a function. **T1:** anyone want to deny S23_C1's opinion? **Students:** No sir, he is correct.
Codes	• Involving learners directly to ICT • Providing scope to explain students' thought with proper justification • feedback by peer

In the above table, the first row represents the duration of the episodes which I intended to describe. The second row represents the content description of the nearly the first 10 min of video episode without interpretation. The third row describes the episode which is identified as a critical event in relation to the guiding research question 1. The fourth row is the transcription of the recoded data where the critical events are embedded. The identified codes (applying color coding technique (Bianco et al., 2015)) are presented in the fifth row.

In the similar manner, all the collected data from different sources for Case-I were analyzed and 29 code were identified by color coding technique. The identified codes are shown below (Table-4.2).

Table 4.2: Themes emerged as effective pedagogical approaches for Case-I

<table>
<tr><th>Identified codes for pedagogical approaches</th><th>Similar codes
Under various groups</th><th>Category/ theme created from groups</th><th>Pedagogical consideration</th></tr>
<tr><td rowspan="4">• Flexible and adaptable learning space
• Valuing learners' opinion
• Physical space support-observation learning
• Providing scope of- peer discussion, group work, whole class discussion
• Selection of tools
• Facilitating to get the correct path
• Access to technology
• Linking and connecting math with real context
• Teacher provides feedback
• Providing scope to explain students' thought with proper justification
• Involving learners directly to ICT
• Providing counter example
• Encourage to apply math language
• Using ICT (screen) to perform the task accurately
• Providing scope to apply acquired knowledge in a new situation
• Providing homework for practice
• feedback by peer
• student's self-reflection
• Physical space support-collaboration
• ICT provides feedback
• Encouraging rapid recall
• Identify mistakes (by peer, by learner's own)
• Praise the learner
• Providing attractive picture</td><td>• Flexible and adaptable learning space
• Physical space support-collaboration
• Physical space support-observation learning</td><td>Rearranging classroom amenities</td><td rowspan="4">Rearranging classroom amenities

Ensuring Technology Accessibility and Its Appropriate Usage

Adopting different strategies to make the learning meaningful

Offering multi-channel feedback

Offering opportunities to identify error/ imprecision</td></tr>
<tr><td>• Selection of tools
• Access to technology
• Involving learners directly to ICT
• Using ICT (screen) to perform the task accurately</td><td>Ensuring Technology Accessibility and Its Appropriate Usage</td></tr>
<tr><td>• Linking and connecting math with real context
• Providing scope to apply acquired knowledge in a new situation
• Exploring and linking math with prior knowledge
• Encouraging rapid recall
• Providing homework for practice
• Providing multiple ways of representation and strategies
• Providing scope of- peer discussion, group work, whole class discussion
• Encourage to apply math language
• Offering challenging tasks
• Providing variety of several examples
• Providing scope to explain students' thought with proper justification</td><td>Adopting different strategies to make the learning meaningful</td></tr>
<tr><td>• feedback by peer
• student's self-reflection
• Teacher provides feedback
• ICT provides feedback</td><td>Offering multi-channel feedback</td></tr>
</table>

• Providing variety of several examples • Exploring misconception • Providing multiple ways of representation and strategies • Exploring and linking math with prior knowledge • Offering challenging tasks	• Exploring misconception • Providing counter example • Identify mistakes (by peer, by learner's own)	*Offering opportunities to identify error/ imprecision*	***Engaging students through motivation***
	• Praise the learner • Providing attractive picture • Valuing learners' opinion • Facilitating to get the correct path	*Engaging students through motivation*	

A whole transcript of a lesson has been given in Appendix K to give the reader a complete scenario of what happened in a class.

4.1.2.2 Pedagogical approaches applied by T1

Theme 1: Rearranging classroom amenities

The teacher T1 conducted six classes in the ICT lab room where the learning space is to some extent flexible and adaptable (e.g., availability of extra chairs and desk, portable board etc.). The room was well equipped with ICT technology. There was a projector, a laptop (for the teacher) and 20 computers for the students. Each computer has internet connection as well. There was a white board where the projector screen was projected and it was placed in such a way that it was easily visible to all the students. The teacher's laptop was placed beside of the projection screen. Teacher also hired a portable white board to link the screen to the board by himself as well as by the students. During the post-lesson interview session, T1 justified his actions:

> *[…] only one board was in the class. There was no extra facility to project the screen. So, I brought an extra portable board so that students can work on the board. Umm.. I also brought the board to explain some of my work. […] sometimes I use the board to explain more what was projected on the computer screen so that students get the concept clear.*

This statement highlighted the fact that T1 rearranged the classroom suitable for observation learning, that is, he reorganized the classroom setup in such a way that all the resources were visible to the students and such an environment helped to develop students' mathematical concept as well.

Besides, the board was also used as a means of multiple ways of teaching techniques. For instance, while displaying one procedure to perform a task on the screen, the board was used to perform alternate way to do the same task. A sample of some portion of classroom scenario on this issue is shown below.

T1: look at the graph (teacher displays a graph on the screen). Does the function have slope?

Students: Yes, sir (loudly).

T1: who will come?? Raise your hand.

(some of the students raise their hand)

T1: S22_C1, come here. Tell us about its slope.

S22_C1: Sir, it is '1'.

T1: why?

S22_C1: here the rise is '1' and the run is '1' (showed by his hand on the graph)

T1: what do you (students) think?

Students: he is right, sir (all says loudly).

T1: any one can find the slope differently?

(some students raise their hand)

T1: S5_C1, take the marker and go to the board. Show us another way to find the slope.

(S5_C1 do the task on the board)

T1: explain us what you have done.

S3_C1: I use y=mx+c formula here. Here c=-1 and I choose the point (1,0) from the graph. So, when I put the value of y=0 , x=1 and c=-1 here (in the equation y=mx+c), I get m= 1

In the post-lesson interview session, the teacher also talked about supporting this issue. He asserted:

> *[…] suppose there's an example of graph of a function on the screen, now I called a student and said, you write another equation that draw the same graph. We also needed that board to see how we could do it in different ways.*

The sitting arrangement for the students were in two parallel columns (Figure 4.1) and placed in such a way that the white board was easily visible to all. There were also some extra chairs and a table. T1 asked to use these extra chairs while students needed to engage

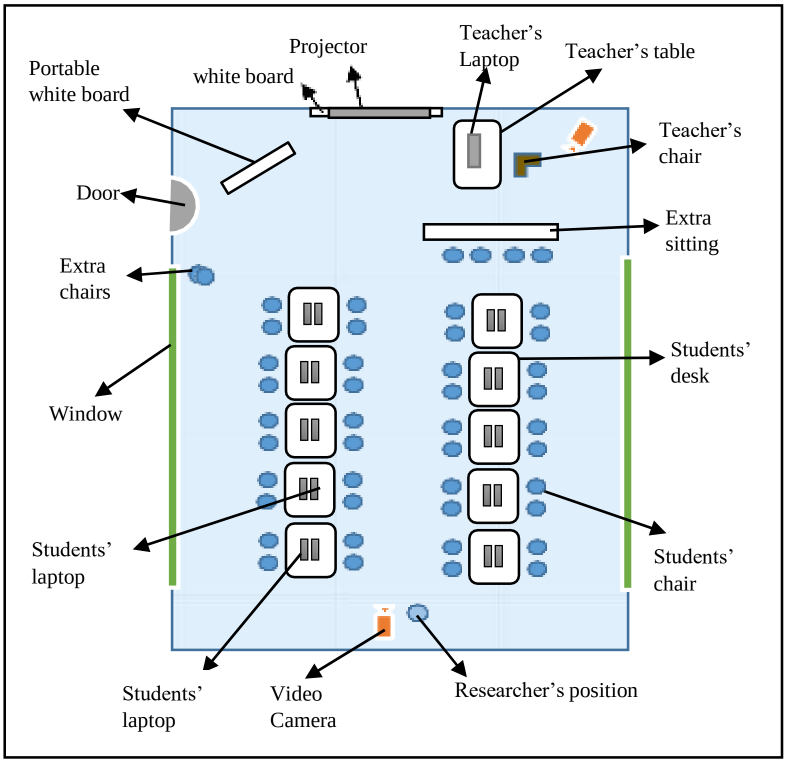


Figure 4.1: Classroom layout of the teacher T1

in group discussion. The extra table was placed so that student can sit alone or group if necessary. Though the option for flexible learning was present, T1 did not ask students to work by their own choice (such as, choice to work individually or pair or group). According to the teacher, it is important as such type of experience helps students to develop their leading capacity and increases students' satisfaction level in learning. The teacher argued:

> *[…] it was not actually made but it was needed. Every student should be given the freedom to sit as he/she wants. And can work freely by themselves. This environment is needed. It means that he should be given the opportunity to work in all environments and he should develop his leadership capacity. He cannot be stopped. Doing these things may have a satisfactory effect on his brain and his pressure is reduced.*

This means that T1 stressed on the importance of flexible learning to create students' leadership and persistence qualities which ultimately reflect their development of productive disposition.

It is also seen that while students worked with technology in a group, T1 changed the sitting arrangement with the combination of high and low ability students where the ability was setup by their use of technology. He stated:

> *The classroom arrangement is done because some students have little idea about ICT, some students have clear idea about ICT. While some are skilled in ICT. For this reason, a seating rearrangement has been done by considering students who have less knowledge about ICT and those who have more knowledge about ICT.*

Thus, the physical space support observation learning as well as collaboration. Though the physical space support collaboration, during the post-lesson interview, T1 argued that it was a bit challenging for him to get students involved in group activity as the classroom was not so spacious and the table was fixed. He also argued that it would be better to set-up the sitting arrangement in round shape pattern. He stated:

> *[…] we needed the space of the room to be bigger. Each computer and the table were very close, if there would be a little gap, it would be convenient for us to work in group, we could have placed them far away, the gathering would have been a little less. [...] For group work, table should be placed in such a way that it would be convenient for them to sit in round. But since we are sitting straight, the participation of all students was not proper. […] if everyone sits in a round shape, everyone's participation would be correct.*

Since the classes were conducted in the ICT lab room, the lighting arrangement was properly adjusted and it did not distract the TL process. In almost every classes, teacher changed the students' sitting arrangement. According to T1, the reason behind this was to ensure everyone's participation. The main concern was to conduct participatory method and sitting arrangement was considered with the combination of strong and weak students so that, weak students can be benefited by the stronger ones. He stated:

There was an issue of seating arrangement in each class. Because all students in the class were not in the same category, some of them were meritorious and some were less meritorious. I planned to sit them in a combination of meritorious and less meritorious ones. [...] As my target was to apply participatory method, I have made such a seating arrangement.

Theme 2: Ensuring Technology Accessibility and Its Appropriate Usage

Throughout the six classes, T1 used different sorts of technology for TL purposes. Along with the whiteboard and multimedia projector, T1 used PowerPoint presentation, GeoGebra software and Desmose app. He also asked students to use calculator if necessary. Both T1 and students have access to technology. In almost every classes, T1 used PowerPoint presentation as well as Geogebra software. Students also used the technology directly when teacher asked to operate them. While students directly worked with the technology, T1 monitored students' work and assisted them where necessary (Figure 4.2). For example, a conversation between a student and T1 was like this:

T1: S12_C1, come here, move the vertical line on the graph and tell us, whether the graph is function or not.

S12_C1: sir, the slider is not moving

T1: just press here, then move. Clear?

S12_C1: yes, sir.

Figure 4.2: Teacher assists student to operate ICT tool

During the post lesson interview, T1 expressed that while students directly work with technology, he needs to monitor them carefully and assist them if necessary, so that they get engaged into the lesson. He stated:

> *I was monitoring them while they were doing the tasks to see if they were on the right track, whether they understood or not. […] I was monitoring them to see if their commands were correct or not. […] to understand if anyone is having any problems, to see whether each of them was active or inactive.*

It is observed that the teacher opened the scope for students to use technology very often as he thinks it is necessary. It is seen that initially students were not very willing to work with ICT directly, but in course of time, they seemed very enthusiastic to work with technology. Snapshot of a classroom scenario is shown below.

T1: who want to move the slider?

Students: me me (almost every student loudly say by raising their hands)

T1: S28_C1, came hare, move the slider and keep the value of ‘m’ in ‘0’

T1: everyone, attentively look at the graph (which is displayed on the projected screen) and write your comment in the worksheet (teacher already provide them the work sheet)

S2_C1: sir, can I use the slider for another value?

T1: okay, come

S7_C1: sir, I want to come.

T1: okay, come. Do you enjoy? (teacher asks for all students)

Students: yes, sir, it is very interesting. (all response loudly)

During the post-lesson interview, T1 also argued about the importance of students’ direct interaction with ICTs and stressed that students should do that willingly. According to the teacher, when students engage directly with ICTs, it will help them to reduce their fear about technology and extend their knowledge. He argued:

> *The reason I brought them in front of my laptop was to remove the inertia they had*

inside. At first, I saw they didn't want to come. They had a lot of fear in them. So, to overcome that inertia, to bring them on the right path so that they can apply what they know in the right way, so that they can express, expose, so that they can do their right work. [...] whenever I brought them, I saw that they were very excited and I saw that everyone was very interested in going there to draw the graph of the linear function. I am actually bringing them to generate interest.

During the FGD, students also showed their positive view about their direct involvement with ICT. One of the students argued that working with ICT help him to build confidence and make concept clear as he can use more complex values (different from the value provided by the teacher) as input and by observing the changes happen in the output, he can also understand the reason behind it. He stated:

I set different complex values rather than the values given by sir (the teacher), I saw that if the values are changed, why the lines shifted to the right or the left or up or down. I also tried to select different options (other than the teacher taught) and found it was correct. Um.. it was really exciting. In this case, I feel confident and I get accurate knowledge, I think. (S6_C1)

This is an indication that students' ability to select appropriate commands (reflection of PF) with solid conceptual knowledge can be developed (reflection of CU) due to the direct involvement of students with ICTs. It also suggested that it enhanced students' confidence as well (reflection of development of PD).

T1 also used the digital screen to perform tasks. For instance, teacher displayed graph paper on the screen so that students could plot the graph accurately. He argued that it helped them to perform the task fluently and more perfectly (i.e. enabled to develop PF). In addition, it saved their time. Besides, as they could draw the diagram by thinking in different angles and understood the concept more clearly (reflection of CU). As he expressed:

Since the image of the graph paper was on the screen, there was no chance of error. They can correctly draw the graph on it and it seems very easy for them. [...]

Besides, when I talk about the slope by definition, it depends on memorization. Now, they actually understand what is the slope, when they saw on the screen how the diagram was drawn in different ways, they understood what happens when the angle is acute, what happens when the angle is obtuse, they can compare these things. These things they quickly understood and it will save their time as well.

During the FDG, one student also expressed that ICT not only saved their time but also saved their teacher's time as it took limited time to draw a graph perfectly. According to him, ICT ultimately helped teacher to engage students in collaborative activities as it saved teacher's time (*ICT_Role-3*). He argued:

[…] too much effort and time are required to bring that graph into perfect shape. If we can save that amount of time through digital technology, then the extra time can be given for group study or group work.

T1 also displayed the graph of a function created in GeoGebra and applying zoom in and out option (Figure 4.3) made the graph clearer to the students. The teacher and students' conversations during this issue is given below.

S19_C1: sir, from '-1' to '-2', the graph has slope '0'

T1: why?

S19_C1: because it is one the x-axis.

T1: others, what do you think?

(Some of the students agreed with S19_C1, some look confused, some were thinking)

T1: ok, now I zoom in the picture

(teacher enlarge a specific portion of the graph by zoom in option)

T1: tell me now

Students: oh! It is not on the x-axis

T1: S19_C1?

S19_C1: yes sir, it is not on the x-axis

T1: then? What you have seen?

S19_C1: it has both positive and negative slopes but they are very small. (he showed by his finger)

Before zoom in **After zoom in**

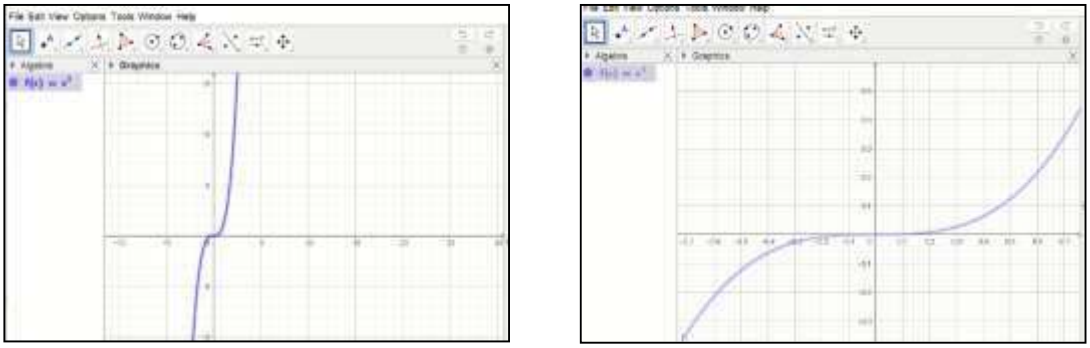


Figure 4.3: Applying zoom in & zoom out option in GeoGebra

During the post-lesson interview, the teacher argued that ICT helped them to make the complex topic easier (*ICT_Role-9*). He stated:

> *I show one problem and then show another one with a slightly more upgraded problem. By hand, it gets complicated. But when we have seen that through ICT tools, a complex problem, a big problem can easily show in a variety of different ways. And they (students) were actually amused by seeing how the big problem is so easily changed by changing some variables or by changing the values of some variables.*

During the FGD, students also argued about the benefits of ICTs for performing a task accurately (*ICT_Role- 2*). One of the students claimed that while “I draw a graph using Geogebra, it is very smooth diagram. If I zoomed (in or out) it, I will get the perfect diagram.” (S1_C1). Another student stated:

> *When we try to draw a diagram, there is a chance to do mistake. Once I did it, the rectangle became a square. But there I see that the circle is just like the circle, the square is like the square, the rectangle is like the rectangle. You can see that there is no problem in the figure. We get the accurate diagram. (S5_C1)*

Theme 3: Adopting different strategies to make the learning meaningful

The analysis shows that T1 adopted variety of strategies while conducting class using ICTs.

He sometimes used technology and sometimes did not, based on needs. In every classes, he tried to connect mathematical concept with their prior knowledge. Besides he often tried to link the mathematical concept with real-life situation. For instance, to teach the concept of function, he did not start the lesson with abstract concept rather he linked the concepts with real context (e.g. switch on the button of fan, the fan starting to move). He also explained the concept of function by showing relation among mother and son. He argued:

> *[…] previously their learning was rote learning, their knowledge was only based on theory, book-centered. They actually had no idea what a function is. When we turned on the fan with a switch and link them with the concept of function, they got an idea practically. […] I tried to explain the concept of function by life*-oriented *example. When I said, one input cannot have more than one output, they only gain the knowledge but when I brought the mother son relationship in the form of mapping it showed that one mother can have more than one child but one child cannot have more than one mother. About these things they understand that when a child claims or is related to more than one mother, it cannot actually be true. their concept of function becomes clear.*

To link mathematical concept with real-life, T1 often used ICT tools as he thought that ICT helps to reduce the abstractness of a mathematical concept, as a result, students can learn with proper understanding rather than rote learning. For instance, the teacher used animation option in the PowerPoint to show how a juicer machine acts while providing orange and football (as input) separately and then linked the operation of the machine (i.e. input and output issue) with the concept of function (Figure 4.4). According to T1, such kind of animated diagram made the learning more visible and interesting as well as sustainable and concrete (*ICT_Role-6*). He stated:

> *When ICT tools used for showing the pictures it was very enjoyable and they realized that earlier we were relying on rote, abstract thinking. Now we can see a real face of this thought, we can see the real shape, we are thinking concrete thoughts…. then they were very happy. […] and I think, when students learnt in this way, their understanding become concrete and long lasting.*

In line with the opinion of teacher, during the FGD, students stated that ICT helps them to clear their concepts and retain their learning for a long term. One of the students said:

> *We have known the definition of functions for a long time. We saw in the class the real example, um.. if one thing is input, exactly one thing will be output, it is a function. We are discussing the whole thing through images and relating it with real-life. […] In fact, when something is explained with real examples, it is fixed in mind for life long. (S2_C1)*

Action of Juicer Machine | Linking Juicer machine to the concept of function

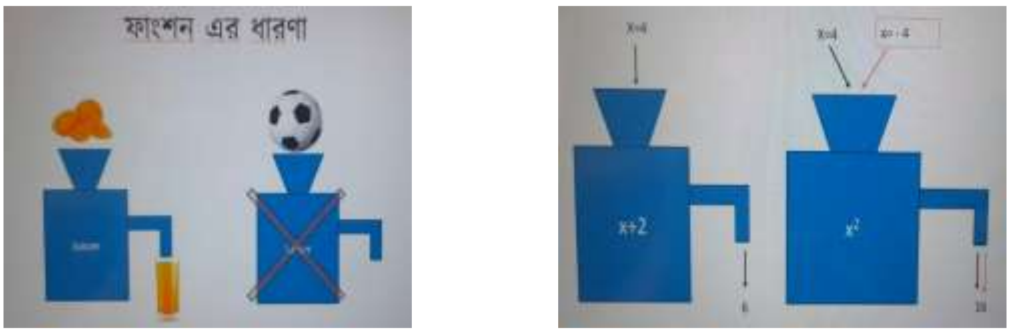


Figure 4.4: Connecting concept of function with real-life

Another student expressed that due to the use of simulation, they can visualize the meaning of mathematics in real-life context (*ICT_Role- 1*). He stated:

> *The example we have seen for the uniform velocity or constant acceleration, in this case we saw the animation, the graph changes with time, I think it was not possible in analog without digital system. […] that was very helpful to build-up our concept. (S1_C1)*

During the FGD, one of the students also expressed his opinion about the importance of ICTs in their life. According to him, the necessity of ICT in learning cannot be ignored, if the prime intention of mathematics learning is to connect math with real world situation and also to make the learning enjoyable. He also argued for the need of ICTs to adapt with future world (*ICT_Role- 7*). He claimed:

First, it is essential to enjoy mathematics or to understand its relevance to our real life. Secondly, since now is the era of globalization, we should adapt to it for our future (S4_C1).

The above quotes clearly indicate that while mathematics was taught connecting with real-life situation, students' both the productive disposition and conceptual understanding were developed.

In the last class, T1 also provided the scope to apply students' acquired knowledge in the new situation. For instance, when students fully get the knowledge about linear function and its graph, he provided an interesting simulation on linear function (race between tortoise and dog) related to real-life situation and asked students to draw the distance vs time graph of a newly entered animal dog (graph of tortoise has already present) by setting some new conditions. Those situation is totally new for the students, however T1 permitted to apply their gained knowledge in the new situation. He claimed:

[…] they were taken to another situation, to understand their understanding about function. […] I have given an example that the distance versus time graph, is a kind of function working here and the changes in the movement of different animals with time. They were focused on this diverse learning and they were realizing that the function that we learned is not in a specific place but that it has a wide range and that it has applications in different areas. Got real and clear ideas.

This statement clearly highlights the significance of applying acquired knowledge in new situation to develop students' conceptual understanding.

The teacher used the Desmose app to apply the simulation (Figure 4.5) and invited students to draw the graph using the option of Desmose app (click on the blue box and dragging the cursor). Since the language of the problem instructions in the Desmose apps are in English and the participant students are of Bengali medium, the teacher translated the instructions and condition of the problem in Bengali in a paper and provided that to each of the students.

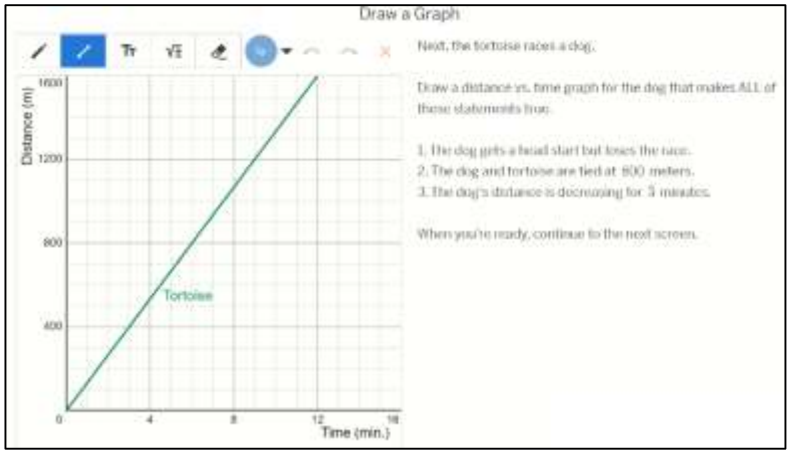


Figure 4.5: Students use simulation to apply their gained math knowledge in new context

The analysis also reveals that teacher tried to explore students' prior knowledge before starting and during a lesson. He tried to explore the prior knowledge to understand students level of knowledge and based on these he could move forward for further lesson. Besides, during the lesson he also tried to explore the prior knowledge to understand how quickly students can recall the information to do for further task and can move forward from easy to complex problems. Based on students' prior level of understanding, he may apply different strategies. He claimed:

> *[…] my intention was always to understand what knowledge students previously have about the topic, so that I can plan what I need to provide them what need not. […] And, of course there is a need to recall, because if he can't recall then he cannot connect mathematics contents to each other. Besides, how quickly they (students) can recall, I (the teacher) can understand their ability of math fluency. […] we need to recall to move from simple to complex problems in mathematics. So, we need to know their previous knowledge and based on that I adopted various strategies. Um..I think, adopting different strategies ultimately capable students to work with different techniques.*

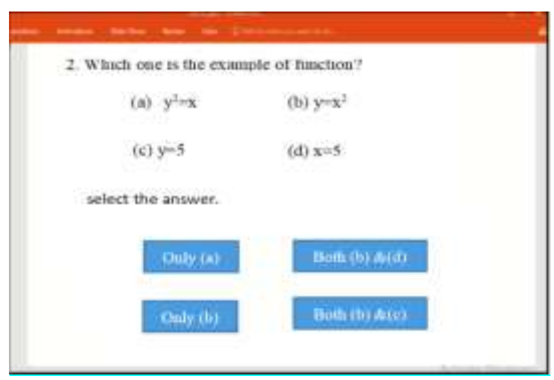
This clearly suggests that exploration of students' prior knowledge facilitated teachers to apply different strategies in the class and which eventually helped students' to become skilled in SC. Besides, this quotes in fact support the fact that ability to quick recall reflects students' procedural fluency.

It is found that while recalling quickly was considered important, T1 also argued about the importance of practice. According to him, to become fluent in mathematics, there is no alternative of practicing. He stressed that students have to practice after grasping the concept fully rather than practice blindly. He claimed that to create interest in practicing, they (teachers) can provide tasks prepared by the ICT tools and by clicking on the tasks they (students) can show the result and they can do it repeatedly. He mentioned that he already used those sorts of task in the classrooms (see Figure 4.6), but he yet might provide those as homework. He stated:

> *I think, it word be an effective work for the home, they can practice those tasks over and over at their home. They become skilled on that, I think.*

This means providing homework for practice is important to develop students' procedural fluency.

Original Task



Translated version of the original task

Figure 4.6: Task for drill and practice

The analysis also shows that T1 provided the scope to represent mathematical concept in different ways. For instance, while discussing about function concept, he showed different ways to represent a function. He used GeoGebra software to represent functions in different form (e.g. tabular form, graphical form and algebraic form) at a time (Figure 4.7).

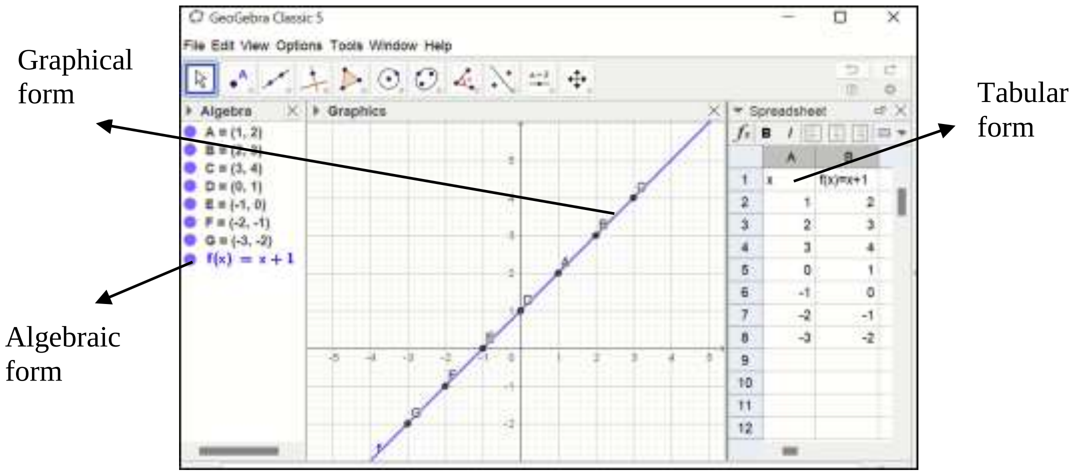


Figure 4.7: Representation of function in different form in one frame in GeoGebra

According to him, learning becomes more effective due to the use of ICT as they can visualize the concepts of the functions with all possible representations in a single frame and by connecting them, their gained knowledge become more concrete. T1 expressed:

> *[…] to show different types of relationship such as relationship among price and item, different types of graphical representations, we used the ICT tools. In one screen they can see all possible ways which help them to link and connect their knowledge strongly.*

This means that providing multiple ways of representation helped students to develop solid mathematical concept.

Besides, he also encouraged students to solve a problem in different ways. According to T1, it is very essential to make students skilled in strategic competence to compete with this complex world. Since, in real-life, all problem is not come so simple, so students need to be ready for dealing with all situations easy to complex. Besides, the ability of doing a problem in different ways, helps students to develop their understanding more solid. According to him, ICT not only creates the environment to deal with math problem in various ways within a short period of time, but also opens the scope to visit the tutorial classes of scholars and gain the knowledge of different approaches applied by different scholars. He argued:

> *In fact, there are some strategies behind everything. Before starting a problem, we have to think about the tricks so that we can solve a complex problem easily. That is why it is very important to develop strategic ability in students. […] if a student solves a particular problem in different ways, his understanding of the subject is clear and he can use it in real world situation. […] In real-life every human being has to face different problems […] all problems cannot be solved with the same method. That's why our student has to adopt different strategies when different problems come. […] And they can watch different tutorial classes on YouTube, so they can learn how to approach the same problem in different ways. ICT plays a huge role in this.*

This statement clearly indicates that T1 intended to apply multiple strategies to solve a problem so that students' conceptual understanding and strategic competencies develop.

During the FGD, students expressed that their teacher gave them the opportunity to do a problem in different ways which was very effective as it helped them to think a problem critically. One of the students argued:

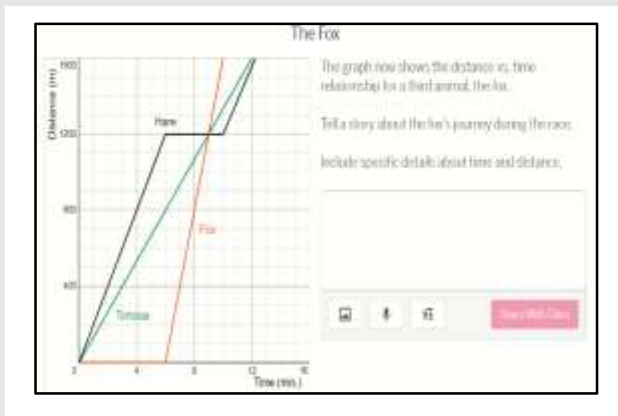
> *Before these classes, when I used to do math, if I found a result by doing in one way, I thought that OK all is done, but after doing these classes, the question comes that why this happens, can it be done in another way? Why do we do it this way? This question comes to my mind repeatedly. (S3_C1)*

Another student stated that due to gaining knowledge to solve a problem in multiple ways, he could verify his performed task in different ways, which ultimately made him confident. He claimed:

> *Sir (the teacher) has taught us different ways to solve a math. We know that this math can be done in this way as well as in that way. So, I can check my work by applying different methods and can increase confidence. (S2_C1)*

This means that providing the scope to solve a problem in multiple ways enhance students' confidence level (reflected development of PD).

In almost every class, T1 created such an environment that students could get involved in the whole class discussions. An example of students' engagement in the whole class discussions is shown below.



T1: S14_C1, come here. Tell us what you have seen on the screen

S14_C1: I have seen 3 graphs, one is for Hare, one is for Tortoise and the other is for Fox journey. I have to say a story about Fox journey.

T1: okay, then tell the story to your friends.

S14_C1: Fox starts first and win the race.

T1: class, now the floor is open to you. You can disagree or agree with S14_C1 or add more.

S3_C1: Sir, S14_C1 is not correct.

T1: is it? Then what should it be?

S3_C1: three animals have started at the same time, but initially Fox's velocity is not increasing but after sometimes it increases and win the race.

S24_C1: No, sir. They have not started at the same time. Fox started 6 minutes later. And wins the race.

S30_C1: Sir, can I add something?

T1: of course.

S30_C1: they met when the distance is 1200 m.

S11_C1: Here all graphs are linear, so the animals are travelled in uniform velocity.

The teacher applied such kind of approach to increase students' thinking ability as well as to develop clear concept about the topic. He claimed:

> *A student gives his idea about a topic or issue, whether the idea is correct or not, whether it is clear or not, if he throws it in the classroom among all the students, then everyone thinks about it and express their idea. [...] then the idea about the issue becomes clear. By knowing the ideas from others, he clearly understood where his lacking was, where to connect, what to do and the right thing came out. That is why idea sharing is very important in teaching learning activities.*

It is observed that T1 gave importance on students' active engagement during collaboration (*Std_Role-1*). While students worked in a group, teacher frequently monitored each group and observed whether all the group members were actively participating in the discussions or not. He claimed, "every member of the group must have to work. Their active participation is very important". In addition, the teacher did group work in some classes and emphasized on peer discussion very often. More specifically, he often asked students to come in front of the class and to discuss with peer what has been displayed on the screen (Figure 4.8). According to T1, these techniques were very effective as students enjoyed to solve problems by discussing with their peers. Moreover, use of ICT tool made the environment more interesting. He argued:

> *I let them work through discussion with their peer. And they were very lively, cheerful and they could solve problems by discussing. And here we have used some ICT tools to make their learning enjoyable and also to make them understand the lesson in an interesting way.*

Students also shows their positive thought regarding solving problems discussing with their peers during the FDG. One of the students claimed:

> *When sir (the teacher) let us to discuss a problem with our friend, we worked on that problem together and developed our thinking. I enjoyed to do a task discussing with my friends, I feel more comfortable. I think, we can learn better by helping each other. (S4_C1)*

Figure 4.8: Students involve in peer discussion

Another student argued:

> *Everyone does not think in the same way. I may know one rule to solve a problem, my friend may know another rule. Another may think another way to solve. So when we do that problem all together, we can enhance our knowledge by getting opinion from each other. (S1_C1)*

These quotes in fact support the argument that while students engage in collaboration (i.e., whole class discussion, group work etc.), they develop their conceptual understanding, increase their thinking ability (reflection of AR) and enhance the capacity to learn with cooperation (reflection of PD).

It is observed that teacher provided variety of problems (see Appendix G, Appendix H) sequencing from easier to harder. According to the teacher, it is important to set diversified problems in the worksheet so that student can attempt to solve the problem by proper logic rather than rote memorization. He stated:

> *[…] I usually set problems from easy to hard and diverse. I think, this process helps*

them (students) to connect their understanding and grasp concept clearly. There are many problems students can give based on guesswork, that kind of problem was not there. In solving the problem, he has to be logical, they have to think- for what reason or for what purpose such problem was inserted there. For their different dimensional thinking, increase their capacity to solve a problem quickly and skillfully in different ways, these problems were provided in this way.

This statement indicates that providing variety of diverse tasks, not only make the concepts clear to the students but also increase their reasoning skills and procedural fluency.

The analysis also revealed that T1 sometimes provided unfamiliar and non-routine task to the students. According to the teacher, he offered such kind of tasks so that students could prepare themselves ready for any unfamiliar situation. The teacher stated:

[...] *different kinds of problems may come suddenly and they (students) have to adapt to different environment. So, I tried to prepare them (students) for that, um.. no matter what kind of problem comes, they can solve it. um.. those type of problems were set which they did not experience directly before.*

T1 was also found to throw challenges to the students sometimes. For instance, in 3rd class, students were directly operating the computer by their own and working with GeoGebra software to explore how the graph of linear function y=mx+c would form for different values of slope 'm' and y-intercept 'c'. To explore these, students moved the slider in GeoGebra and tried to understand how the different form of linear graphs occur for distinct values of m and c. According to the teacher, in that way students faced different sorts of challenges as well as overcome these challenges and deepen their conceptual understanding with the help of ICT. While students performed this task by group discussions, T1 asked them to try to draw a line which is parallel to the line y=2x+5. It was a big challenge for the students as they did not know what would be the algebraic form of the parallel line of the equation y=2x+5. However, though the task was really challenging, the ICT tool makes the challenges quite easier as students explored these issues by moving the slider (Figure 4.9).

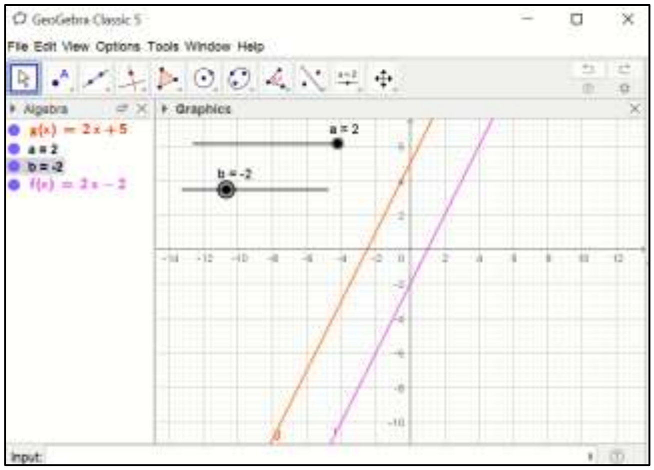


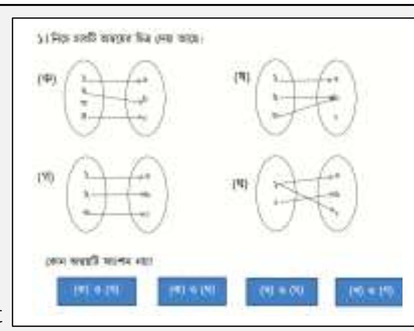
Figure 4.9: Exploring parallel line using slider of GeoGebra

During the post-lesson interview, the teacher argued:

> *[…] it was very challenging because to draw a parallel straight line, they have to have an idea of how to draw a parallel line of a straight line. These were really challenging but they were able to solve them through ICT tool. […] They can see what happens if the slope is different, if the slope is same. They saw two parallel lines in the same place, then challenges became much easier to them.*

The analysis shows that in every class T1 asked students to talk about the reason behind their answer. It seems that teacher was not only concerned about right or wrong answer, he always tried to understand what was the reason behind the students' thought. He often asked students to justify their answer. A sample of classroom situation regarding this issue is given below.

T1: S23_C1, stand up. Tell us about 2nd diagram.
S23_C1: it is a function.
T1: why?
S23_C1: for every input there are exactly one output.
T1: look at 'c', is it associated with any input?
S23_C1: no sir.
T1: then, still, is it a function?
S23_C1: yes sir, to be a function each input must be associated with exactly one output. Here 'c' is not input and every input has one output. So it is a function.



It is observed that the teacher tried to create the ability of reasoning skills within the students. Besides, he encouraged students to speak in mathematical language. He stated:

> *[…] when a student delivers a correct result it does not mean that he understands the problem properly. So, it is very important to know how he solves the problem, why he does in that way, need to understand the logic behind his work. [...] In fact, mathematics is everywhere, we can express everything through mathematics. Thus, if we can take that thing into mathematical language, then students could find mathematics in everything and connect math with their life. This is why, knowing mathematical language is very important.*

These statements indicate that offering challenging tasks and providing scope to use mathematical language helps students to connect mathematics with their real-life context (reflection of CU) and also providing opportunity to explain their (students) ideas with logic help them to enhance their adaptive reasoning skills.

Theme 4: Offering multi-channel feedback

Our analysis shows that students get multi-channel feedback during their learning. It is observed that teacher was prompt in instant and timely feedback. During providing feedback by himself, T1 did not specifically mention *right* or *wrong* for the students' response rather he assisted the students to reflect on their own learning. Moreover, he established a dialogue with the students to move their learning and provided clear and actionable steps to facilitate to the correct path. According to T1, providing feedback in this way would help students to make their understanding strong (i.e., develop CU) by thinking logically (reflection of AR) and creating them responsive and constructive (reflection of PD). He stated that:

> *[…] when I give feedback to my students, I try to give clear feedback so that they are not confused. I try to expose their wrong idea or mistakes by conversation. I think when students identify their mistakes in this way, their understanding become more concrete. They usually did not do the same mistakes further. […] um.. I always try to give timely feedback so that students can hold their attention and become productive.*

My analysis shows that students not only got feedback from their teacher but also from their peers, ICT tools and their own. In Almost every class, T1 engaged students in peer feedback (*Std_Role-3*). For instance, while completing a task by a student, teacher often invited another student to provide his opinion whether his peer's performed task was right or wrong and asked to explain the reason behind his thought. A small sample of such type of classroom situation is shown below.

> **T1:** S7_C1, tell us S11_C1's answer is correct or not?
>
> **S7_C1:** No sir. I think S11_C1 is partially correct. The 4th diagram is also not a function. So the correct option will be this one.
>
> **T1:** Explain us, why.
>
> **S7_C1:** To be a function, every input must have exactly one output. But here, one input has two output i.e 'a' and 'c', which is not true for function.

According to T1, peer feedback is very effective. He stated:

> *[…] current modern teaching is not teacher-dependent, it is student-dependent, our job is to assist them, to cooperate, not to tell them the correct answer rather bring out the answers from them. […] different students think differently, one students may think this way is right, another student may think that if it can go that way then the rule is correct. That's why, I tried to give feedback through students so that students can get clear idea about the content. […] As a result of this, students' leading capacity is increasing, his range of knowledge is increasing. And by sharing their understanding what is right and what is wrong and they are able to take decisions by coordinating their understanding.*

This statement highlighted that T1 performed as a facilitator rather than instructor and created the environment so that students get feedback from their peer. His intention was to develop students' conceptual understanding as well as enhance leading capacity (reflection of PD).

In the focus group discussions, students also expressed their positive view about peer feedback. One of the students argued:

> *When our teacher told us to say what is right or wrong of our friend's work, we thought and tried to identify what mistakes he has done, I believe it insisted us to think more and getting opinion from our friends were really interesting. (S3_C1)*

The analysis also reveals that both the teacher and students considered students' self-reflection is vital for concrete learning (*Std_Role-4*). According to the teacher, when students provided feedback on their own work, he/ she may identify or add his/ her new thought. T1 stated:

> *I think it is important that students give feedback to themselves. Then they can find out their gaps by their own. When students try to give feedback of their own work, they may add some new things, can often find out their mistakes.*

During the FGD, one of the students claimed:

> *I think a man's greatest teacher is that man himself. So when we sit and think by ourselves, no one knows whether I can do the math or not. […] At home, when I think about what our sir (the teacher) taught us in the class, sometimes I get confused, maybe I did not concentrate fully in the class, but when I look at my (classwork) notebook and try to think why the teacher did that and then I think, I actually understand the meaning of the problem. (S6_C1)*

It is also observed that students got feedback from ICT tools (*ICT_Role- 4*). For instance, after drawing graph of a linear function manually in the graph paper, student checked whether the graph was correct or not by plotting the graph by GeoGebra software. The teacher suggested them to cross check students' written work with the help of ICT tools. According to T1, as ICT tool provides them the result with maximum accuracy, they can get proper feedback from the ICT tool. Moreover, this sorts of activity enhance their capacity to do a task in multiple ways. He argued:

> *[…] It is important because ICT tool provides accurate result and also students can do the same problem in different ways. That is why this method has been adopted to increase the ability to solve a problem differently.*

During the FGD, one of the students stated:

> *I am using many options of that software by myself. Given many more values, see how the output comes out. I have created interest on my own. No one told me. I developed my own interest and learned the work of this option. This is the work of that option. (S1_C1)*

This means that ICT provides the scope for the student to select many options and helps to decide the correct one by providing feedback. It eventually develops students' strategic competence and procedural fluency.

Theme 5: Offering Opportunities to Identify Error/ imprecision

It is seen that teacher tried to explore where students have misconception or where students might be having misconception. While discussing the graph of linear function, teacher came up with an example with the assistance of ICT tool (GeoGebra) where students may have misconception and tried to make the concept clear. Teacher intentionally set the value of m and c equal to zero in the general form of linear equation y=mx+c and asked students to tell about the equation and its graph. He stated:

> *[…] what would the graph look like if 'm' and 'c' suddenly became zero. They probably always had the idea of those graphs which intersecting both axes. Suddenly seeing that there is only one variable y=0. Then, what is the equation mean and what is the equation of x=0, these type of challenges arose, they were successful and slowly they understood it using ICT tools.*

The analysis also shows that to understand whether students' concept about function is clear or not, T1 emphasized on counter example. For instance, T1 asked students to say an example which is not a function. He argued, "*when they know what is a function and what is not a function, then their idea will be correct and they will understand everything*."

In addition, T1 sometimes confused students by saying wrong answer to realize whether students respond with proper thinking or not. He expressed:

> *I misguided them by taking a correct answer in the wrong direction and then see whether they understand, or giving a guess answer. Everyone was enthusiastic, engaged. Means there was no opportunity to be careless. […] And the answer I gave intentionally was not the correct answer, but they were able to identify that the answer was wrong.*

Identifying mistakes has been found as another pedagogical approach applied in the classroom. In most of the cases, mistakes done by the students were not identified by the teacher, rather teacher focused on whether students could identify by themselves or by their peers. For instance, teacher often asked students to find where his friend made mistakes. In addition, teacher expressed that ICT tools helped students to point out the mistakes done by themselves. He stated:

> *I always tried to find the mistakes of one student's work by the other students. I think it will help both students. And of course I think ICT helps to identify the mistakes as well. Um.. because, for example when a graph is shown through ICT tools, they can check whether the function intersects at multiple points by drawing a vertical line over the function, and can say that it is function or not a function. They can realize their mistake.*

These quotes reflect that teacher applied different strategies (e.g., identify mistakes, providing counter example etc.) to develop students' mathematical concepts.

Theme 6: Engaging students through motivation

According to the teacher, students must have to be engaged into the lesson willingly, otherwise the teaching-learning will not be effective (*Std_Role-3*). Our analysis shows that the teacher took several initiatives to motivate students and engaged them actively into the lesson. For instance, if a student performed a task perfectly, the teacher praised him verbally and clap for him along with the whole class. Teacher stated:

> *Students need to be kept active, active because if the learning process is enjoyable then the complex subject seems easy to them. Therefore, teaching and learning through encouragement is done through appreciation or clapping.*

Besides, sometime attractive picturerelated to the topic (Figure 4.10) have been shown to hold the attention of the students and make the class interesting.

Figure 4.10: Using real-life oriented attractive picture

During the FGD, one of the students, S8_C1argued:

> *Teacher shows us Pizza menu chart. Teacher uses here ICT, which make the picture more attractive. I think it motivates us to learn*" (ICT_Role-5).

It is also observed that teacher always value students' opinion. If students answered incorrectly in response to a question, teacher never criticized him, rather he valued the student's opinion and scaffold students to think in correct path. Finally, the teacher provides the concrete conclusion from the discussions/opinion of students. He stated:

> *If I said, your answer is correct or wrong, the competitive spirit among the students will be reduced. And their thinking capacity decreases. And when the correct answer is not given, they start thinking differently. So, I adopted this approach for holding their attention. […] We always have to be positive. The point is that a student can't be told outright that you didn't do it. Because every student has a reason behind what they say. That's why I never neglect each of the student's opinion. […] I think; each student can improve by himself. And he can concentrate on the lesson with interest and he is not demotivated. […] I always listen what they say and absorb their ideas and finally took their ideas directly or indirectly I gave the gist that it is like this the correct answer will be like this.*

Since the teacher applied all the above discussed pedagogical approaches in the ICT-facilitated TL environment, he performed different kinds of instrumental orchestrations to effectively apply those approaches which are discussed in the subsequent section.

4.1.2.3 Performed Instrumental Orchestration

In an ICT-facilitated environment, the above mentioned pedagogical approaches were applied by the teacher with different sorts of instrumental orchestrations. It is observed that throughout the six classes, the teacher performed different types of instrumental orchestration. Almost in every class, T1 used both the multimedia projector and the white board. Teacher often used the projection screen and the white board at the same time to connect the ICT environment and non-ICT environment (link-screen-board). It is observed

Figure 4.11: Link-screen- board orchestration

that while teacher performing link-screen board orchestration, students listened and observed the teacher's explanation and instruction very attentively. According to T1 link-screen-board is necessary as our education system is not fully online based and if we used different modes for teaching-learning process, learning becomes more effective since it helps to hold students' attention. He stated:

> *In our examination system, we are totally dependent on paper and pen for students' assessment. Besides I think, mathematics is a subject that can never be understood without hands-on- activity. Again, when we adopt the same one-sided approach for every work, then sometimes it seems boring. So, what to do? We have to use ICT*

tools and learn hands-on with them. Different participatory methods should also be considered through use of ICT tools or not. Then the student is always attentive.

During the FDG, one of the students also talked about the importance of linking screen to other setting. He claimed:

If we only learn digitally, we won't learn how to actually do this in analog setting. In computer, just we give the input and the image comes out. But if we are not supposed to write in the paper how to draw, many of us will not be able to do it. (S2_C1)

It is also seen that before starting to work with GeoGebra, T1 discussed about the software specifically its necessity for learning (Discuss-tech-without-it). T1 stated:

Since a new idea has come up, I have given them the idea about it in advance that it is interesting and very easy method, so that they do not hesitate about this, so that they do not panic and so that they can easily accept it. That is why they are given the idea about these ICT tools.

Besides, T1 did not allow students to work with ICT tools (GeoGebra) without any prior direction though students have access to GeoGebra software. Moreover, he demonstrated how to operate the ICT tools such as spread sheet, GeoGebra software (Technical-demo). According to him, it is necessary as "*without proper direction, student may become confused since this tool is totally new for them*". In the similar manner during the FGD, one of the students claimed:

[…] to use it, we must have knowledge about it. So, when the teacher first explains it to us, we will be clear about how to use it. Then we can use it better and do something new. (S5_C1)

It is observed that after showing image of a problem on the projection screen, in most of the classes teacher invited students to come in front of the classroom and asked to explain about their ideas about the projected image (Discuss-the- screen). For instance, in the 3rd

class, T1 displayed different graphs on the screen and welcomed students to identify the graphs of linear function (Figure-4.12) and explained the reasons behind them. The teacher also encouraged others to raise questions, arguments and came up with different thoughts. According to the teacher, such types of collaboration help students to build their idea stronger. T1 stated:

> *[…] They are able to quickly draw pictures through ICT tools and they got a clear idea. […] they are able to think multi-dimensionally. […] I engaged them by asking various questions from what they see on the screen and in this case, the students were lively as our ICT tools brought the complex activities into simple activities and such complex problems that they only can express verbally, can visualize due to ICT tools.*

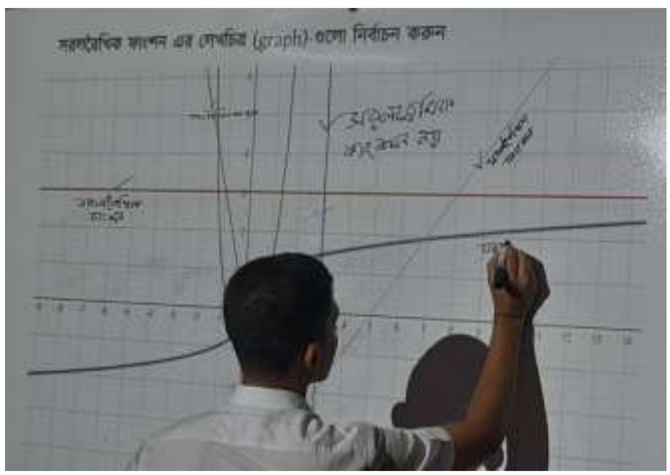


Figure 4.12: Discuss-the- screen orchestration

The analysis shows that at the third class T1 instructed the students how to change the value of the slope and y-intercept by moving slider of the GeoGebra and showed them on the projection screen and explain the different graphs created for those changes. Then teacher asked students to work with GeoGebra in a small group and develop as well as verify their understanding (Guide-and-explain). It is also observed that while students worked with GeoGebra, the teacher was ready to provide them technical supports such as, students of a group couldn't move mouse properly due to technical issue, T1 came to sort out that problem. Besides, sometimes students felt uncomfortable to move the slider in the

GeoGebra, T1 solved this issue as well (Technical-support). T1 stated:

> *[...] I was monitoring them to see if they were having any problems or not. [...] If I will not support them, they may be stuck and may not be interested for further learning.*

In day-6, T1 provided worksheet to all students and invited a student to present his work with the help of GeoGebra. The student worked as a Sherpa; operated the ICT tool and tried to explain his work with justification (Figure 4.13). He opened the floor to ask questions to the Sherpa and get involved in discussions (Sherpa-at-work).

Figure 4.13: Sherpa student operated laptop and explain; another student arguing his opinion.

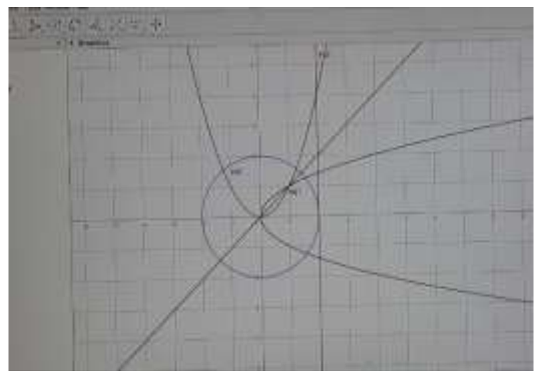


Figure 4.14: Graphical presentation of different math expression using GeoGebra

After completing a lesson, in most of the classes, T1 provided the students with some tasks related to the lessons and asked them to perform. T1 moved inside the classroom and watched what the students were doing and provided them feedback verbally and sometimes used the board to explain if students faced difficulties to do the task (Work- and- walk-by). In the first class, initially to introduce the basic concepts about a function, T1 used familiar examples and white board to explain the concepts rather than using the ICT tools (Not-use-tech). It is observed that while he was conducting class with the assistance of GeoGebra, students sometimes asked few technical questions and teacher answered the question by showing the operation on the screen (Monitor-and-guide). For instance, in day-2, while teacher showed different graphs of function using GeoGebra, students asked for drawing the graph of circle and also arose questions what will happen if they try to draw a graph of a function whose power is 100. T1 answered all their queries and showed the graph on the screen (Figure 4.14). According to him such an ICT-facilitated teaching environment helps to fulfill students' queries easily, build their trust and make the learning satisfactory. He stated:

> *[…] when I drew those graphs with the help of GeoGebra, they were very excited,it was quite impossible to show them in traditional teaching, I mean using marker and board.*

By analyzing the data elaborately, it is found that T1 tried to conduct the classes interactively by involving students in different types of collaborative activities. It is found that the teacher's intention was to build students' strong mathematical concept with proper reasoning skill. Besides, he created the environment as such that students can solve a problem fluently and with different strategies. In addition, his another intention was to making the class interesting and motivating. It is found that the use of ICT helps him to successfully execute his plans. The analysis found some specific roles of ICTs (Table 4.3) and highlighted some explicit roles of students (Table 4.4) during the whole orchestration process.

Table 4.3: Role of ICTs

ICT_Role-1	Help to visualize the real meaning of math
ICT_Role-2	Helps to deal with problem with minimum error
ICT_Role-3	Encourage collaboration
ICT_Role-4	Provide instant feedback
ICT_Role-5	Add fun factor in learning and motivate
ICT_Role-6	Make the learning sustainable
ICT_Role-7	Prepare students for the future
ICT_Role-8	Time saver
ICT_Role-9	Make the complex topic easier

Table 4.4: Role of students

Std_Role-1	Engage actively in collaboration
Std_Role-2	Work willingly /directly with ICT
Std_Role-3	Provide peer feedback
Std_Role-4	Identify own mistakes/ self-reflection
Std_Role-5	Engage lesson willingly
Std_Role-6	Attentively follow teacher's instructions

4.1.3 Understanding students' level of mathematical proficiency (MP)

4.1.3.1 Students' baseline understanding of MP

To measure students' baseline understanding about MP, a paper-pencil test and survey question were administered. The analysis in Table 4.5 shows the mean score of all the five strands of MP before the intervention. All the strands were scored ranging from 1 to 10 except the productive disposition. The scoring range of productive disposition was 1 to 5. The scoring range of all stands of MP were measured by comparing with the standardized scoring range proposed by Lerís et al. (2017) and Diknas (2008) (discussed in section 3.4.3.1 of chapter-3). It is observed from the analysis that the mean score of the two strands, conceptual understanding and strategic competence are very low having a value of 2.07 and 2.40 respectively, whereas the mean score for adaptive reasoning is at a moderate level.

Table 4.5: Descriptive statistics of the strands of MP

Conceptual Understanding		Procedural Fluency		Adaptive Reasoning		Strategic Competence		Productive Disposition	
Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2.07	1.26	5.63	2.67	3.63	2.48	2.40	1.61	3.82	0.38

Score range from 1 to 10 (Conceptual Understanding to Strategic Competence)

Score range from 1 to 5 (Productive Disposition)

The mean score is 3.63. Again, the proficiency level for procedural fluency seemed good as the mean score is 5.63. On the other hand, students' productive disposition seems higher as the mean score is 3.82 (since, mean score lies between the 3.41 and 4.20) which represent that students show their positive view regarding mathematics.

The seven distinct indicators of productive disposition analyze rigorously to see which factor(s) influences highly the overall productive disposition. Figure 4.16 shows that all most every indicator for productive disposition (except the indicator *confidence*) has a higher mean score i.e., more than 3.4 which means students' positive agreement about most of the items of the survey. It is observed that students showed their strong positive agreement (mean score >4.2) about the usefulness and worthwhileness of mathematics. It is also revealed that among all the indicators, *confidence* indicator has the lowest mean score (i.e. 3.27). That means, students have the lower confidence about their math ability

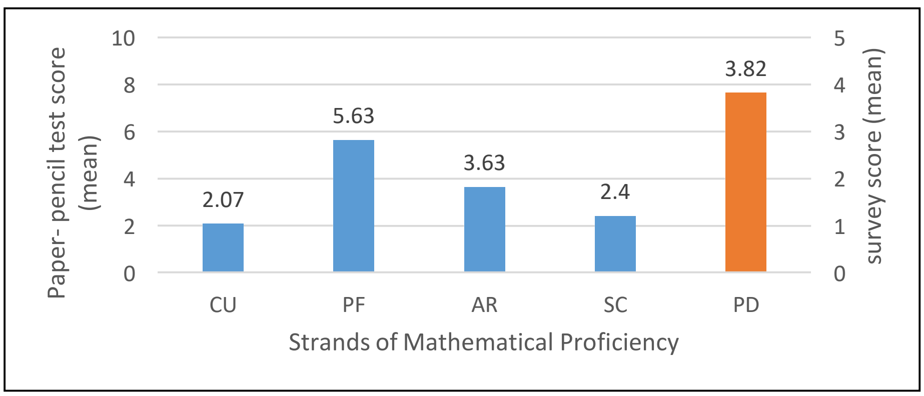
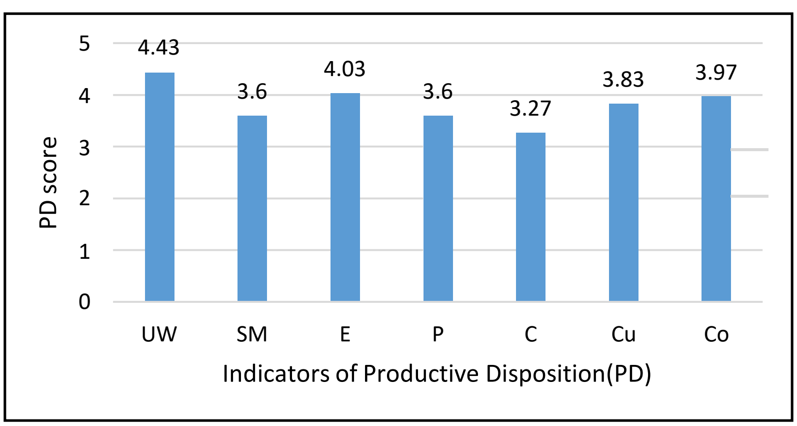


Figure 4.15: Mean scores of each strand of MP before intervention



UW: Useful and Worthwhile

SM: Sense-Making Endeavor

E: Enthusiasm

P: Persistence

C: Confidence

Cu: Curiosity

Co: Co-operation

Figure 4.16: Mean scores for each indicator of productive disposition before intervention

skill compared to the other indicators. It is observed that the mean scores of sense-making endeavor and persistence are alike (3.6) and the rest of the indicators' mean scores are almost same (about 4). A detail descriptive statistics including mean, median and standard deviation has given in Appendix N (Case-I).

Thus, my analysis based on the survey data and paper-pencil test data reveals that students' mathematical proficiency was not so noticeable prior to the intervention. It is also found that students' habitual inclination about mathematics (i.e. PD) was good and they were skilled to apply math procedure (i.e. PF) whereas their ability to connect the mathematical concepts in a new situation (i.e. CU), represent and solve problems in variety of ways (i.e. SC) and explain the idea with proper justification (i.e. AR) were very low.

4.1.3.2 Students' mathematical proficiency after intervention

After completing the intervention that is experiencing six classes in ICT-facilitated environment, students' mathematical proficiency was again measured by both the paper-pencil test and survey. The mean scores of all components of the MP after the intervention

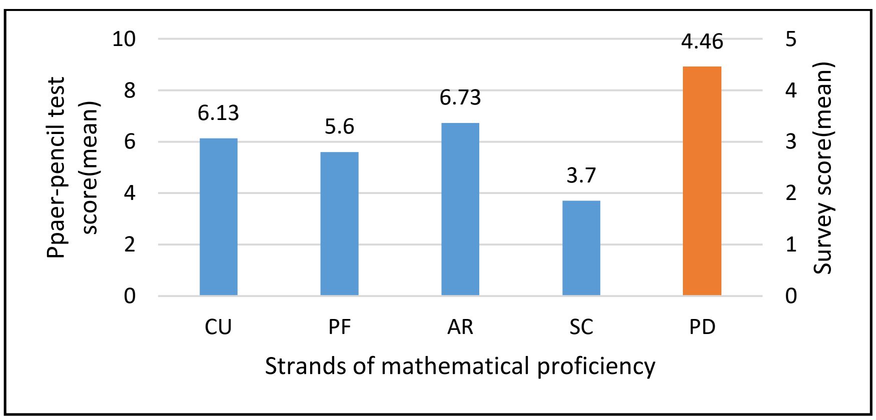


Figure 4.17: Mean scores of each strand of MP after the intervention

is shown in the Figure 4.17. It is depicted from the figure that all the four mathematical proficiency strands CU, PF, AR and SC show good mean score except the strategic competence (SC) score. The mean score of strategic competence is 3.7 (SD 2.37) which belongs in the moderate level of proficiency. It is seen form the figure that the highest mean score for the strands of MP is adaptive reasoning(AR), which is 6.73 (SD 2.27) whereas the other two strands conceptual fluency and procedural fluency are lowered by 0.6 and 1.13 respectively. On the other hand, the overall productive disposition mean score is 4.46 (SD 0.34) which reflects that the students considered to have high productive disposition on mathematics.

To compare the pre and post test scores, *Shapiro-Wilk test of normality* was conducted to determine whether the data come from paper-pencil test (before and after intervention) was normally distributed or not. The results indicated that data (before & after intervention) for conceptual understanding, procedural fluency, adaptive reasoning and strategic competence were normally distributed (as ***p*** value of each component is greater than 0.05, see Appendix L(a)). Thus, a paired sample t-test was conducted to measure whether there was any change in students' conceptual understanding, procedural fluency, reasoning skill and strategic competencies after participating in the experimental six classes.

The data in Table 4.6 are used to find out whether there is difference between the students' scores from the pre-test and post-test of the paper-pencil test. It is observed that there is significant change (as $p<0.05$) in the mean scores of the pre-test and post-test for all components excepts for the procedural fluency. This means that students' ability of math conceptual understanding, reasoning skill and ability to solve math in multiples ways have increased after attending the six experimental classes.

Table 4.6: Comparative statistics of CU, PF, AR and SC

Four strands of MP	Test	Mean	Std. Deviation	Mean Difference	t-value	p-value
Conceptual Understanding	Pre test	2.07	1.26	-4.06	-9.80	<.001
	Post test	6.13	1.99			
Procedural Fluency	Pre test	5.63	2.67	0.03	0.11	.915
	Post test	5.60	2.69			
Adaptive Reasoning	Pre test	3.63	2.48	-3.10	-5.94	<.001
	Post test	6.73	2.27			
Strategic Competence	Pre test	2.4	1.61	-1.30	-3.01	.005
	Post test	3.7	2.37			

Figure 4.18 clearly shows that students' conceptual understanding about mathematics (i.e. *ability to connect math in new situation* and *represent math in various ways*) is increased to a large extent. It is found that before the intervention, students' mean score of conceptual understanding was 2.07 and after the intervention it increased by 4.06. On the other hand, mean score of procedural fluency was almost same (in pre-test 5.63 and post-test 5.60).

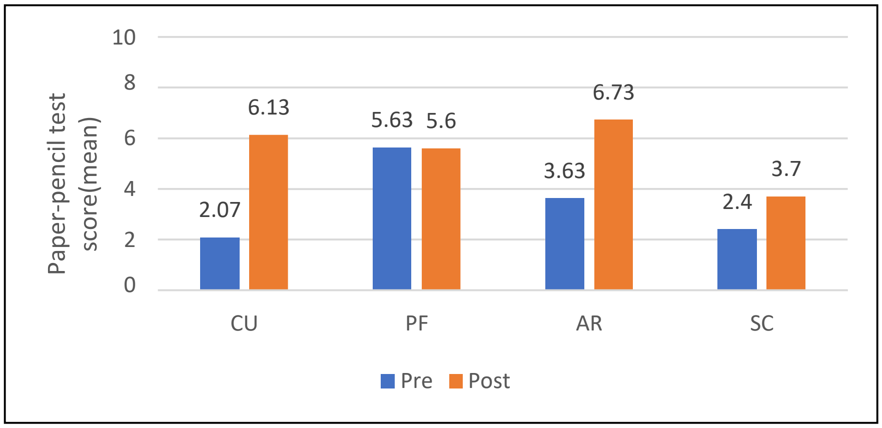


Figure 4.18: Mean MP score of four strands before and after intervention

The other two components adaptive reasoning (i.e. *ability to estimate the answer with proper justification* and *ability to draw conclusion*) and strategic competence (i.e. *ability to formulate, represent and solve math in multiple strategies*) also improved after the experimental classes. Before the intervention the mean score for adaptive reasoning and strategic competence were 3.63 and 2.4 respectively, whereas after the intervention they increased and reached at 6.73 and 3.70 respectively.

In order to evaluate if there is any change in the productive disposition (PD) of students as a result of participating in a ICT-facilitated teaching-learning environment, a Wilcoxon Signed Rank Test was done as the data collected form survey were ordinal and not normally distributed (see Appendix M(a)). It is found from Table 4.7 that all the factors of productive disposition increase after the intervention. A statistically significant positive change is found for all the factors of the PD except the factor useful & worthwhile (as z=-0.655 and p=.513>0.05).

My analysis (Table 4.7) shows that the productive disposition scores for the indicator “*sense-making endeavor*” were significantly higher after the intervention (Md=4.5, n=30) compared to before (Md=3.67, n=30), z=-3.605, p<.001 with a moderate effect size r=-0.465 (for details see Appendix N(a) & Appendix O(b)). It represents that after the intervention, students’ belief about “*having a solid knowledge of mathematics helps them to understand more complex topics in their field”* moderately strong. Besides, they can make sense of what they do in math more clearly. In addition, their thought about “*making mistakes are necessary to be good at Mathematics*” become moderately strong. The analysis also reveals that students have positive agreement (as the median is >3.5) about *enthusiasm, confidence, persistence, curiosity* and *cooperation* factors. However, in the post-test, those scores increased. A Wilcoxon Signed Rank test reveals a statistically significant improvement in students’ *persistence* (z=-4.23, p<0.001) and *confidence* (z=-4.48, P<0.001) after the experimental classes with a large effect size (r>0.5, see Appendix O(a) for details). The median score on the *persistence* increased from pre-test (Md=3.67)

Table 4.7: Comparative statistics for the factors of PD

Factors of PD	Test	N	Mean	Median	z-value	p-value
Useful & worthwhile	Pre test	30	4.43	5.00	-0.655	.513
	Post test	30	4.46	5.00		
Sense-making endeavor	Pre test	30	3.60	3.67	-3.605	<.001
	Post test	30	4.35	4.50		
Enthusiasm	Pre test	30	4.03	4.00	-2.465	.023
	Post test	30	4.57	5.00		
Persistence	Pre test	30	3.60	3.67	-4.226	<.001
	Post test	30	4.38	4.33		
Confidence	Pre test	30	3.27	3.50	-4.481	<.001
	Post test	30	4.35	4.50		
Curiosity	Pre test	30	3.83	4.00	-3.143	.002
	Post test	30	4.53	5.00		
Cooperation	Pre test	30	3.97	4.00	-2.753	.006
	Post test	30	4.57	5.00		

to post-test (Md=4.33) whereas the median score on *confidence* increased from pre-test (Md=3.5) to post-test (Md=4.5). This means that students feel strong confident on their ability of mathematics to help their peers and to try to solve problems in different ways. Besides, increase of median score on the persistence means that their belief about "*anyone can learn mathematics if appropriate effort is given*" becomes stronger. In addition, their positive agreement reveals that they can keep more attention whenever they do math and they do not stop to work on math problem even they struggle with that problem. On the other hand, Wilcoxon Signed Rank test shows that *enthusiasm (*z=-2.465, p=0.023*)*, curiosity (z=-3.143, p=.002) and cooperation (z=-2.753, p=.006) increased significantly after the intervention with a moderate effect size (as r>.3, see Appendix O(a) for details). Increase of scores in the post-test for enthusiasm, curiosity and cooperation means that students are more interested on mathematics, more curious to know the real-life oriented math problems and how to solve them. Besides, their eagerness to share mathematical ideas and solve problems by discussing with their peers has increased.

Figure 4.19 shows the comparative mean score of paper-pencil test and survey data for both the pre and post-test. It is seen from the figure that students' ability of conceptual understanding, adaptive reasoning skill, skill of strategic competence and productive disposition increase to a large extent after the intervention. On the contrary, the figure shows that students' ability to perform the procedure fluently is almost same after performing six experimental classes.

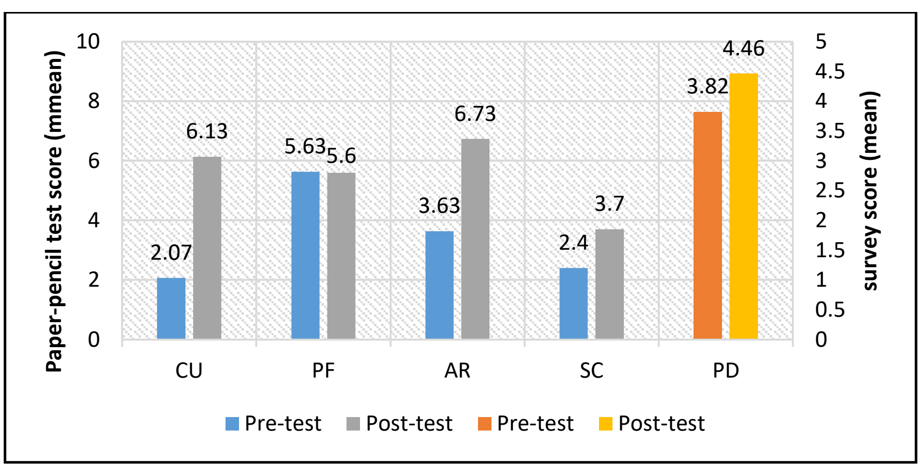
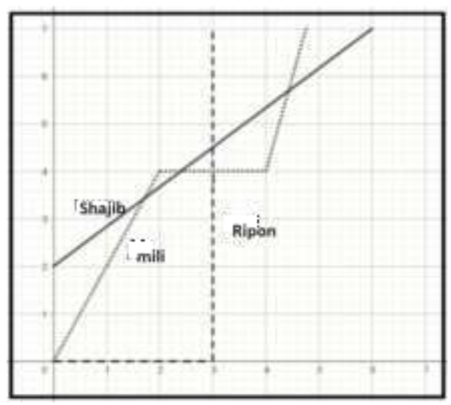


Figure 4.19: Students' mathematical proficiency before and after intervention

4.1.3.3 Understanding student's development of MP through FGD

Students responses from FGD also reflect their development of mathematical proficiency. During the FGD, I provided them a contextual problem on the topic 'function' and asked them to answer on some specific questions by discussing with each other. Their responses showed that they have very strong conceptual understanding about the provided topic. They can explain the reason behind their answer with proper justification. They can think to solve the problem in multiple ways and can plot the graph perfectly and fluently. The question which I asked during the FGD and their responses (transcribed) are given below.

Mili and Shajib started from their home to train station at the same time and Ripon started 3 minutes later. The relation between the distance vs time of their travels are shown in the following graph.



1. Explain Mili's journey.
2. Who reached first? How do you understand that?
3. Who travelled the fasted at the beginning? How do you understand that? Can you explain it any other ways?
4. Whose house was the closest from the station? How do you understand that?
5. Do all graphs in the diagram represent graphs of function? Can you explain them connecting with real world situation?
6. Mili's brother Dipu started to travel for station 1 minute later of Mili started. After 4-meter distance, he met with Mili and Shajib. If he reached the station directly (without stopping anywhere), what will be the graph of his journey?

R: Can you talk about Mili's Journey? Here x-axis is in time(Minute) and y-axis is in distance(meter).

S1_C1: Mili moves from a stationary position to 4 meters in 2 minutes with uniform velocity. Then there is no change at 4 meters for 2 minutes. That means she was not in motion for 2 minutes. After that she went again with uniform velocity from 4 m to 7 m.

Reflect CU

R: Why uniform velocity, not acceleration?

S1_C1: here the line is straight, if the motion is accelerated, then the graph should be in curve form.

R: any other opinion?

S2_C1: I think; it is acceleration as the curve is increasing.

S3_C1: No, I think S1 is right. If it is acceleration, then velocity would change with time. But here distance is changing with time it is uniform.

S2_C1: Oh, yes. I did not notice that. It should be uniform velocity.

R: can you think of this in other way? Such as linking with slope?

S4_C1: yes, here for first 2 minutes the value of slope is same. And also the slope is positive.

Ability to explain with logic (Reflect AR)

R: why you say, the slope is positive?

S4_C1: As the line creates acute angle with the x-axis.

R: okay, if the slope is negative, then we cannot say that uniform velocity, right?

S5_C1: No mam, it could be uniform velocity but in that case she is not going forward, she must be gone backward from her position.

Ability to explain with logic (Reflect AR)

R: any other opinion?

(all showed their negative response by nodding)

R: Okay, now what do you think for second question?

S1_C1: Ripon

S2_C1: Yes, Ripon

S3_C1: Of course Ripon

R: Do, all have the same opinion?

(all showed their positive response by nodding)

R: okay, now we move to the question 5, what do you think?

S5_C1: here these two lines (solid line and dotted line) are graph of function. Graph for Ripon is not function.

R: why?

S5_C1: because, here the slope is undefined.

R: why undefined?

S5_C1: since the angle is 90^o here and slope means $\tan 90^o$ here, which is undefined.

Ability to explain with logic and draw conclusion (Reflect AR)

S6_C1: yes, in another way, if we use vertical line test, it fails that is the vertical line will cut the line in infinite points. So, for one input, we get many output, which is impossible for function.

Ability to apply multiple strategies (Reflect SC)

R: Okay, all you give your opinion using mathematical term, concepts. Is it possible to explain it with real-life phenomena?

S1_C1: No, it's not possible. If it has to do in reality, we have to fixed the time, which is impossible.

R: Okay, do you now want to change your answer for question no. 2?

S3_C1: Yes, it should be Mili.

S4_C1: Yes, Mili.

R: Why not Sajib?

S4_C1: since Sojib takes 6 minutes to reach at 7 meter while Mili takes less than 5 minutes.

[Ability to connect math concept in real-life (Reflect CU)]

(all showed their positive response by nodding)

R: Now, think about question no. 3.

S2_C1: initially, Mili was traveling fastest.

S3_C1: No, it's Sajib. No no it is Mili.

R: why?

S3_C1: Here the slope of Mili's graph is more than the slope of Sojib's graph.

S5_C1: In 1 minute Mili went 2 meter, where as in 1 minute Sajib went less than 1 meter.

[Ability to apply multiple strategies (Reflect SC)]

So Mili must be fastest.

R: any other opinion or explanation?

(all showed their negative response by nodding)

R: okay, can you draw the graph for question no. 6?

S3_C1: yes.

R: please draw the graph in this paper.

S3_C1: Here it is.

(S3_C1 plot the graph by discussing with his peers)

R: Could you please explain a bit about it?

S3_C1: Dipu started to move after 1 min of Mili, so his starting time was at 1 minute. He met with Mili and Sajib at 2.2, no no 2.4 minutes. Since, Dipu never stopped and finally reached at the station, so he was moving onward, thus the slope should be positive and we consider here Dipu went in uniform velocity, so the graph will be straight line (Figure 4.20)

[Ability to do the procedure correctly (Reflect PF)]

R: you told that you consider Dipu's velocity is uniform. Why?

S3_C1: Since in the question it is not clear.

R: so, it may be non-uniform? If it is non-uniform, then what should the graph be?

S4_C1: curve form not straight line.

[Ability to explain with logic and draw conclusion (Reflect AR)]

R: Thank you all.

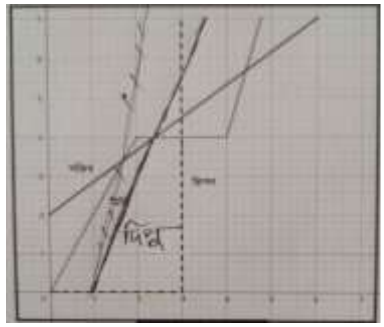


Figure 4.20: Performed task during FGD

By analyzing data collected from paper-pencil test, it is found that students' procedural fluency did not increase after participating the classes whereas it was observed from the classes and also from the FGD data that students developed their fluency in mathematics very well. In the classroom, while the teacher asked them to work on a task selecting appropriate procedure, most of the students were found to perform that task perfectly. During the FGD, the task I provided them to do, they performed the task fluently and correctly. It represents that students' procedural fluency developed after participating classes with ICTs. Again, the analysis shows that during the FGD, students showed their positive views about these classes and they enjoyed to learn math in the modern approach beyond the traditional approach. One of the students claimed:

> *As we discuss, it is creating a different environment from the traditional classes. There was a beautiful atmosphere in front of us because in our traditional classes, there are some people who disturb but here it was completely different and if we didn't understand something, if we asked sir (the teacher), he would help us. But sir (the teacher) didn't need to say because there was someone (peer) next to us who knew. […] We enjoyed these classes very much. Our interest about math is increased a lot. We realized that it is actually very useful in real life, it is not like, just memorizing something. (S8_C1)*

Thus, based on the analysis of the paper-pencil test, survey, FGD, classroom observation and teacher's interviews, it can be argued that students' mathematical proficiency (each and every strand) enhanced and to foster this, the teacher applied several types of effective pedagogical approaches in an ICT-facilitated TL environment.

4.1.4 Factors affecting integration of ICTs in teaching-learning process

4.1.4.1 Developing themes for influencing factors

By analyzing the data collected from teacher and head teacher via semi-structured interviews and classroom observation, factors which affect teachers' ICT integration in their practice are identified and coded. After a close and repetitive observation within and across the data set for each participant, I observed patterns among the factors and grouped the factors of similar patterns into four themes- *Teacher factors*, *Student factors, School context and National context* (Table 4.8).

Table 4.8: Developed themes for influencing factor of ICT integration in PL process

<table>
<tr><th>Identified codes for affecting factors</th><th>Similar patterns under group</th><th>Developed theme</th></tr>
<tr><td rowspan="4">Departmental ethos
Physical facilities
Teachers' perceived usefulness
Students' misuse of ICTs
Teachers' attitude
Parents' attitude
Teachers' interest
Students' home environment
Teachers' class load
Teachers' preparation
Large size class
Teachers' TPACK
Curriculum
Professional development
Teachers' experience
Financial support
Teachers' confidence</td><td>Teachers' attitude
Teachers' perceived usefulness
Teachers' interest
Teachers' TPACK
Teachers' confidence
Teachers' preparation
Teachers' experience
Teachers' class load</td><td>Teacher factors</td></tr>
<tr><td>Students' misuse of ICTs
Parents' attitude
Students' home environment</td><td>Student factors</td></tr>
<tr><td>Large size class
Departmental ethos
Physical facilities</td><td>School context</td></tr>
<tr><td>Curriculum
Professional development
Financial support</td><td>National Context</td></tr>
</table>

The four themes emerged as enabling factors are discussed below.

4.1.4.2 Teacher factors

My analysis shows that ICT integration in teaching mathematics is influenced by several factors associated with teachers. Eight factors are identified and categorized under the theme *Teacher factors* and they are discussed below.

Teachers' attitude

The analysis shows that T1 believes that teachers' attitudes towards ICT influence their teaching practice. According to him when the teachers have the positive mindset about technology, they are willing to use technology in their teaching practice. He stated:

> *[...] teachers should have the attitude to love the technology. [...] It is unlikely to use ICT properly if teachers are unwilling to accept the technology.*

In line with the teacher's opinion, the head teacher also stated, "*one must have a positive attitude when teaching mathematics using ICT*."

Teachers' perceived usefulness

It is found that teachers' perceived usefulness of technology is also an influencing factor to integrate ICTs in teaching- learning process. When teachers believe that use of ICTs in their practice will enhance students' learning ability, then they will be interested to conduct the classes with ICTs. T1 stated:

> *If the teacher feels that conducting class with ICTs is helpful for students' learning, then he/she will be interested to use it. In that case, the teachers have to get support. If he does not get support, he cannot advance. Having mental satisfaction is very important. If he is not mentally satisfied, he cannot give anything good to the nation.*

Teachers' interest

The analysis shows that teachers' interest is another factor to integrate ICTs in their teaching practice. T1 discussed that if teachers have to conduct the class using ICTs without their interest, the class will not be effective. He also argued that if a teacher possesses positive attitude on use of ICT in TL purpose, then he/she will be interested to conduct class with the help of ICTs. He emphasized:

> *In order to use ICT, it is very important to have the interest of the teacher first. If he is interested, he will think about what tools can be used and how they can be used to conduct the class. And umm.. when teachers hold positive attitude regarding technology, they will willingly apply ICT in their practice.*

Teachers' interest was also identified as an important factor by the head teacher as well. She claimed, "*teacher must have interest in ICT. If he cannot take it with interest, he cannot give it to the students*."

Teachers' TPACK

T1 explained about the necessity of teachers' knowledge on technology along with the proper content knowledge to conduct classes using ICT. If teachers have lack of knowledge about content as well as technology, they become confused and cannot utilize the ICT tools properly. He also argued that when teachers are skilled on TPACK, they are interested to use ICTs in their classroom practice. He claimed:

> *Teachers' content knowledge and technical knowledge, both are important. If there are any gap between these two, teaching-learning will not be meaningful. […] And for that he must have to be skilled in technology. When he has the practical skills, he will be interested in conducting class activities using ICT and can take classes using different methods. When the teacher is interested, then the classes will be fruitful and can spread interest among the students.*

Teachers' confidence

Teachers' confidence is identified another influencing factor to integrate ICT in TL process. The analysis shows that if teachers are less confident to work with technology, they try to avoid it. It is found that teachers sometime want to avoid technology and feel less confidence to use technology in the classroom due to the unreliable functionality of technology. T1 expressed that while conducting classes, he faced a variety of technological problems. For instance, sometimes computers did not work properly; sometimes it took time to log-on or log- off the computer or other application program; sometimes networks created certain problems. He stated that some of his colleagues have lack of confident to use technology due to the unpredictable functionality of it and try to avoid it. He expressed:

> *Some of my colleagues try to avoid to use technology as they think it is not reliable. They afraid that it may be failed to function in the middle of instruction.*

My analysis also shows that if teachers are confident to perform class with the help of ICTs, the class become productive. According to T1, teachers' confidence depends on their TPACK, experience and preparedness for the class. He stated:

> *[…] when teachers are experienced and skilled in TPACK, they seem very confident while conducting class using ICTs. […] He (the teacher) comes to the class with proper preparation, he can conduct the class with confidence, which is very important for teaching.*

Teachers' experience

T1 argued that teacher with many years of teaching experience, does not mean that he/ she will teach effectively. Rather conducting class with ICTs, he/she needs to be technologically skilled as well as experienced and have the knowledge of how to teach with technology to achieve the learning goal. T1 stated:

> *[…] Teacher experience is very important. However, this experience is not enough if you have many years of teaching experience. In addition, the teacher must have technological skills and experience of how to effectively use different types of resources for teaching.*

Teachers' preparation

The analysis of the study shows that T1 highlighted the need of teachers' preparation to conduct a class with ICTs. While conducting class with ICTs, a teacher has to proceed the class very systematic way. Without taking proper preparation, it is quite difficult. If preparation is not taken properly, the class will be haphazard and it won't be possible to take the class properly. T1 argued:

> *And if a teacher wants to take a class nicely and effectively, he has to prepare, he has to prepare it at home. […] if teachers are not well prepared, they cannot deliver the lesson properly and students become confused.*

The head teacher shared similar opinion in this regard. She claimed that to execute the class with the help of ICTs, a teacher must have to perform dual role. He/ she has to take the class, on the other hand, he/she has to operate the ICT tools. Thus, teachers' sound preparation is must. She stated:

> *If he is not well prepared before entering the class, he will not be able to take the class with ICT properly. Because here two jobs at the same time, he will take the class, he will also use the ICT. So if he does not have enough preparation, he will not be able to understand the children and the children will not be attentive in the class.*

Teachers' class load

The analysis shows that teachers' class load influences their adoption of technology in their teaching. T1 stated that teachers are already loaded with so many classes in a day, it is quite impossible for them to take a good preparation for the class which is the major criteria for conducting a class using ICTs. That is why, many teachers avoid to take the support of technology during their teaching. He argued:

> *Teacher's class load is a big issue. To conduct a class using ICT, the teacher needs good preparation. If a teacher has 5-6 classes every day, he doesn't really want to take additional preparation to use technology and avoid it.*

From the above discussion, it can be argued that some of the factors (e.g. Teachers' interest, attitude, TPACK and confidence) directly influence teachers' use of ICTs whereas some other factors (e.g. perceive usefulness, preparation, experience, class-load) indirectly effect on integration of ICTs in TL process. The factors related to "*Teacher factors*" affecting integration of ICTs are shown in Figure 4.21.

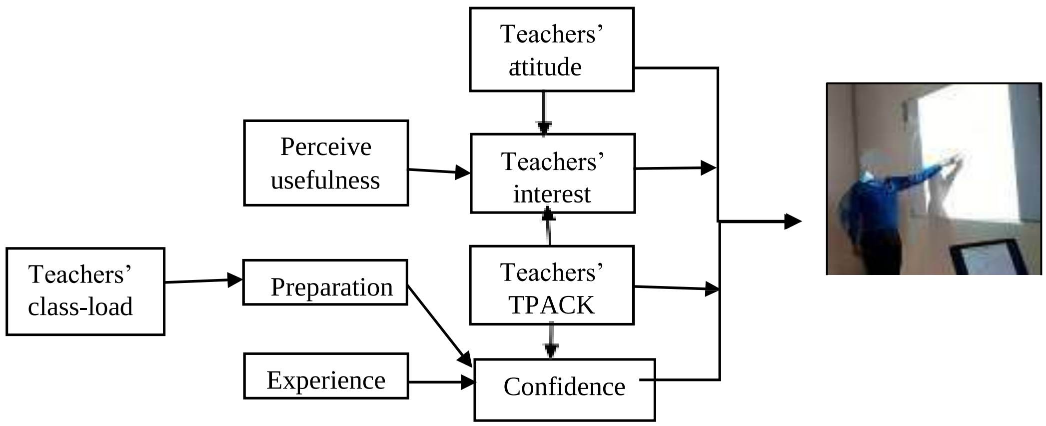


Figure 4.21: Factors affecting ICT integration related to teachers

4.1.4.3 Student factors

My analysis identified three factors related to students. These factors categorized under the theme *Student factors* and they are discussed below.

Students' interest

The analysis shows that students' interest is one of the factors which influence ICT integration. According to the teacher if students willingly engage into the class while teacher use ICTs for TL purpose, it will be very convenient for them to continue the class effectively. T1 claimed, "*when students are interested to learn with technology, we can run the class very smoothly*."

Students' misuse of ICT tools

T1 expressed that one of the barriers of an ICT-suits teaching environment is that there is always a big chance for students to misuse the computers. So, it is the responsibility for both the teachers and parents so that the students are not misguided by the technology.

According to the teacher, while students work with technology teachers and parents have to monitor them. He stated:

> *[…] Because there is an opportunity to misuse technology, I think both teachers and parents have a responsibility. When children use technology, both teachers and parents should observe whether they are using technology for learning or abusing technology*.

Students' home support

Parents' attitude towards technology is also found as a factor which influences integration of ICT in education. According to the teacher, parents negative view about technology sometimes influence students. As a result of that students possess negative attitude regarding technologies and are not interested to use them. T1 claimed that though there are huge potential of ICTs in learning, parents often hold negative thoughts about it as they believe that this environment misguide students rather than learning. Since the positive effect of integration of ICTs in education is more than the negative effect, it is necessary to create awareness of parents about this issue. Moreover, parents' mindset also influences students' attitude to some extent, thus it is vital to give attention on it. T1 suggested for conducting discussion meeting with parents in the school so that school authorities can discuss about benefits and need of ICTs for students' learning. He stated:

> *Many times students misuse technology and parents have a negative attitude towards learning using ICT, which in a way affects learning. In this case, it is very important to change the mindset of the parents. For this, a discussion meeting with the parents can be organized in the school. They can be informed that there are positives as well as negatives impact of ICT, but the positives outweigh them. To create parents' awareness, the need of ICTs in leaning should be informed them […], the future citizen must have to be technologically strong and it is quite impossible if we would not blend the teaching-learning with ICTs.*

Though the head teacher did not directly talk about the parents' attitude, she discussed about the adverse home environment of students to work with technology and for that reason students are not interested on technology. She stated:

> *[…] the environment students are coming from; they don't get that support at home.So, sometimes students are less interested.*

By analyzing the data on student related factors, it is found that few of the factors (e.g. students' interest, attitude) directly effect on ICT integration while few factors (e.g. home environment, parents' attitude and misuse of ICTs) have indirect influence on it. Figure 4.22 shows the influencing factors to integrate ICTs related to students.

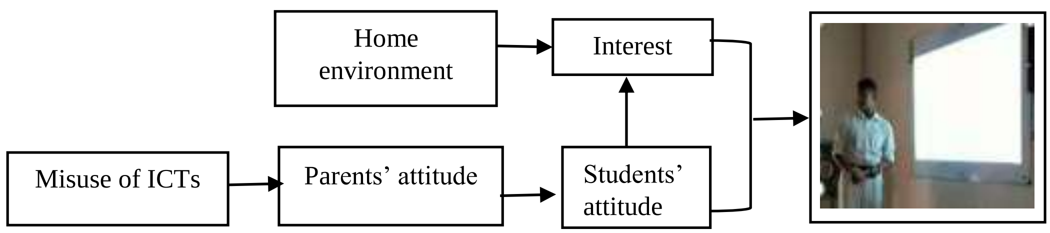


Figure 4.22: Factors affecting ICT integration related to students

4.1.4.4 School context

By analyzing the data several factors related to school context are identified and classified under the theme *School context* and they are discussed below.

Departmental Ethos

Departmental ethos is another vital factor to integrate ICT in teaching-learning environment. If the head of the institution does not show positive attitude regarding technology, the teachers of the institution will not be motivated to use ICT in their practice. As integration of ICT in TL practice need extra attention and planning, teachers may not be encouraged to use in their practice if they do not get support from the school head. Besides, despite conducting class using ICTs, sometimes teachers feel stress and does not get any mental support from their colleagues as they showed doubtful behavior regarding his/ her class. T1 stated:

> *The head of the institution should have a positive attitude towards ICT and this attitude should be transmitted to other teachers. It can be seen that 5 to 6 teachers*

conduct the class using ICT tools, and since most of the teachers do not use, it is not seemed so much important. […] In many cases it is seen that the teachers do not take the matter easily. Sometimes they possess doubt that whether the teacher is conducting the class properly in the name of conducting the class using ICT tools. For this, the school authorities should be encouraged to use ICT tools to conduct classes and provide adequate support.

In line with the teacher's comment, the head teacher of the school highlighted that it is vital that the head of the organization possesses positive attitude regarding technology inclusion in the teaching- learning. According to her, if the head of the organization has enthusiasm, then he/she can motivate the students as well as colleagues. She also claimed that she always encouraged teachers to accept the new things and use ICT effectively in their classroom as it has huge impact on students' learning. She argued:

[…] I say to them (teachers) that something new has to be accepted. If you can't do it yourself, learn it from your colleagues. Learn it and try to give it to the students. […] I always tell the teachers to use ICT in a positive way that if they take classes using ICT, the students are more attentive and that learning has a permanent effect on them.

She also highlighted the importance of teachers' mental support and positive acceptance of the little noises in the classroom environment while conducting classes using ICT. She claimed:

In many cases, it can be seen that boys can make a little mess while using ICT in class, this should be seen positively. This doesn't mean that boys don't respect teachers or anything. When a teacher goes to re-arrange the class, there will be a bit of commotion.

Along with the support of the organization head, the other teachers of the organization also have some responsibility. The head teacher stated "*if our teachers are a little sincere and support the head of the institution, it will be effective. As the head of the organization, it becomes easier for me*."

Large size class

The analysis shows that T1 expressed class size as a big issue to conduct class using ICT. He explained that while an ICT integrated classroom is suitable for 30-40 students in a class, the total number of students in his class was almost double which caused a lot of difficulties. According to him, with a large class size, it is quite impossible to apply different learning strategies which is important to effectively conduct the classes with the assistance of ICTs. T1 emphasized:

> *Now we have teacher-student ratio 1:70, it is not possible to take classes effectively using ICT with such a large number of students. If the teacher student ratio is 1:40 or 1:30, I think, the students will be able to learn properly as in that class size, teacher can conduct the class using ICTs by different techniques.*

The head teacher also had similar opinion regarding the class size. She stated, "*our teacher-student ratio in the classroom is high. If we can reduce that ratio, then the teacher can take classes through the use of ICT. If the ratio is 1:30 maximum, then the class can be taken effectively*."

Physical facilities

T1 claimed that to conduct the class using ICTs, it is mandatory to prepare the classroom setup suitable for it. If all sorts of facilities such as multimedia, internet, resources are not available then it is not possible to conduct the class fruitfully. The teacher emphasized on the availability of uninterrupted internet in the classroom as this facility help teacher as well as students to gather information and provide the scope to see videos which will help them to acquire diverse knowledge and enhance learning. T1 stated:

> *[...] to take classes using multimedia, it is very important to set up the room properly. For example, availability of electricity, various resources, internet facility. If internet facility is available, tutorial classes, various information can be collected very easily. I think internet is very useful for acquiring various knowledge.*

The analysis shows that within the six experimental classes, in the last class, the teacher had the plan to conduct the class with the assistance of Desmos apps which required an uninterrupted network support. As internet created trouble during the class, the teacher had to use the mobile data via hotspot and performed the class activities. Though the problem was temporarily solved, but teacher argued that school authorities have to ensure the internet facility as using mobile data incurs cost and also there is no network facility option for the students in that case. The teacher stated:

> *There is a financial aspect to room arrangement. Apart from this, logistic support, for example various tools for using ICT are not available in sufficient quantity. The convenience of uninterrupted internet is also very important. For example, I needed internet in the last class. But during conducting the class, the internet was getting trouble, in that case I continued to work using hotspot. The work can be carried out on a temporary basis, but in that case there are financial issues. Apart from that, only the teacher can show but not able to connect the students to the internet. I think school internet facilities should be available for everyone.*

As like T1, the head teacher argued, "*to conduct a class using ICT, I need technical facilities. First of all, I need to have the necessary materials and I need to have projectors, microphones in each classroom.*" She revealed that her institute had several classrooms with multimedia facilities. There were also ICT lab rooms where teachers could conduct class if they desired. She stated:

> *[…] we have several project rooms in which they can take classes. Where I don't have one, I have phased the routine so that the teachers can conduct the classes in the labs.*

The head teacher also stressed about the rearrangement of classroom furniture and the importance of availability of adequate ICT tools (e.g. laptop, smartboard) so that students can directly use them. She argued:

> *The first thing we need to do with the supports in my classrooms is to rearrange our furniture. For example, a laptop may be given to two children or three children.*

> *Then his sitting place should be made like that. We have a problem with this thing. […] if I can fix the classroom environment, I can make every boy if not at least two boys sit with a laptop then they will be attentive. if we can arrange a smartboard in the classroom, then they will be more interested and the necessary knowledge can be imparted in them.*

Technical support

My analysis shows that T1 also gave importance on availability of technician in the school. According to him, if the school authorities want to introduce all sorts of ICT facilities in the school, they must have to ensure skilled technician. While observing the class, it is found that the teacher faced some difficulties to turn on the power of multimedia as it was a bit high and the remote was not properly functioning. So, he asked for a student to perform this operation by standing on the chair. During the interview session, he mentioned that sometimes some technical issues occur (e.g. connection issue related to multimedia, software installation issue etc.) in the classroom for which technical support is needed. He argued:

> *[…] sometimes multimedia connection create problems, umm.. to install software in each computer, it is necessary to have a technician.*

The head teacher also talked about the necessity of assistant or computer operator to support the teachers. She argued, "*if I can have an assistant or a computer operator with him as soon as he goes to the classroom. If I can provide such a person who will operate the computer, then it will be easy for him to take the class*"

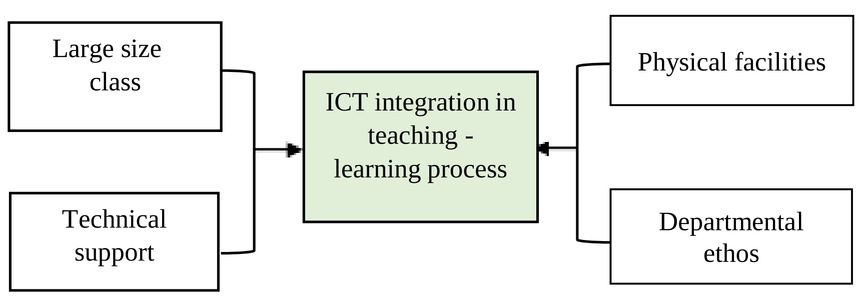


Figure 4.23: Factors affecting ICT integration related to school context

Thus, the analysis found that large size class, departmental ethos, availability of physical facilities and technical supports are factors related to the school context that affect integration of ICTs in teaching-learning process in (Figure 4.23).

4.1.4.5 National context

My analysis shows that ICT integration in teaching mathematics is influenced by three factors associated with national context and these factors are discussed below.

Curriculum

Curriculum has been identified as one of the influencing factors by T1. He argued that if curriculum is clearly spelt out on how the technology can be assimilated to teach a specific mathematics content, then teacher can easily use it in their practice with proper planning. He claimed that though teachers currently use ICTs in their practice to teach mathematics, the existing math curriculum somewhat is not supportive for teaching-learning with ICTs as there is no explicit direction for the teacher. He suggested that in curriculum, every content of mathematics should be linked with ICTs and a definite indication to both the teacher and students, so that they are compelled to use ICTs. T1 expressed:

> *The current mathematics curriculum is not fully supported for classroom teaching using ICT. That is, there is no direct instruction in the curriculum. However, if the teacher wants, they can do by their own willingness, […] um.. become efficient by their own effort. Then he can teach the class using ICT. In my opinion, the new mathematics curriculum should be designed in such a way that both teachers and students are forced to use ICT. Every content should be related to ICT. […] In addition, along with the traditional exam, ICT-based exam can be conducted, such as using Google Forms to assess the students.*

On the contrary, the head teacher expressed that the existing math curriculum is proper if teachers want to teach math with ICTs. She argued, "*I see that the materials that our teachers sometimes use or take classes in multimedia classrooms, our curriculum or the* *books that we have, I think it has enough content to work with ICTs.*" Besides, she expressed that while preparing the class routine, the classes where ICTs will be used, are mentioned so that students and teachers are informed earlier. She stated:

> *In that case, we indicate in our routine that these classes will use ICT, the students also know and the teachers know.*

Financial support

According to the teacher, funding is a big issue to integrate ICTs in education as all sorts of logistics supports depend on the financial ability. The teacher claimed that there are lack of resources such that inadequate amount of computers, supporting tools required for ICT-classroom environment etc. He stated:

> *There is a financial aspect to room arrangement. Apart from this, logistic support, for example, various tools for using ICT are not available in sufficient quantity.*

The head teacher also expressed that financial issue is a challenging factor to use ICTs in the teaching practice. She claimed that if adequate financial support is available, then teachers who are interested to integrate ICTs in their class can effectively use it. In addition, she thinks the interactive white board which is very fruitful ICT tool for teaching-learning, require fund. She also talks about the importance of maintenance of the ICT tools. She argued:

> *[…] the use of ICT requires financial support. If it is enough and if our teachers who are little sincerer, to create an environment in the rooms and rearrange and use ICT, […] I think if an interactive board is provided or an ICT room is made then I think the institution will take responsibility for its maintenance. It will try to maintain it anyway. What I do, I visit on a weekly basis and I check those rooms and ensure the operability of all the laptops, I do it myself so that the things of the institution are not damaged.*

Professional development

The analysis found that teachers' professional development is a key factor to successful integration of ICTs into classroom teaching. T1 argued that teachers become interested to use ICTs in their practice if they are skilled in technology. Besides, their competencies can be boosted by providing professional development training program. So, he claimed, "*Government should give importance on that issue*". T1 also proposed to provide in-house training to teachers of the institution to enhance their skills. He claims:

> *Teachers need to work with technology to develop skills on technology. Besides, training should be given to teachers. In-house training can be arranged. 5/6 teachers of the school can receive training and then they can train other teachers of the school through in-house training. In this way, it is possible to improve the professional skills of all teachers.*

The head teacher also discussed about the importance of training for teachers' professional development specially to become expert for applying ICT in their practice. She explained that the teachers of her school took several trainings inside and sometimes outside of Bangladesh. She also talked about the necessity of in-house training and her supportive role for arranging the training for the development of teachers' professional skills. Such as, she organized in-house training by the teacher who received training, acts as a trainer for the other teachers of the school. She argued:

> *Necessary training should be provided to the teachers to be proficient in using ICT. If someone takes the training, I then arrange in-house training and give them the classes later so that the students benefit. Also tell the teachers that if they need any support like a laptop etc. they should ask for it. […] In fact, our teachers are also receiving training from outside the country through various ICT projects. […] Definitely effective. I myself have trained from Korea. It turns out that when I train for 10 days, 15 days, 1 month, as long as I'm training, I work on it. Due to which the experience increases.*

By analyzing the data focusing on national context, several factors such as curriculum, financial supports, professional development programs are found critical in integrating ICTs in TL process (Figure 4.24).

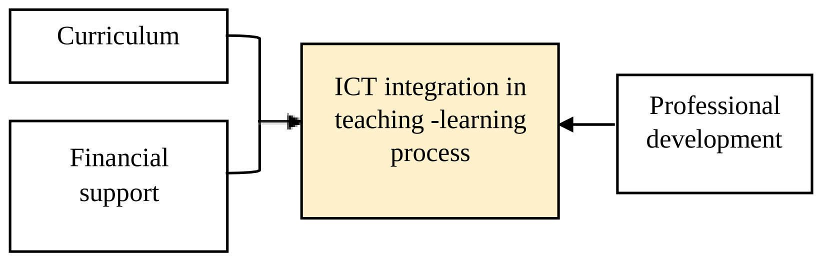


Figure 4.24: Factors affecting ICT integration related to national context

4.1.5 Summary of the findings

In summary, it is found that the teacher applied a number of pedagogical approaches with the help of ICTs. He made the class interactive by involving students in group activities, peer discussion and whole class discussions. To fulfill his intention, he rearranged the classroom setup such as, keeping extra chairs (if required in times of group work), extra desk, portable white board etc. It is also found that the classroom space was supportive for both the collaboration and observation learning (e.g., all the resources used in the classroom was easily visible and useable for both the teacher and students). The teacher facilitated the environment as such that the students feel motivated to learn with technology (e.g., linking mathematics concepts with real-life with the simulation program, informing the benefit of the tools to perform a specific task etc.) and engaged students to work directly with technology as much as possible. It is found that the teacher used multiple TL strategies to engage students into the lesson with proper conceptual understanding and reasoning (e.g., offering challenging task, encourage students to explain their ideas with proper logic etc.). In addition, some of the applied strategies such as encouraging for rapid recall, providing task for home practice etc. were also found helpful for students to develop their procedural skill. Some strategies (e.g., solving problems in multiple strategies, ICT provide feedback etc.) were found effective for developing strategic competence. The teacher used diverse ways (e.g., valuing learners' opinion and praise them, providing attractive picture etc.) to motivate students into the lesson. It is found that the teacher applied multi-channel feedback (e.g., teacher provide feedback, peer-feedback, ICT provide feedback and self-reflection) too to guide and assess students. As, the teacher used different types of ICT tools (e.g., multi-media projector, GeoGebra software, calculator, desmose app etc.) to conduct the classes, he applied several types of instrumental orchestrations (e.g., link-screen-board, Sherpa-at-work, monitor-and-guide etc.) during applying the multiple TL strategies. From the analysis it is also found that during the TL process, students perform several roles which ultimately were the intention of the teacher. For instance, they engaged into the class actively, willingly involved to work with technology, provided peer feedback, involved in self-reflection, tried to identify their own mistakes and overall followed teacher's instructions attentively. The analysis also identified some of the role of ICTs while performing the classes with the assistance of those such as ICT helped to visualize the real meaning of mathematics, provided instant feedback, made the learning interesting, easier and sustainable.

With respect to MP, it is found that students initially were not good at every strands of MP. But after participating the classes with the help of ICTs, every components of MP increased. From the classroom observation, paper pencil test, survey questionnaire and FGD, it is found that students' conceptual understanding, procedural fluency, strategic competence, adaptive reasoning and product disposition improve after participating the ICT-facilitated classes. It is found that different pedagogical approaches applied by the teacher ultimately help to foster different skills among the students. The study identified a few challenges the teacher faced during conducting the class and also a few factors that influenced him to incorporate ICTs in TL process. Some of the factors found relating to teachers are teachers' attitude towards technology, teachers' preparation, confidence, teachers' TPACK, while factors related to students' are students' interest, home environment etc. In addition, a number of factors related to school context (class-size, departmental ethos, physical facilities etc.) and national context (curriculum, financial support, professional development etc.) are identified which influenced integration of ICTs in TL process.

4.2 Case-II

4.2.1 Teacher T2

T2 is the participant teacher in Case-II. Teacher T2 is a female teacher and she is serving in a private school (English version & co-education) of Dhaka city. She has completed her BSc (Hons) in mathematics and MS in pure mathematics from University of Dhaka. Besides, she did Bachelor of Education (BEd) degree due to her professional responsibility. She has four years teaching experience. To enhance her professional skills, she received basic ICT training conducted by BANBEIS and also attended in several in-house trainings on pedagogy and ICT. Though the teacher T2 is not so experienced teacher, but she is very skilled in ICT. She has knowledge about MS office (Word, Excel, PowerPoint), GeoGebra, MATLAB, FORTRAN, Mathematica and can use some of those efficiently. Thus, being guided by the head teacher of the school, I approached to her and T2 agreed to participate in this study. Though T2 was familiar with the GeoGebra software previously, she never used it in her practice. Due to her prior knowledge about the Geogebra software and her skills in technology, it took very limited time (only four meetings) to guide her about the functions of GeoGebra. For this study, she used PowerPoint presentation in every classes. Besides, in two classes she used GeoGebra and in one class she used Desmos application. She conducted all classes in the traditional classroom (available facilities with multimedia and internet) except one in the lab room.

4.2.2 Teacher T2's pedagogical considerations in ICT-facilitated teaching-learning environment

4.2.2.1 Developing themes for T2's pedagogical considerations

By analyzing the data collected from Case-II through video, field notes, post-lesson interview and FGD of students, a total of 23 pedagogical approaches have been identified and coded and approaches of similar patterns are grouped into themes in the similar manner as discussed in section 4.2.1. T2's pedagogical considerations in an ICT-facilitated TL environment can be described collectively by the six themes emerged (Table 4.9).

Table 4.9: Themes emerged as effective pedagogical approaches for Case-II

<table>
<thead>
<tr><th>Identified codes for pedagogical approaches</th><th>Similar codes under groups</th><th>Category/ theme</th><th>Pedagogical consideration</th></tr>
</thead>
<tbody>
<tr>
<td rowspan="6">• Physical space support-observation learning
• Providing scope of- peer discussion, group work, whole class discussion
• Selection of tools
• Facilitating to get the correct path
• Access to technology
• Linking and connecting math with real context
• Teacher provides feedback
• Providing scope to explain students' thought with proper justification
• Involving learners directly to ICT
• Providing counter example
• Providing scope to apply acquired knowledge in a new situation
• Encouraging for individual work/thought
• feedback by peer
• ICT provides feedback
• Identify mistakes (by peer)
• Praise the learner
• Providing variety of several examples
• Providing homework for practice
• Exploring misconception
• Providing multiple ways of representation and strategies
• Exploring and linking math with prior knowledge
• Providing well organized and systematic lesson
• Encouraging rapid recall</td>
<td>• Physical space support-observation learning</td>
<td>Rearranging classroom amenities</td>
<td rowspan="6">Rearranging classroom amenities

Ensuring Technology Accessibility and Its Appropriate Usage

Adopting different strategies to make the learning meaningful

Offering multi-channel feedback

Offering opportunities to identify error/ imprecision

Engaging students through motivation</td>
</tr>
<tr>
<td>• Selection of tools
• Access to technology
• Involving learners directly to ICT</td>
<td>Ensuring Technology Accessibility and Its Appropriate Usage</td>
</tr>
<tr>
<td>• Linking and connecting math with real context
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</tr>
<tr>
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</tr>
<tr>
<td>• Praise the learner
• Providing well organized and systematic lesson
• Facilitating to get the correct path</td>
<td>Engaging students through motivation</td>
</tr>
</tbody>
</table>

4.2.2.2 Pedagogical Approaches applied by T2

Theme 1: Rearranging classroom amenities

The teacher T2 conducted six classes among which one class was conducted in ICT lab room. The classrooms were well spacious with adequate benches and desks for students. The benches were arranged in four columns and placed in such a way that students faced towards the board (Figure 4.26). There was a multimedia projector and a screen for projection at the front of the center of the room. There was also a large white board available at the front of the center of the room so that students could easily see the board. Since, the white board and the projector screen were at the center of the room, the teacher argued for the importance of another board which should be placed beside the screen. She claimed that in the lab room the screen of the multimedia projector is projected in such a place so that the space of the white board is totally free for writing (Figure 4.25), so it is very convenient to link screen with the board and observe. She justified her actions:

> *[…] if there were another board next to the screen, it would be easier to show simultaneously. If we do the class in the ICT lab room, it would be very easy to do. Because in ICT lab, the setup is done in such a way that the slide will be in one place and the white board will be in a separate place. So, it is easier to see both together.*

Traditional classroom

Lab room

Figure 4.25: Traditional classroom vs Lab room

She also expressed the necessity of white board to link with the projected screen. According to her, projection screen does not contain all information about a topic rather the key points or notes are presented in the slide. Thus to explain in details, the necessity of white board cannot be ignored. Besides, it helps students to easily understand the topic as they can compare by observing both (projected screen and white board) at the same time. In her voice:

> *In many cases, I have shown the formula but how the formula is derived, may have not shown details in the slide. I can explain it on a board. [...] So if they are together, students can compare and can understand it easily.*

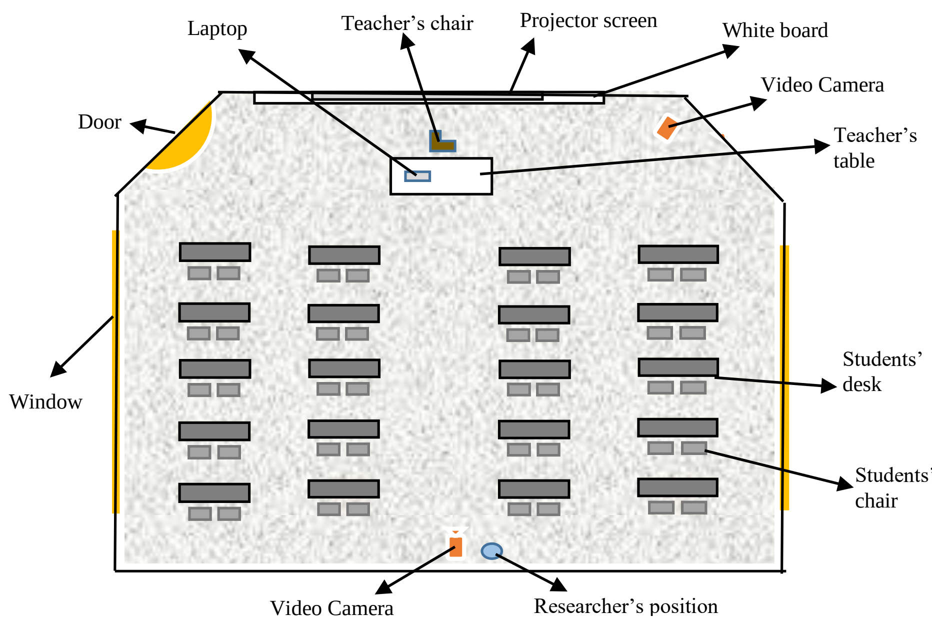


Figure 4.26: classroom layout of the teacher T2

The assigned classroom was full of sunlight due to its large size windows. For which it was a bit inconvenient for the students to see the slides on the projection screen. It reflected the necessity to control the lighting arrangement in the class. According to the teacher, while displaying something on the projection screen, it is important to remain the classroom a bit darker so that screen can be easily visible to the students. That is why she preferred to conduct the classes in the lab room.

She also claimed that it was better to have curtain or blind in the classroom to control the lighting arrangement so that multimedia supported activities could be easily used in the traditional classroom rather than lab room. She stated:

To display PowerPoint slide, proper lighting is important. Normally there will be enough light in the rooms. But when we want to do the PowerPoint display, if the room is not a little dark, the display cannot be seen well. So, the facility to control light is actually needed in the room. In most cases traditional classrooms do not have curtains, while the labs actually have it. So, taking classes in the lab is more convenient.

In the ICT lab room, there were 40 computers, so students could easily use computer as one to one basis. Though the teacher conducted one class in the ICT lab room, she did not allow students to operate the computer directly in that class. In the last class, the teacher intended to do some activities which required internet connection. Since, the internet connection was available both in the ICT lab room and traditional classroom, she could execute her teaching plan in the classroom smoothly. She argued:

Internet connection is definitely important because the display shown was real-life application and a stable net connection was required. We have that facility in the classroom.

It is observed that the teacher did not take any initiatives to rearrange benches so that students could work in collaboration. According to T2, there is no need to change the classroom setup if a teacher's intention is to teach the class in traditional way, that is students will observe and listen what the teacher teaches and performs the task individually. However, though the teacher did not rearrange the sitting arrangement, she argued about the necessity of rearrangement of classroom setup if students get involved in group activity. She argued that there should be a little gap between two groups so that one group is not influenced by the other group. Besides, benches should be ordered in such a way that students can sit face to face and communicate to each other easily. She also claimed that 6 to 8 students of varied capability are perfect to form a group. She expressed:

The need of classroom arrangement depends on the kind of activities performed in the classroom. Task for individuals should be conducted traditionally while for a group task it is better to rearrange. I think the arrangement should be done with a little gap so that one group is not influenced by the ideas of the other group. If

> *there is a little gap, students try to think on their own. […] Besides, moving the bench and making students sit face to face, interaction becomes easier. […] I think 6 or 8 people in a group is perfect. Same category students should not be in a group. Rather, students of different capability should be in a group for a fair comparison among the groups.*

Thus, in Case-II, though the learning space supported *observation learning*, it was not properly re-organized to support flexible and collaborative learning.

Theme 2: Ensuring Technology Accessibility and Its Appropriate Usage

The analysis reveals that except the 6th class, T2 used PowerPoint slide in every class. She used the multimedia projector to project her laptop screen and also used white board when necessary. She used GeoGebra software in two classes and Desmos apps in one class. Though she used the mentioned ICT tools to conduct six classes, she claimed for different tools, software and apps such as Mathematica, FORTRAN, Geometry Pad, Khan academy which are effective for mathematics teaching-learning. Besides, she emphasized on the use of graphics tab and interactive whiteboard for math teaching. According to her, all these tools are very fruitful for learning mathematics, as these tools have some features to visualize the abstract nature of math in real context (*ICT_R-1*). She stated:

> *I think other than GeoGebra, Fortran and Mathematica are effective for beginners. A lot of things can be shown easily using these two software. Plotting or other topics, Um.. real-life implementation of mathematical problems can be easily demonstrated. […] the graphics tab seems to me a useful replacement of white board. It is very easy to do because, in the case of the white board, I am erasing text or documents. But if I use graphics tab, I can store the document as a soft copy and can show again if required. […] interactive white board (IWB) is very effective, some schools have this facilities, I think every school needs to have at least one IWB.*

It is observed that T2 was very skilled in operating technology. However, she rarely invited students to use ICT tools directly in the classroom. Among the six classes, in two classes she created the environment so that students could use ICT tool directly. For instance, she welcomed students to operate GeoGebra (in the 4th class) and Desmos (in the 6th class) at her laptop and see what happened. Though the teacher did not invite the students frequently to use ICTs directly, she expressed her positive viewpoint and intention to involve students with ICTs directly. She argued that students should willingly work with ICTs and if possible we should create scope for them (*Std_R-2*). She stated:

> *Actually, our planning was to do the graph with GeoGebra in the lab. But unfortunately in the lab, exam was going on at that time. Moreover, the authority did not give us the permission to install GeoGebra software in computers. So, I was forced to operate my laptop. […] I actually used the slider (which is a functional option of GeoGebra) and students were given the answers to various questions. But it would be better if they could do it individually. […] So I think if we could make the arrangement, they would not be deprived. We could actually make the connection between traditional learning and actual learning. I could make the connection with the help of ICT. Now actually the situation was not in our favor.*

Theme 3: Adopting different strategies to make the learning meaningful

The analysis shows that the teacher applied variety of teaching strategies to make the learning effective. It is found that in some of the classes, T2 tried to teach the mathematical concepts linking with real-life situations. For instance, T2 showed simulation to link the real-life context with the math concepts (Figure 4.27). An example of such a classroom context regarding is shown below.

T2: Class, we have already learnt about graph of linear function, right?
Students: yes, miss.
T2: here, you see three graphs (teacher displays Figure 4.27 on the screen). One for hare, one for tortoise and one for fox. Now I will play the button, then you can see what is the real meaning of these graphs.
(teacher pressed the play button)
Students: wow!! (students enjoyed the motion picture)
T2: look carefully, the graph of the hare and the motion picture of hare.

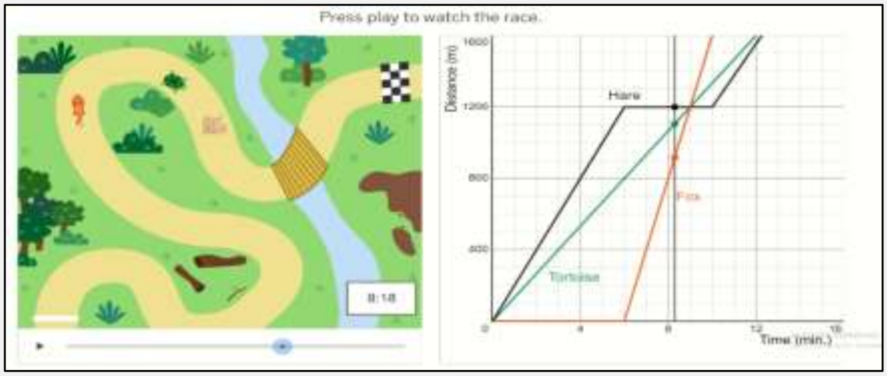


Figure 4.27: Use simulation to link math with real context

S5_C2: miss, can you play it again?

(teacher pressed the play button again)

T2: where did the three animals meet?

Students: at 1200 m

T2: S23_C2 stand up. graph of hare is parallel to x-axis for some time- what is the meaning of this?

S23_C2: the hare is in rest at that time which means it has no motion.

T2: class, do you agree with S23_C2?

Students: yes, miss (loudly).

T2: good, sit down.

According to T2, such kind of initiatives helps students to visualise the actual meaning of mathematical concepts rather than abstract and make the learning environment enjoyable by adding some fun factors (e.g. animated picture) (*ICT_R-2*). Moreover, due to use of ICTs, comparatively difficult topics can be presented in simple way and become easier for the students (*ICT_R-3)*. She argued:

> *Capacity of all students are not same, what happens, in some cases students cannot visualize, the concepts remain abstract to them. Again in many cases, they think that they are learning just for the sake of learning, it has no real life application. When we relate the concepts to real-life, majority of the students are interested. […] if we give direct example, they may not be able to make connection so easily. But when we represent the examples through ICT using different tools, it becomes*

easier to explain, even if the topic is difficult. Thus, their learning becomes easier and learning is also fun. I personally think, the use of ICT is pragmatic. Even easier.

As like T2, it is found that during the FGD, students talked about the importance of linking mathematics with real-life for their learning and the benefits provided by ICTs on that issue. One of the students argued:

> *[…] if ICT is used, many things can be easily related with real-life. In that case, it is very convenient to understand, many things can be caught up quickly. For example, in the last class, an animation related to functions' concept was shown to us, I mean a race between rabbits and tortoises. So I got a clear idea about what is the actual meaning of that concept in real-life. (S3_C2)*

Another student claimed:

> *I do not get interest to learn math if I can't relate it to real-life. I like these classes as what I'm learning, I can actually use in my practical life. It is because of using ICT. We can visualize the problem due to ICT, So, I think it use is very helpful. (S6_C2)*

The above quotes in fact support the argument that connecting math with real-life situation, representing problem with the help of ICT, makes the learning enjoyable (reflected PD) and concreate (reflected CU).

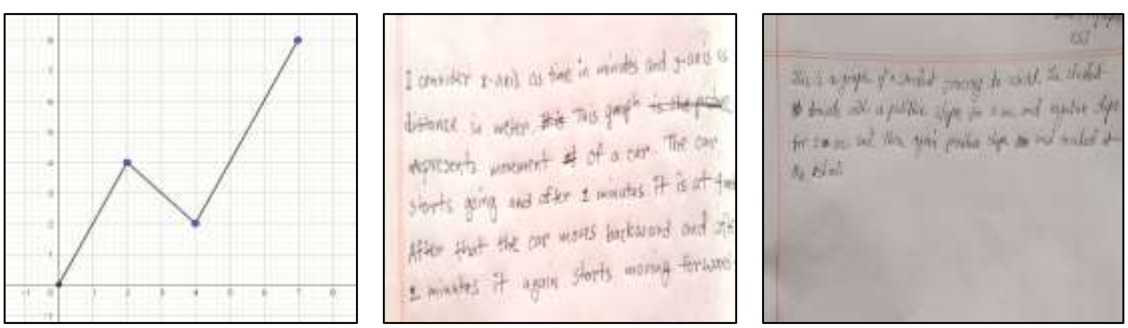
It is also observed that in most of the classes teacher tried to explore students' prior knowledge about the topic and extended the discussions connecting with the prior knowledge. According to T2, based on students' responses she could apply different strategies which would be helpful for students and eventually develop students' strategic competency ability. In support of this argument the T2 stated:

> *While checking students' prior knowledge, I could identify any deficiency that some of them have and also their level of understanding. Based on that, I may apply different techniques. Um.. which ultimately help them to think about different ways*

to solve a problem, I think. […] in case there are some lacks of knowledge, I might have an opportunity do discuss them for discussion in the next class. we are actually continuing a topic, just moving to the advanced version. If they don't have clear idea of the previous concept, there will be problems. That is why prior knowledge is checked and I actually give a little review. I gave it so that those who have already been done can remember a little, and those who have forgotten a little or are not paying attention, they can remember a little.

The analysis also reveals that in the last class, T2 created such an environment so that students could try to apply their acquired knowledge in a new situation. For instance, by projecting a linear graph on the screen (Figure 4.28(a)), the teacher asked students to write a story about the graph by specifying the units of x-axis and y-axis by their own choice. As the teacher provided no specific clue about the story except the line graph, students had the full freedom to apply their knowledge in the new context. One of the students wrote a story about the motion of a car (Figure 4.28 (b)) whereas another student wrote about a student's journey to school (Figure 4.28 (c)). According to T2, such kind of initiatives help students to clear their concept with proper reasoning, at the same time, it makes the learning interesting to them. She explained:

[…] they learned about the slope, they just got the idea of slope in theoretically. So when they can apply their knowledge in different situations and explain with accurate logic, that indicates that they grasped the concepts clearly.



(a) (b) (c)

Figure 4.28: Applying knowledge in the new context

It is also found that T2 gave emphasized on multiple ways to represent and solve a problem. For instance, in the 5th class, the teacher showed a co-ordinate plane with two points (Figure 4.29) and asked students to draw the line which is passing through those two points. She also asked to find the equation of the graph at least in two different forms. A sample of classroom scenario in this issue is shown below.

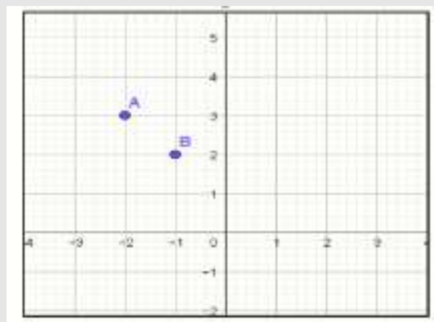


Figure 4.29: Problem for enhancing strategic competence

T2: Students, look at the screen. What do you see?

Students: two points on graph paper.

T2: Okay. S13_C2, what is the coordinate of 'A' and 'B'?

S13_C2: (-2, 3) and (-1,2), miss.

T2: okay, good. Students, draw a line passing through these two line. You willget 5 minutes. Don't look at others. Try yourself.

(students draw the graph in their own script/paper)

T2: S4_C2, come here, sketch the graph on the board.(S4_C2 draw the graph)

T2: Students, is the graph correct?

Students: yes, miss.

T2: S1_C2, come here and write down the equation of that graph.(S1_C2 has written the equation x/1+y/1=1 on the board)

T2: explain it.

S1_C2: here, x intercept is 1 and y intercept is 1, so I use x/a +y/b=1 formula.

T2: Students, what do you think?

Students: S1_C2 is correct

T2: Who can write another equation for this graph? Raise your hand
(most of the students raise their hand)
T2: S22_C2, come here and write (on the board)
(S22_C2 has written on the board)
T2: Explain it.
S22_C2: I use y=mx+c , here c=1 and m=-1

According to the teacher, this strategy was applied to enhance students' ability to build connection among the information and to foster their capacity to solve a task in multi-dimensional ways. She stated:

> *This is important because in many cases students cannot do math using information. For example, same straight line can be represented in many ways. Basically it depends on the information which formula I use and which approach I go for. So it has been tried to teach them in multiple ways so that they can make the connection among the information clearly. That is, when performing a task, they (students) will think, yes, here is the information to go into this approach. If this information is not available, that approach will be invalid, I have to try a different approach. Besides, it was tested whether the same thing can actually be solved in different ways. My intention was to make students understand that one task may be done by several ways, not just only a single rule.*

Students too discussed about the importance of learning multiple strategies to solve a problem during FGD. One of the students argued, "*teacher showed us many formulas that could be used to solve a problem. This will increase the chance to use different form of formulas efficiently to solve problems*". (S1_C2)

Moreover, T2 often asked students to explain *what and why* he/she has solved a problem in that way. She argued:

> *Just by listening to their 'yes' or 'no' response, I can't confirm whether they actually understood or not. When I know their reasoning, why they say function or*

why they say relation, I can realize that how much they actually understood. That's why I always ask 'why'.

It is also observed that in all classes except 4th class, T2 encouraged students to work individually. She often asked students to solve a task by their own thought rather than being biased by others. She argued:

As I said, some students are not fast learners, they are more influenced by others. They think, I have to learn it right now. As he is better than me (means better results academically) and he says this, so it will be right. I mean, they wanted to close their thoughts. So I tried to discourage it. I always encourage them to think by their own and told them that we can learn from mistakes. […] I tried to monitor if everyone was trying when they (students) were working individually. And by looking at their responsesand their body language, I tried to decide whether they understood or not.

In class 4, she allowed students to work in groups. She formed the groups with the combination of relatively weaker and stronger students but did not rearrange the desks. According to T2, such combination creates the performance better, students can learn from each other. She invited all group leaders to operate the computer directly (Figure 4.30) and fill-up the worksheet (Appendix J) which was provided by her. In addition, she requested the group leader to share his/ her thought with the other group members who fill-up the worksheet as well. As per the teacher, such kind of approach is effective. Since, due to the limitation of resources, it is not possible to involve all students directly to the ICT tools, group leader can operate the tools on behalf of group members. However, the teacher also permitted the other group members to operate ICTs in case they were not satisfied by the performance of the group leader. She mentioned:

Figure 4.30: Group leaders work directly with ICT

In terms of group formation, I tried to have students from all categories in the group, I mean mixing fast learners or quick learners and those who are a bit slow. They can learn from members. [...] In fact, it would be best if everyone could use computer directly. But it was not possible to give everyone a chance. In that case the group leader was the only choice. But the group leader was told to collect questions from his group members and based on those, sifting the graph (using Desmos simulation apps). What's happening is that even though the group members can't come themselves, they can understand that by looking at the display.The group leaders are members of their group, worked as a representative. He didnot lead; he was actually a representative. I also allow other group members to come, if they want to come. [...] if the desks could be rearranged, then it would bebetter. But I did not do it as it takes time to do that.

Though the teacher rarely involved students in group work, during the FGD, students talked about their positive view about group activity. According to them, while they worked in a group, they felt comfortable and it enhanced their knowledge through easy interaction with their peers. One of the students argued:

In my opinion, the capacity of all students is not the same, so when many students work together, if the concept of one student is a little blurry, another student can cover it up through group work. (S3_C2)

In support of this argument, another student expressed:

Students usually feel much more comfortable when an activity is done with friends. There is a bonding between them too. Working in a group benefits us from that side as well. (S5_C2)

These quotes indicate that proving scopes of collaboration (e.g., peer work, group work) help students to develop their conceptual understanding and enhance the capacity to learn with cooperation (reflection of PD).

It is also seen that the teacher encouraged students to rapid recall about any mathematical topic as per requirement. In most of the classes she repeatedly asked students whether they could recall or not. She stated:

> *Every piece of information is related to the each other. If they think each information is unique, in the near future it seems that learning will become more complicated. If they can find the link, it will be interesting to know that the whole thing is actually very simple, gradually going deep and very deep. That's why I tried to emphasis the recall.*

Though the teacher did not create any specific arrangement in the classroom setup for collaboration (group work), she stated about the importance of collaborative work. She claimed that she often involved students in collaboration such as called one student to perform a task and invited other student to discuss about that performed task. According to T2, students should actively participate in collaboration (*Std_R-1*) as this helps them to expand their knowledge and enjoy their learning. She stated:

> *Yes, there was an opportunity to work with collaboration. We did it as one gave input and from others we take the output. Sometimes I set the question from the students. Then I use to ask its' answer from one student and ask other students whether the answer is correct or not.[…] I think, it is very effective and students also love to learn in this way.*

During the FGD, one of the students argued that the teacher invited them to solve a task on the board after completing a topic and verified the performed task by other students. So, their class became interactive. He stated:

> *So after a lesson, every student was requested once to come forward, solve the task and check whether the solution was correct or not by the others. From this side it can be said that it was interactive. (S5_C2)*

Besides, it is observed that the teacher provided different sorts of tasks (Appendix I) in the class. The tasks were of diverse dimension and most of them were in the sequence from easy to difficult. Besides, the teacher gave emphasis on students' practice. According to T2, if students do continue their practice, they can revise the problem and become more capable to do the problem smoothly. She claimed about the importance of giving homework in this regard. By practicing task at their home, they can identify where they are facing problem and can discuss on those issue in the next class. She stated:

> *[…] actually we have to learn things step by step. We will first calculate without condition, then apply for one condition and then for different conditions. That is, we go sequentially from easier to harder. […] actually practice is needed. If they practice a little by themselves, then actually learning will be good. As such, some homework has been given so that they can practice and we can discuss the problems they find in the next class.*

Theme 4: Offering multi-channel feedback

The analysis shows that in most of the classes T2 provided feedback to students by herself or by their peers. While providing feedback to the students, the teacher tried to understand whether the students perform the task with proper understanding or not. She asked students the reason behind the way they have done the task. She tried to understand whether students can capture the link among the contents and they can understand the logic behind them. It is also observed that the teacher often verifies the solution of a students by the other students and asked the reason why the result was correct or not. A sample of classroom situation regarding this issue is shown below.

> **T2:** S17_C2, come here, draw a graph which is increased for 2 minutes and decreased for 3 minutes and then increase again.
>
> **(**S17_C2 drew the graph on the board**)**
>
> **T2:** S17_C2, tell us S25_C2's answer is correct or not?
>
> **S17_C1:** No miss, she is wrong.
>
> **T2:** why?
>
> **S17_C2:** you told that the velocity is decreasing for 3 minutes, but she kept the velocity constant for 3 minutes.
>
> **T2:** okay, come here and correct her graph.

According to her, this way of offering feedback by peers is very effective for teaching-learning (*Std_R-3*) as by this way she can assess more than one students at a time and students become motivated to learn as they feel that they are given importance by the teacher. She argued:

> *What mainly considered is, whether students understand the logic, are they able to identify where the difference is, how the topics are related. This was actually my plan to understand while providing feedback. […] feedback by peers is necessary because when someone else can judge one's judgment, it means that the concept of both of them has been cleared. Also I can evaluate two people at the same time. Um.. It is important in learning in the sense that he will be inspired next time because I gave him the opportunity to correct someone else, I gave priority in a sense.*

This means that feedback provided by peers helps both the students who got the feedback and who has given the feedback. As to provide feedback, students' need to justify their thought with proper logic, it ultimately develops their reasoning skills. This quote also indicates that while teacher asked a student to provide feedback to his peers, it ultimately inspired him in learning (helps to develop PD).

It is also observed that students get feedback from the ICT tool. In the last class, T2 created the environment as such students can verify their task using ICT tool. The teacher used a program (using Desmos apps) by which students could draw graph of straight line for some given conditions of a real-life problem and the apps automatically convert the graph in motion picture (Figure 4.31). By clicking on the play button, students can see the motion picture of their plotted graph and can check whether their result is correct or not for the given conditions.

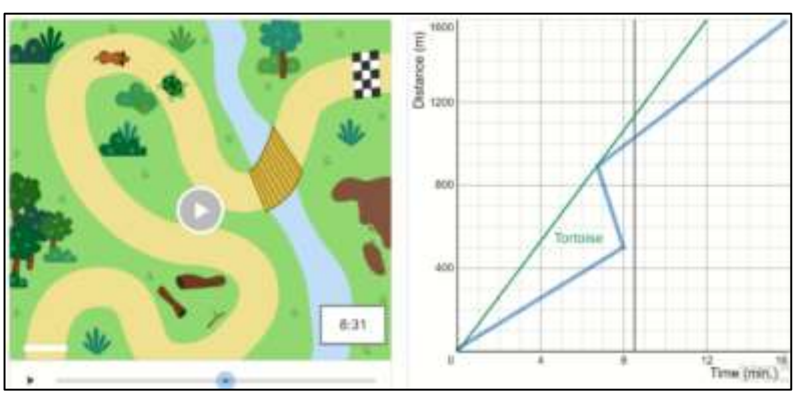


Figure 4.31: ICT provide feedback on students' work

According to the teacher, such type of feedback provided by the ICT tool makes lesson interesting and develop students' concept clear. She claimed:

> *[...] It was set up so that they would do the graph, so the motion capture would be done. They can see for themselves that whether the graph they drew is correct or not, they can verify themselves. That is why they were asked to come. After drawing the graph, others tried to make corrections or others agreed. The issue was that everyone could judge whether it was correct or not.*

During FGD, students also talked about the feedback provided by ICT (*ICT_R-4*). One of the students claimed, "*I sketched the graph in my paper and then checked it by running the software (Desmose). I found my graph was correct*". (S2_C2)

Theme 5: Offering opportunities to identify error/ imprecision

The analysis shows that throughout the classes, the teacher emphasized on counter example along with the example of any mathematical idea. For instance, after discussing about the concept of relation and function, T2 invited students to come to the board and asked them to write an example which is a relation but not a function. According to the teacher "*the reason for this was that they would not guess the answer. If they have a clear concept, then they can answer the questions by proper logic*". Besides, it is also observed that after performing a task by a student, the teacher asked other students to identify the mistakes. According to the teacher, this technique is effective as by this way she can assess the students whether they were attentive in the class or not. She argued that it is vital for the students to follow the teacher's instruction attentively (*Std_R-5*). Otherwise, their learning will be incomplete. She claimed:

> *The purpose of this was that in some cases many students actually became a bit inattentive and they just agreed with the teacher. If they have the concept fully clear, they can judge whether the information is false or correct. So intentionally I give some wrong information. When they are opposing, I get confirmation that they are in the right track. […], in this way I also confirm whether students attentively follow my instruction or not.*

It is observed that T2 emphasized on the issues where there was a possibility to create misconception by the students. For instance, while teaching about function, teacher not only used "f(x)" for function notation, instead she used g(x), h(x) so that no misconception arises on that issue. A sample of how teacher explores students' misconception in the classroom is shown below.

(teacher write f(x)=5x+3 on the board)

T2: Students, what is f(x)?

Students: it is a function

T2: can I write g(x) or h(x) instead of f(x)?

(Students seem confused, some students say 'yes', some say 'no' in low voice)

T2: Okay, we can write h(x), g(x), M(x) whatever, for the notation of function but it must follow the properties of function. Clear?

Students: yes, miss (loudly).

The teacher stated:

> *In many cases, we see that traditionally f(x) is used more to represent a function. Thus, a misconception can be created that function must be represented by f(x) only. That is why, I try to clear them that it does not matter, we can use any capital letter, small letter. But we must have a logic to it.*

It is seen that the teacher was very concern about making the lesson effective. She argued about the necessity of students' active involvement into the lesson (*Std_R-4*). According to her, "*if students do not engage willingly, the teaching-learning will be not effective*". It is observed that in every classes, the teacher prepared the PowerPoint slides very systematically and in very organized way. She tried to provide all possible vital information in the slides and slides were arranged sequentially (e.g. Figure 4.32). According to T2, if slides are prepared maintaining proper sequence, it is convenient for the teacher to deliver the lesson within a short period of time (*ICT_R-5*) and the class becomes effective.

Moreover, she argued that it helped learners to learn topic connecting with each other and make the lesson easier as well as sustainable (*ICT_R-6)*. She claimed:

I actually tried to maintain the sequence to keep the students engaged and ICT helps me to prepare my lesson sequentially. I personally believe that if we can learn by maintaining sequence, we can relate the topics, and learning become easier. And when we learn by relating, we actually remember it for long time. […] And I can handle a lot of information in a short amount of time, so I can give my full attention on problem solving.

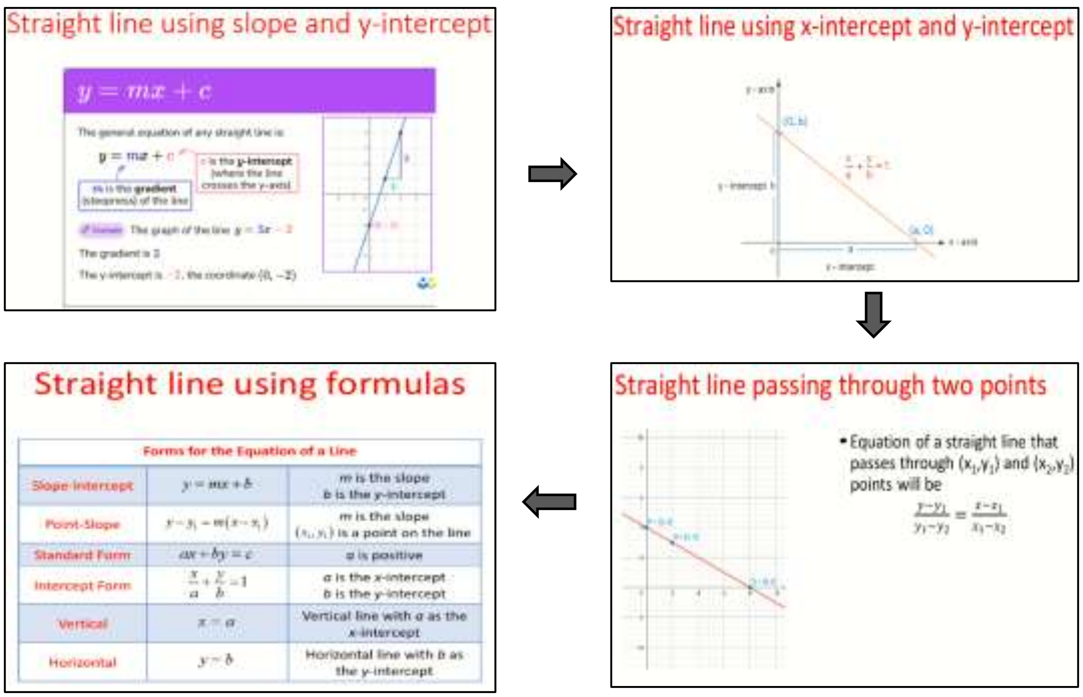


Figure 4.32: Sequence of slides to teach difference forms of equation of a straight line

The analysis also reveals that while performing a task by students, the teacher scaffolds them so that the students get the correct path to do the task accurately. For instance, in the last class, T2 asked students to draw linear graph using Desmos apps. While performing the task, the teacher asked them some probing question to keep on the right track and assist them if they face struggle to operate the tool. She expressed:

I was trying to monitor them and sometimes asked some questions to think themselves so that they do not proceed in the wrong way. […] I tried to give some guidance when they use the slider because they have never used GeoGebra software before. Thus I tried to help as much as I could to make it very easy for them to operate.

All the above discussed strategies were adopted by T2 to conduct the classes using ICTs. Besides, the teacher applied several types of instrumental orchestration techniques while using the above mentioned pedagogical approaches. Various types of instrumental orchestrations performed by T2 are discussed in the next section.

4.2.2.3 Performed Instrumental Orchestration

The analysis shows that the teacher applied different types of instrumental orchestrations throughout the classes. It is observed that T2 did not use ICT tool prior to any discussion about mathematical topic (not-use-tech) though ICT tools were available in the class. In most of the classes, she explained the mathematical concepts with the assistance of white board if necessary, then used the ICT tool. She often showed information on the screen and directed students to write on their paper (link- screen-board). According the teacher, she kept the major point on the slide and explained the details on the white board. She explained the topic on the board linking with the slide presented (Figure 4.33) and also asked the students to keep record on their paper, so that they could revise them when necessary. She stated:

Figure 4.33: Link-screen-board

> *[…] it's better to write down the notes on their paper because they can review it when they want. This is the reason for which I actually asked them to write. […] I have shown the formula in the slide but how the formula is derived I didn't show the details in the slide. So, if I explain them a little by using the board, I think learning becomes easier. Thus, if screen and board are side by side they can compare easily.*

While she displayed mathematical content on the screen, she explained clearly what is displayed on thescreen (Explain-the-screen). It is also observed that T2 welcomed students to talk about what is displayed on the screen (discuss- the-screen). For instance, in the 4th class, the teacher invited a student to discuss what is displayed on the projection screen

(Figure 4.34). According to the teacher, she applied this strategy to understand whether students clearly grasp the idea or not. She stated:

> *[…] in most cases, if I ask students whether they understand or not, there is a chance that they will say "yes" without understanding. Thus, I welcome them to explain me what is shown on the screen, if they are able to explain, that mean their understanding is clear.*

Figure 4.34: Discuss-the-screen orchestration

It is also observed that while operating the GeoGebra software for discussing about the graph of function, the teacher did not show any demonstration of the technical issue of that software. That is why, when students directly operate the ICT tools (i.e. GeoGebra), teacher provided them different sorts of technical support (technical-support) such as how to move the slider, how to draw a graph in the Desmos app, etc. It is seen that the students seem very used to with technology and operate the ICT tools with minimal direction by the teacher. Besides, while students work individually, the teacher moved in the classroom and observed what the student doing. She sometimes scaffolds students when students stuck with the task (Work-and-walk- by).

By analyzing the teacher's overall pedagogical consideration with ICTs, it is found that the teacher tried to conduct the classes with the combination of traditional (lecture-based) method and modern (interactive) method. It is found that throughout the lesson, teacher tried to build students' solid concept about mathematics with proper logic, become skilled on procedural fluency as well as ability to solve problem in multiple ways. In addition, she tried to make the lessons interesting so that students feel motivated to learn. While the teacher implemented different approaches with the help of ICTs, some specific roles of ICTs (Table 4.10) as well as students (Table 4.11) are explicitly identified which are shown below.

Table 4.10: Role of ICTs

ICT_R-1	Help to visualized the real meaning of math
ICT_R-2	Add fun factor in learning and motivate
ICT_R-3	Make the complex topic easier
ICT_R-4	Provide instant feedback
ICT_R-5	Time saver
ICT_R-6	Make the learning sustainable

Table 4.11: Role of students

Std_R-1	Engage actively in collaboration
Std_R-2	Work willingly /directly with ICT
Std_R-3	Provide peer feedback
Std_R-4	Engage lesson willingly
Std_R-5	Attentively follow teacher's instructions

4.2.3 Understanding students' level of mathematical proficiency (MP)

4.2.3.1 Students' baseline understanding of MP

A paper-pencil test and survey questionnaire were administered before the intervention and data were analyzed to understand students' baseline understanding about MP. The analysis in Table 4.12 shows the mean score of all the five strands of MP. All the strands were scored ranging from 1 to 10 except the productive disposition (scoring range from 1 to 5). My analysis (in Figure 4.35) shows that among the four strands of MP that is conceptual understanding, procedural fluency, adaptive reasoning and strategic competence; students' procedural fluency is higher than that of all other strands. It is also found that students' level of mathematical conceptual understanding, ability of strategic competence and adaptive reasoning are almost same (about 2) and very low.

The analysis also shows that students have the mean score 3.82 for the productive disposition strands. This survey mean score represents that students' shows their positive agreement about overall productive disposition. So, the students considered to have high productive disposition on mathematics.

Table 4.12: Descriptive statistics of the strands of MP

Conceptual Understanding		Procedural Fluency		Adaptive Reasoning		Strategic Competence		Productive Disposition	
Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2.23	1.61	6.13	2.16	2.33	1.56	2.13	1.41	3.82	.34

Score range from 1 to 10 — Score range from 1 to 5

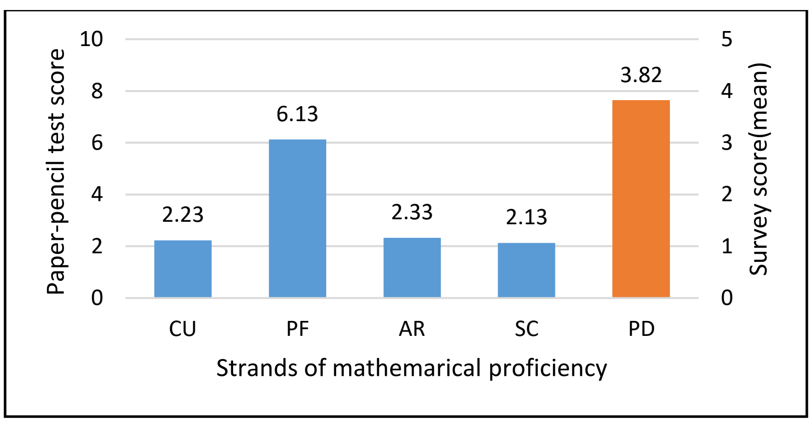


Figure 4.35: Mean scores of each strand of MP before intervention

Since overall productive disposition is influenced by seven distinct indicators; each indicator is analyzed rigorously to see which factor(s) greatly influenced the overall productive disposition. Figure 4.36 shows that all most every indicator except confidence have higher mean score (as mean score > 3.4). This reflects that other than confidence factor, students' shows their positive viewpoints about all the items. As the mean score of confidence factor is 3.27, students' confidence about their math ability is Neutral. This reflects that students considered to have moderate level of confidence about mathematics. It is also revealed that students showed their strong positive stand (mean score >4.2) about the usefulness and worthwhileness (UW) of mathematics as well as about their curiosity (Cu) to know the real-life oriented math problems and how to solve them.

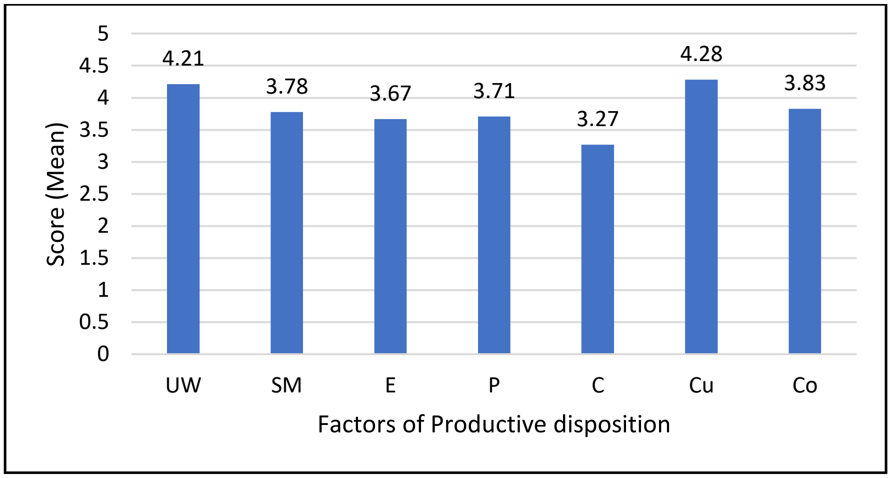


Figure 4.36: Mean scores for each indicator of PD before intervention

The analysis also depicts that for sense-making endeavor (SM) and Cooperation (Co) aspects, students have almost the same mean score (about 3.8). This means that students considered to have high ability to make sense of mathematics and to cooperate their peers in leaning mathematics. It is also found that enthusiasm (E) and persistence (P) have almost the same mean score (about 3.7) which reflect that students have high enthusiastic and persistence in learning mathematics.

Thus, my analysis based on the survey and paper-pencil test data reveals that students' mathematical proficiency was not so notable prior to the intervention since their CU, SC and AR skills among the five strands of MP were very poor. However, they performed good in procedural skill and showed high productive disposition on mathematics.

4.2.3.2 Students' mathematical proficiency after intervention

After completing the intervention that is participating six classes in ICT-facilitated environment, students' mathematical proficiency was again measured by both the paper-pencil test and survey. After the intervention, the mean scores of all components of the MP is shown in the Figure 4.37. The figure shows that students' conceptual understanding and procedural fluency are good as the mean score 5.23 and 5.63 respectively which lies between 5 to 7.5. Besides, the other two strands, adaptive reasoning and strategies competence mean score are 4.23 and 3.37 respectively. It reflects that students have moderate level of proficiency on those strands of mathematical proficiency. Nevertheless, the mean score of overall productive disposition is 3.86 which represent students' high productive disposition on mathematics.

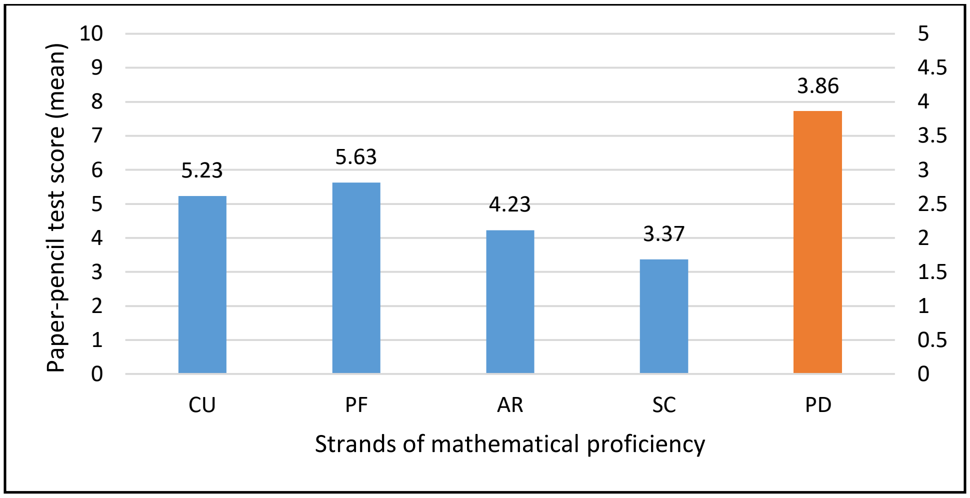


Figure 4.37: Mean scores of each strand of MP after intervention

To observe factor's influence (e.g. UW, SM, E etc.) on the overall productive disposition after the intervention, each factor under the productive disposition were analyzed further. Figure 4.38 shows that all most every indicator except confidence have higher mean score (as mean score > 3.4). This reflects that other than confidence factor, students' shows their positive viewpoints about all the items. As the mean score of confidence factor is 3.17 (SD 0.69), students' confidence about their math ability is medium. It is also revealed that students showed their strong positive stands (mean score >4.2) about the usefulness and worthwhileness of mathematics. Which reflects students' strong belief about the usefulness of mathematics for their future. The analysis also shows that for sense-making endeavor (SM) and Curiosity (Cu) aspects, students have almost the same mean score (about 4) whereas the mean scores (about 3.8) have been found for the indicators persistence (P) &

cooperation (Co) and 3.73 for enthusiasm (E). This means that students considered mathematics as interesting, show their high level of persistence and cooperate each other in learning mathematics. A detail descriptive statistics including mean, median and standard deviation has given in Appendix N (Case-II).

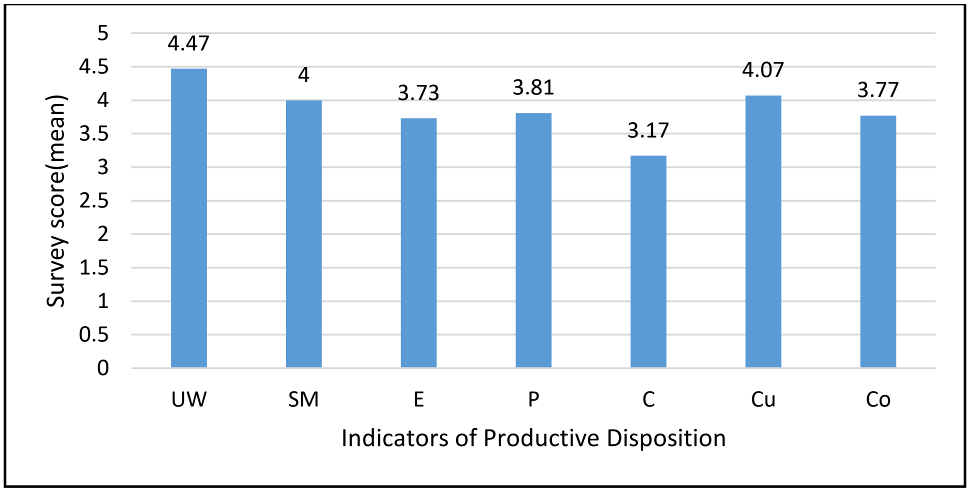


Figure 4.38: Mean scores for each indicator of PD after intervention

Again, to determine whether the data collected from paper-pencil test (before and after intervention) was normally distributed or not, Shapiro-Wilk test of normality was conducted. The results indicate that data (before and after intervention) for conceptual understanding, procedural fluency, adaptive reasoning and strategic competence are normally distributed (as p value of each component is greater than 0.05, see Appendix L(b)). Thus, a paired sample t-test was conducted to measure whether there was any change in students' conceptual understanding, procedural fluency, reasoning skill and strategic competencies after participating in the six experimental classes. The data in Table 4.13 are used to find out whether there was any difference between the pre and post paper-pencil test score. It is observed that there is a significant change (as $p<0.05$) in the mean score of the pre and post-test for all components excepts for the procedural fluency. This means that students' ability of conceptual understanding, reasoning skill and ability to formulate and solve math in multiples ways have increased after attending the six experimental classes.

Table 4.13: Comparative statistics of CU, PF, AR and SC

Four strands of MP	Test	Mean	Std. Deviation	Mean Difference	t-value	p-value
Conceptual Understanding (CU)	Pre test	2.23	1.61	-3.00	-6.52	<.001
	Post test	5.23	1.91			
Procedural Fluency (PF)	Pre test	6.13	2.86	0.50	0.68	.505
	Post test	5.63	2.99			
Adaptive Reasoning (AR)	Pre test	2.33	1.56	-1.90	-3.28	.003
	Post test	4.23	2.42			
Strategic Competence (SC)	Pre test	2.13	1.41	-1.23	-3.65	.001
	Post test	3.37	1.90			

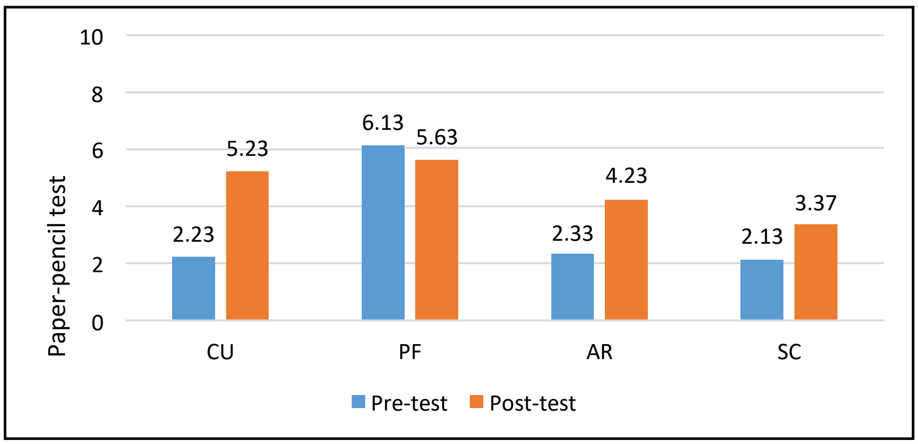


Figure 4.39: Comparative mean score of four strands of MP before and after intervention

It is also seen from Figure 4.39 that though prior the intervention students' *conceptual understanding* was very low, it significantly increased (as $p<0.05$, see table 4.13 for more details) after the intervention. It is also observed that students' procedural fluency became lower after the intervention, though the result is not significant ($p=0.505>0.05$, see Table 4.13 for more details). The other two components *adaptive reasoning* (i.e. ability to estimate the answer with proper justification & ability to draw conclusion) and *strategic competence* (i.e. ability to formulate, represent & solving math in multiple strategies) also improved significantly (as $p=.003$ and $p=.001$ for adaptive reasoning and strategic competence respectively) after the experimental classes.

In order to measure students' habitual inclination about mathematics i.e. productive disposition (PD) changes or not after participating in the experimental classes, a Wilcoxon Signed Rank Test was done as the data were ordinal and not distributed normally (see Appendix M(b)). It reveals from Table 4.14 that the indicators *useful & worthwhile* and *persistence* increased after the intervention (Md=5, n=30 & Md=3.67, n=30) compared to before the intervention (Md=4, n=30 & Md=4, n=30), though the change is not statistically significant and effect size is small (as p>0.05 and r=-0.129, see Appendix O(b) for more details). In addition, for the rest of the indicators, there were no changed after the intervention in compared to before intervention except the factor *confidence* (as Md=4 for all indicators). It is found that after the intervention, students' confidence level become decreased (Md= 3) compared to before intervention (Md=3.5), though the change is not significant and effect size is small (as z=-0.652, p=0.515, r=-.084, see Appendix O(b) for more details). Thus, the survey data shows that students' productive disposition does not change due to experience in the ICT- facilitated teaching-learning environment.

Table 4.14: Comparative statistics for the factors of PD

Factors of PD	Test	N	Mean	Median (Md)	z-value	p-value	Effect size r
Useful & worthwhile	Pre test	30	4.21	4.00	-0.999	.318	-0.129
	Post test	30	4.47	5.00			
Sense-making endeavor	Pre test	30	3.80	4.00	-.977	.329	-0.126
	Post test	30	4.00	4.00			
Enthusiasm	Pre test	30	3.67	4.00	-0.346	.730	-0.045
	Post test	30	3.73	4.00			
Persistence	Pre test	30	3.71	3.67	-0.031	.975	-0.004
	Post test	30	3.81	4.00			
Confidence	Pre test	30	3.27	3.50	-0.652	0.515	-0.084
	Post test	30	3.17	3.00			
Curiosity	Pre test	30	4.28	4.00	-1.313	0.189	-0.170
	Post test	30	4.07	4.00			
Cooperation	Pre test	30	3.83	4.00	-0.090	0.928	-0.012
	Post test	30	3.77	4.00			

Figure 4.40 shows the comparative mean score of paper-pencil test and survey data for both the pre and post-test. It is seen from the figure that students' ability of conceptual understanding, adaptive reasoning skill and skill of strategic competence increased after the intervention. On the contrary, the mean productive disposition score seems almost same after six classes. Surprisingly, after the intervention, students' procedural fluency skill decreased but not significantly.

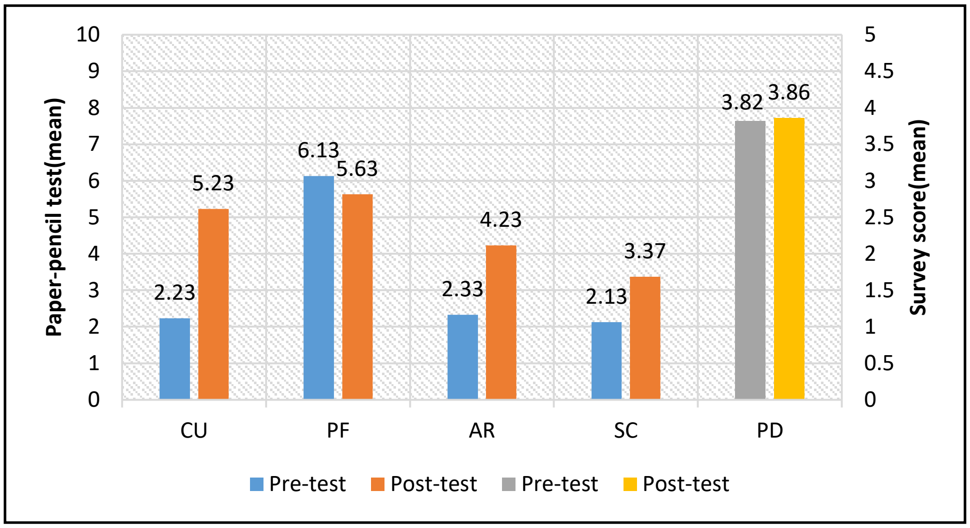


Figure 4.40: Students' mathematical proficiency before and after intervention

Though in the classroom observation, it was seen that students perform well in all strands of mathematical proficiency, the paper-pencil test depicted the trends of procedural fluency is somewhat decreasing. Thus, I conducted a FGD, where an activity was provided to the students and asked them to solve that problem discussing with each other. The analysis of data collected from FGD is discussed in the following section.

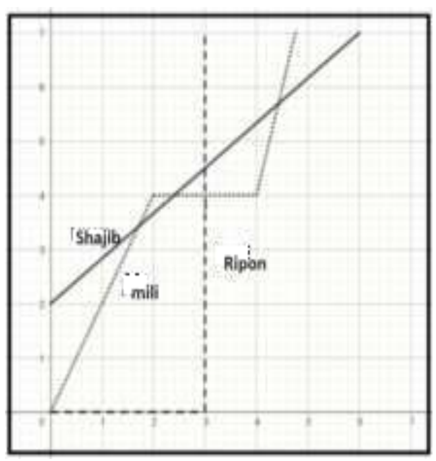
4.2.3.3 Understanding students' development of MP through FGD

By analyzing the data from FGD, it is found that students grasp solid concepts on function, graph of function and its application in real-life. From their responses it can be claimed that students can justify their answer with proper logic and critically think to solve a problem in different ways. Besides, at the last part of the FGD, they drew a graph for given conditions very thoughtfully and fluently. It is also found that they showed their positive view and confident while dealing with the problem and willingly cooperate and discuss with each other. Moreover, they claimed that they enjoy to learn mathematics while teacher conducts the class interactively. One of the students argued, "*When we work together, we enjoy a lot and can learn better, I think*". (S7_C2). Another student stated,

> *Miss give us chance to move slider, it was really interesting. I like to learn math with the help of technology as it helps us to understand real situation. (S4_C2)*

All these phenomena reflect their enhancement of mathematical proficiency ability. A portion of transcribed data while dealing with the problem in FGD and how the data reflect on different strands of mathematical proficiency are shown below.

Mili and Shajib started from their home to train station at the same time and Ripon started 3 minutes later.The relation between the distance vs time of their travels are shown in the following graph.



1. Explain Mili's journey.
2. Who reached first? How do you understand that?
3. Who travelled the fasted at the beginning? How do you understand that? Can you explain it any other ways?
4. Whose house was the closest from the station? How do you understand that?
5. Do all graphs in the diagram represent graphs of function? Can you explain them connecting with real world situation?
6. Mili's brother Dipu started to travel for station 1 minute later of Mili started. After 4-meter distance, he met with Mili and Shajib. If he reached the station directly (without stopping anywhere), what will be the graph of his journey?

S4_C2: Mili travelled with uniform velocity for first 2 minutes. But after that for 2 minutes Mili did not move at all. She was at the same position where she was. But after that she again travelled with uniform velocity for the last 1 minute and reach at her destination or at 7 meter.

R: Okay, you told that Mili travelled with uniform velocity for first 2 minutes and last 1 minute. Is there any difference in the uniform velocity between these times that mean first and last time?

S4_C2: Yes miss. Velocity increased for the last 1 minute.
R: Any other opinion?

(all showed their negative response by nodding)

Reflect CU

R: Okay, now what do you think for second question?

S2_C2: Ripon reached at first

S1_C2: Yes, Ripon. Because Ripon takes the least time than others. Ripon reached at 3 minutes while Mili reached at about 5 minutes and Sajib reached at 6 minutes.

Ability to explain with logic (Reflect AR)

R: Do, all have the same opinion?

(all showed their positive response by nodding)

R: Now, let's move to the question no. 5, what do you think?

S3_C2: The graph for Ripon is not function. Other two are functions.

R: Why?

S3_C2: If we check it by vertical line test, we can see that the graph for Ripon intercept in multiple places.

S5_C2: Since it intersects in multiple place, we can say this not a function because for one value of x, there are many value of y.

Ability to explain with logic (Reflect AR)

R: Any other opinion?

S6_C2: Vertical line test tells that if the graph intercepts the vertical line more than one point, then it is not function. For a function more than one output is not allowed for one input.

Ability to apply multiple strategies (Reflect SC)

R: Do you think the graph for Ripon is possible in real-life?

S5_C2: no.

R: Why?

S5_C2: Because without any time difference he reached at his destination which is quite impossible.

Ability connect mathconcept in real-life (Reflect CU)

R: Okay, do you think your answer to question no. 2 was correct or do you want to change your answer?

S3_C2: If Ripon's graph is not possible, then Mili reached first.

R: Why not Sajib?

S4_C2: Though Sajib was 2 miles ahead from Mili at the starting time, He did not reach first. He took 6 minutes where Mili takes near about 4.8 minutes to reach the destination.

Ability to explain with logic and draw conclusion (Reflect AR)

R: Anyone wants to deny?

(all showed their negative response by nodding)

R: Who was travelling the fastest**?**

S6_C2: Mili

R: Why?

S6_C2: Since here, along y-axis is distance and along x-axis is time, we can determine velocity by the slope.

R: Could you please explain it a bit?

S6_C2: we know slope m=tanθ. Here, θ is the angle with the positive side of x-axis. In case of Mili, we see that θ is greater than that of Sajib and Ripon's one is 0^{o}. Since Mili's graph's angle is more, we can say that her graph's slope is more and her velocity is more as well.

Ability to select correct procedure (reflect PF)

S1_C2: Mili's graph is much steeper than that of Sajib. That is why her velocity is greater than Sajib.

R: Any other opinion?

S4_C2: We can calculate. At first, Mili travelled 4 meters in 2 minutes while Sajib travelled about 1.7 meter within that time

Ability to apply different strategies (Reflect on SC)

R: Okay, Lets go for the last question. Any one plot the graph by discussing with other. You can plot it here.

S8_C2: Here it is.

R: Could you please explain a bit?

S8_C2: Here is Dipu's starting time *(S3 indicated the time at 1 minute by his finger*). He meets with Mili and Sajib after 2.3/ 2.4 minutes. Since he never stops and goes forward, so slope must be positive. This straight line will be the final graph *(*Figure 4.41).

Ability to apply correct procedure (reflect PF)

R: You said, the line will be straight line, is it mandatory?

S1_C2: Miss, in the question, it is not saying that the velocity is uniform. So this graph can be cervical also.

R: How?

S1_C2: For example, he can walk and run without stopping anywhere.

Ability to explain with logic and draw conclusion (Reflect AR)

R: Do you all agree with him?

S2_C2: Yes, miss.

S5_C2: Yes

(S3, S4, S6 showed their positive response bynodding)

R: Thank you.

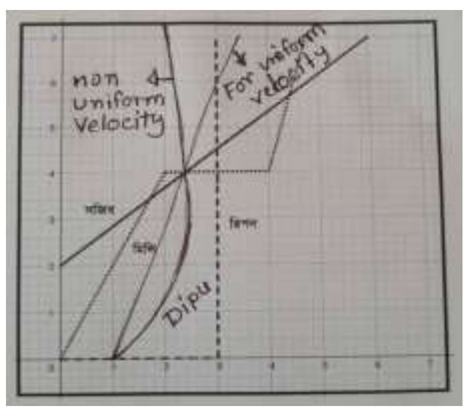


Figure 4.41: Performed task during FGD

Though the evidence from the FGD and classroom observation revealed that students' procedural fluency (PF) increased, the paper-pencil test result showed that students' PF decreased. This might be due to the post-test questions item where most of the students failed to formulate accurate linear equation for given condition and thus, failed to choose the appropriate procedure to solve the problem resulting decrease in PF.

4.2.4 Factors affecting integration of ICTs in teaching-learning process

4.2.4.1 Developing themes for influencing factors

By analyzing the data collected from teacher and head teacher via semi-structured interviews, the factors which affects teachers' ICT integration in their practice are identified & coded and grouped the similar patterns of factors into four themes- T*eacher factors, Student factors, School context and National context* (Table 4.15).

Table 4.15: Developed themes for influencing factor of ICT integration in PL process

Identified codes for affecting factors	Similar patterns under group	Developed theme
Departmental ethos Students; attitude Teachers' attitude	Teachers' Attitude Teachers' TPACK Teachers' preparation	Teacher factors
Parents' attitude Students' interest Technical support Financial support	Students' attitude Students' interest Parents' attitude Misuse of ICTs	Student factors
Teachers' preparation Physical facilities Teachers' TPACK	Departmental ethos Physical facilities Technical support	School contexts
Curriculum Professional development Course duration and assessment policy	Curriculum Professional development Financial support Course duration and assessment policy	National context

4.2.4.2 Teacher factors

Teacher's TPACK

According to T2, teacher's knowledge about technology and how to apply technology for a specific lesson are vital factors for integration of ICT in teaching-learning purpose. She argued that teachers must have to be knowledgeable about the appropriate technology to achieve the goal for a specific math content. Besides, their knowledge about technology as well as content, and how to bridge between them are crucial to get benefit from integration of ICTs in education. According to T2, different sorts of online tutorial for professional development may be helpful for enhancing teachers' TPACK. She stated:

> *[…] both subject knowledge and technological knowledge are actually needed. If he doesn't have subject knowledge, then he won't know what to show and if he knows what to show he has to know how to show it. […] I think YouTube tutorials are very helpful in this case. Because you can't actually learn them by taking a course, you don't even remember them. So if I can decide what I want to do then I can learn how to do it.*

Teacher's attitude

The analysis of the study shows that teachers' attitude is another prime factor of integrating ICT in teaching-learning purpose. According to T2, since teachers have the full freedom to use technology in their class, it fully depends on their attitude. She argued that to perform class with the assistance of ICT, teachers need to have a proper knowledge about the content as well as technology and it requires much time to become skilled. According to the teacher, it is a kind of struggles for the teachers and that is why they sometimes try to avoid the use of technology in their classroom and show negative attitude regarding ICTs use in the classroom. The teacher stated:

> *I have complete freedom and can teach completely in my way. I can do what I want without taking anything from anyone else. So it is necessary that there must be a desire to use the freedom. There are many opportunities, now the question is how much I want to utilize the opportunities. […] As a teacher, I have to learn the available software first and have to give enough time to get proper knowledge about the software. Because if you don't learn it yourself, you can't show it to someone else. When I use the software, if I have any gap in knowledge, I can't apply it correctly. [...] And different software has different applications, each one has a specific code. So knowing these codes seems to me as a teacher I have to struggle a little bit. And in many cases, to avoid this struggle, we become discouraged that there is no need for us to take this approach.*

Teacher's preparation

The analysis of the study shows that teachers' preparation is another factor for conducting class using ICT. According to T2, to conduct class with ICTs, teachers need to be well prepared which ultimately boost teachers' TPACK. In addition, it helps them to predict what will be the probable questions from students and how they will response on those questions. She also claimed that it will help them to identify their gap in the lesson. On the contrary, TPACK knowledge is essential to get prepared for the class using ICTs. T2 stated:

> *When I plan to take a class using ICTs, I have to be well prepared. Because when I go for preparation, I will see where is my lacking. If I can think from students' point of view that this question can come. And how will I tackle this question, so I have to increase the subject knowledge. Um.. also the technical knowledge. Because students may sometimes ask for technical questions also. So I think it will definitely enhance my skills as a teacher. […] Also, to be prepared for the class perfectly, I must have solid knowledge about content and technology.*

Moreover, T2 stated that while conducting class in multimedia setting, teachers can deliver lots of information during a short period of time due to their well preparation. T2 claimed that in most of the classes, she prepared the lesson in chronological order that help her to show easily the step by step method within a limited time. That is why, large class size was not a big issue for her while conducting class using ICTs. T2 argued:

> *I don't think class size is much of an issue in multimedia classes. I can handle a lot of information in a short amount of time. I can give my full attention to problem solving. I can do it very easily as my lecture is well prepared. If it was a traditional class instead of a multimedia class, it would not have happened. Because I can show step by step process in short time. So I think class size is not a factor here at all. I can also take classes in larger classes. I can take classes easily.*

By analyzing the data on teachers' viewpoint, it is found that two factors- teachers' TPACK and attitude directly effect on ICT integration while teachers' TPACK is influenced by teachers' preparation. Figure 4.42 shows the influencing factors to integrate ICTs related to teachers.

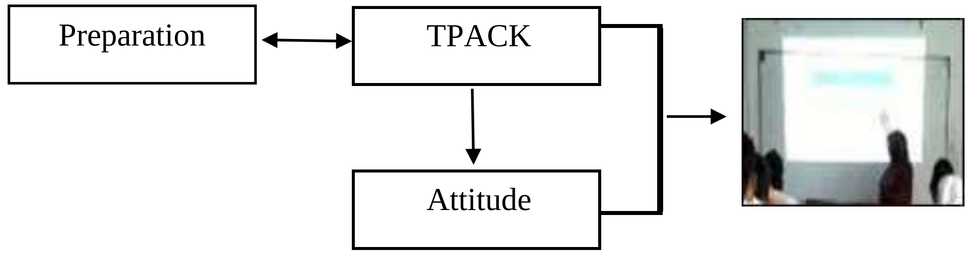


Figure 4.42: Factors affecting integration of ICT related to teachers

4.2.4.3 Student factors

Students' interest

It is found that T2 belief that students' interest to learn with technology is another vital issue to integrate ICT in teaching-learning purpose. T2 did not think that students prior experience about technology affect students' learning rather their (students) interest plays a vital role to learn with technology. She stated:

> *Personally I think if the student is interested in learning with ICT, then it is very easy to manage. We can easily explain using tools many things. Which actually we can't do free hand or explaining will be a bit more time consuming. [...] I think students' prior experience on technology doesn't matter much because actually most of the work the student has to do is not technology related. Even if you don't do it before, you can learn it. He has to learn with interest. That's the difference, if he is only interested that yes, I have to learn this, new way I'm learning then I think that's enough.*

Students' attitude

T2 reported that students' attitude towards the learning with technology is also a prime factor to teach with ICTs. She argued that in the one hand students' positive attitude foster the teaching-learning process, on the other hand negative attitude creates the scenario reverse. She shared her experiences in the online class during Covid that students hold very negative attitude about the online class and that is why they were not willing to learn online.

She expressed:

> *Positive attitude is actually most necessary. What actually happens in many cases for a negative attitude, such as in the case of our online classes, what is the need for online classes? Means, it will be time pass, there is nothing to learn in the online class, how can it be taught from such a distance? Such type of negative thought resist students to learn in online class. In some cases, many multimedia classes have the same attitude that what do I do when I hear them, what do I do when I see them, what is the use, if students have this attitude, then actually learning does not work.*

Parental support

My analysis shows that the students' attitude is also influenced by their family members. According to T2, while parents hold negative attitude regarding technology in TL purpose, it eventually is transmitted to students' attitude. Thus, T2 argued that parental support is very important to integrate ICT in teaching-learning process. She stated:

> *[…] I saw that the attitude of parents somewhat disturbs their children. Umm.. for example, parents who think ICT use is limited, not very effective, a phobia enters into their children. They think that it's not necessary, I can't do it.*

Misuse of ICT

The analysis shows that students' misuse of ICT effect on ICT integration in TL process. According to T2, despite a huge potentiality of ICT, it has some drawback also. If students misuse technology, it may hamper their learning to a large extent. From the head teacher's interview it is revealed that sometimes parents hold negative thought about learning with technology as they think, it has adverse impact on their children. She stated that during Covid period, students had to attend in the online class and sometime they misused the technology and became addicted in device, these issues formed parents' negative perception. According to the head teacher, if the student-focused effective technology is used for teaching-learning purpose, the probability of occurring negative incidents may be reduced and the scenario will change. The head teacher stated:

In the post-covid era, students become addicted in the device and negative things are being observed in their learning. Therefore, parents are sometimes reluctant to use technology. If learner friendly devices are used in teaching-learning activities, then I will be excepted by all.

In addition, T2 believes that along with the teachers, parent should aware of this. T2 claimed that school authority has taken several initiatives (e.g., awaring about the drawback of misuse of ICTs) to educate students as well as parents so that students have not misused technology. Though several initiatives have been taken by the school, T2 argued that the main responsibility belongs to the parent. Parents have to monitor their children so that they are not distracted from the learning due to the wrong use of ICTs. She stated:

In fact, there is scope to misuse technology by the students. For example, we see many wrong uses of the internet. As a teacher, we can explain the adverse impact of this misuse, it means to monitor them to some extent. But the monitor actually has to be done at home, it can actually be done by the family. It is not really possible for the teacher to monitor properly. One thing that can be done is that teachers can check the direction of the student. But the majority of monitoring will come from the family. […] School is actually doing enough. For example, side effects are well explained in class. It was also said in the parents' meeting. In many cases, parents actually unfairly support their children, which is not acceptable. If unfair support can be reduced a little, then I think that the student will also be careful, the thing will be helpful for the authority.

By analyzing the data on student related factors, it is found that students' attitude and interest directly influence ICT integration. It is also found that students' attitude is directly influenced by their parents' attitude and students' misuse of ICT directly affects their parents' attitude. Besides, students' interest is also influenced by their attitude. Influencing factorsto integrate ICTs related to students are shown in Figure 4.43 below.

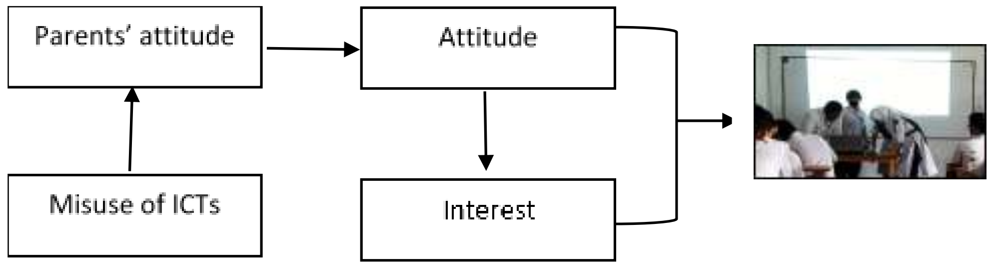


Figure 4.43: Factors affecting integration of ICT related to students

4.2.4.4 School context

Technical support

T2 claimed technical support is one of the factors for conducting class using ICT tools. According to her, while the teacher conducts the class with the help of multimedia, she/he may face some challenges regarding technical issues such as adjusting aspect ratio, proper configuration, trouble shoot etc., thus it is necessary to have a skilled technician to mitigate those problems. In her voice:

> *In fact, the technician may be needed sometimes, not always. Um.. because sometimes the projector gets disconnected, the matter of actually changing the configuration, fixing the aspect ratio like that type of issue. In that case, I think a technician is needed. While using the projector, if the aspect ratio is not right then the display will not work properly. In that case it seems necessary.*

Thus, school management should consider this issue to effectively utilize ICT tools for teaching-learning purposes.

Physical facilities

To get benefits of ICTs for teaching-learning purposes, all sorts of physical facilities, proper infrastructure have to be ensured. If both the teacher and students do not get the suitable environment while conducting/attending the class with ICTs such as adjustable lighting arrangement, spacious space etc., they will not concentrate in the class properly. As a result of that, the expected goal will not be achieved. That is why, it is one of the prime factors to ensure physical facilities if ICTs are intended to be used for TL purposes. T2 argued:

To display PowerPoint slides on the projector screen, the matter of lighting is actually important. Because normally the rooms are arranged in such a way that enough light is occupied in the room. But when we want to do the power point display, if the room is not a little dark, the display cannot be seen well. That means that the matter of the curtain or blind, an ability to control the light is actually needed in the room. In most cases, the curtain or blind are not provided in traditional classrooms. In that case, the labs actually have it. So for this reason, it is more beneficial to take classes in the lab room.

The school head teacher expressed that teachers are already trained and ready to teach with ICTs but could not due to the insufficient logistics support. The head teacher articulates her helpless situation that she could not provide all sorts of physical facilities due to the financial issue. She stated:

Multimedia classrooms are needed to teach mathematics using ICT. Though teachers are positive, trained and prepared, school authorities are not able to provide all kinds of facilities due to financial reasons.

Departmental ethos

Analysis of the study shows that departmental ethos is another big issue in implementing ICTs in the teaching-learning process. To implement ICT in education properly, the school authority must have a positive attitude on it. They have to feel the necessity of it. She stated:

Before it happens, the authority must understand whether it is necessary or not. In many cases, the authority feels that there is no need as the ICT department will handle these matters.

According to T2, her school authority welcomes teachers to conduct classes with ICTs if they want. Similar view was found from the head teacher's opinion '[...] teachers can participate in all kinds of online activities as they wish'. However, in the follow-up interview, the teacher expressed the unsupportive attitude of the authority while she tried to install the software GeoGebra in the school computer. She stated:

> *I wanted to use the lab but the lab was not available, plus I wanted to install it on the computers of the lab by myself, I did not tell them to install it. I took it to pen drive. But they didn't let me install it. The software is not harmful software, it is a very light software. Just use it for graphing and plotting and then uninstall it. But they are not interested in any way. Their approach is like that […] umm.. we don't need it, and we won't need it. So why is it necessary now? This approach seems to me a little harmful.*

Besides, T2 argued that sometimes teachers are not willing to use ICT in their teaching learning purpose, they are not interested to learn about ICTs. While the authority takes decisions for introducing ICTs in education, several backlashes come sometimes, that is why instead of thinking positively, school authority thinks adversely. The teacher claims:

> *[…] if in-house training is organized to enhance teachers' ability on technology, there are many cases that, the teachers get annoyed that why should they learn, it is the responsibility of the ICT department. [...] In many cases teachers are not interested because they are not intent to learn. Since many backlashes have come if any decision has been made, the authority actually appears to be a little less interested in taking risks. So I think it is more important to solve these two issues.*

Again, the analysis shows that school authority can take necessary steps to ensure technology use for TL purposes. For instance, T2 argued that while preparing the routine if there is a mandatory schedule to conduct a class using ICTs, teachers will oblige to use ICTs in their teaching and gradually they become habituated with it. Since there is no obligation to conduct class using technology, teachers are not willing to take class with ICTs. Again since classes with ICT are held rarely, students do not feel interested in it. She stated:

> *Since there is no obligation, most of the teachers have little interest in multimedia classes. So if it can be done frequently then the interest of students, teacher will grow. Then, I think, things will become more normal. Thus I think, if we can do it while making the routine that 'yes' a multimedia class is fixed, that 'yes' how many multimedia classes will be in this session or how many of these should be in this*

half yearly. While there is some obligation, I think it will become a habit for us.

Thus, the analysis found that departmental ethos, availability of physical facilities and technical support are factors related to the school context that affect integration of ICTs in the teaching-learning process (Figure 4.44).

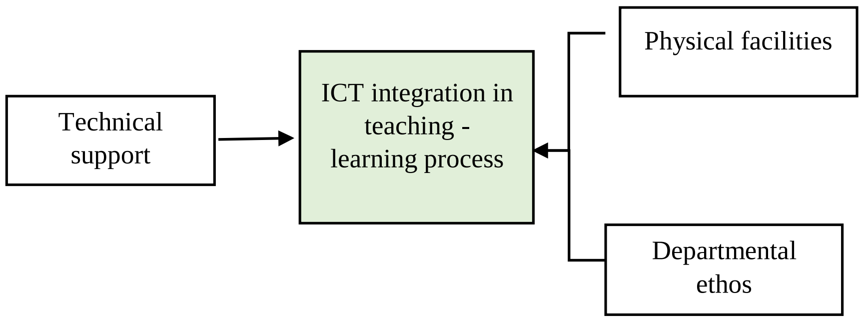


Figure 4.44: Factors affecting integration of ICT related to school context

4.2.4.5 National Context

Curriculum

The analysis shows that T2 stated about the suitability of the existing secondary mathematics curriculum. According to her, teachers already use technology to achieve the objectives of the existing curriculum. She mentioned that teachers can use ICT tools to show some of the trigonometric application, construction of theorems, connection between three and two dimensional figures which already appear in the existing curriculum. She also suggested that if in the curriculum, implications are more emphasized along with the theorems and schemes of work on how ICT could be used in the classroom, the math curriculum will be more rich and teachers can effectively use ICTs in their teaching. She stated:

The existing math curriculum has the scope to teach math content using ICT. In fact, it is already being used. I think it is much more applicable in case of a little higher class. For example, many applications of trigonometry can be shown, then construction theorems, solid geometric cases. Gaining knowledge of the implication of math is very important. Um.. right now it seems to me that implementation is less, theory based teaching is more. So I think if these issues are addressed in the *curriculum, then the math studies will be more rich.*

Course duration and assessment policy

The teacher reported that due to time constrains and the traditional exam system, there is limited scope to conduct class using multimedia. She stated:

> *We have limited scope to use multimedia class. One of the reasons is our traditional exam system. We are in a hurry to complete the syllabus within the limited class. So,many teachers think that multimedia class is an extra burden for them.*

Professional development

The analysis shows that professional development is one of the major factors to integrate ICTs in teachers' practice. T2 stated that some basic training must be provided to the teachers so that they become willing to extend their knowledge by their own effort. She also expressed that there are already some training programs for teachers' professional development. If these training could be conducted properly, teachers will be benefited by those. Besides, she reported about the necessity of in-house training, as in-house training is easier to provide. She stated:

> *Yes, training is required. Because without some basic training, it is not possible to do advanced work. Some basic training is required. Then try it yourself. There is already some training. Like the training we had in BANBEIS, the ICT training that was done for our teachers, I think if that training can be done properly, it can actually be developed in many cases. [...] In-house training is essential, because in-house training is easier to provide.*

The head teacher of the school also stated the importance of teachers' training for their professional development. She expressed that teachers are somewhat trained and if necessary the school provides in-house training by the ICT teachers. She claims:

> *Teachers are more or less trained as they have to process school salaries, examination results, ID card issuance via online. [...] If needed teachers are trained through ICT teachers.*

Financial support

Another important factor discussed by T2 was financial support. According to T2 teachers' interest to use ICTs in the classroom is not sufficient, financial issues have a large influence on it. Since, the traditional classroom setting is not properly suitable for teaching with ICTs. For the whole setup of a multimedia classroom, it requires a big budget. T2 expressed:

> *The financial issue is there because one thing is if there is no support from the authority then it is a matter. Because if we think about every school in Bangladesh, all the schools need a space to have so many projectors and so many multimedia classes. You don't have much space for setup. So it is definitely a financial thing because without financial support how can you do it. It is not possible. Financial matters are necessary for multimedia facilities.*

Like T2, the head teacher of the school also expressed the necessity of financial support. She claimed that though the head teacher and teachers possess a positive thought regarding the use of technology in the teaching learning purpose, due to the limited funding, they cannot properly utilize the benefits of technology. She argued:

> *Despite the head teacher of the school and teachers holding a positive attitude in using technology in teaching-learning activities, it is not possible to use the technology fully due to the lack of financial support.*

By analyzing the data focusing on national context, curriculum, financial supports, professional development programs, course duration and assessment policy are found influential factors in integrating ICTs in TL process (Figure 4.24).

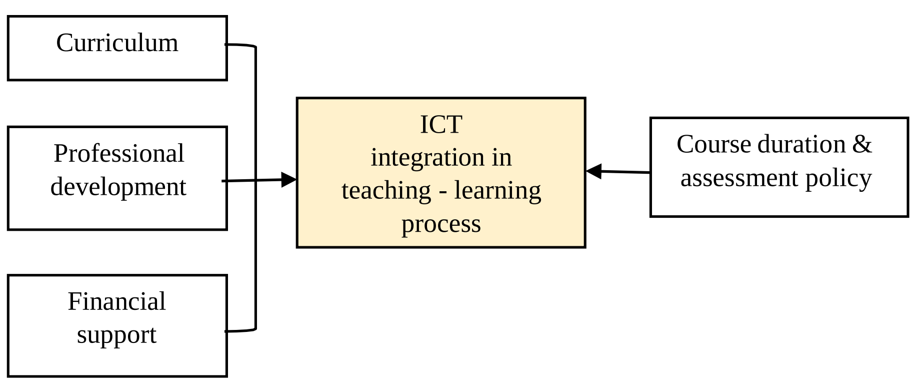


Figure 4.45: Factors affecting integration of ICT related to national context

4.2.5 Summary of the findings

Analyzing the data collected from all sources of Case-II, it can be summarized that, as in Case-I, the teacher in Case-II also applied various types of techniques to conduct class with the aid of ICTs. She used both the lecture-method (e.g., displaying screen and explaining about the topic) and modern method (e.g., invite students to explain their ideas and involve them in peer discussion) in the classes and emphasized on individual learning. As the teacher rarely engaged students in collaborative work (e.g., group work), she did not rearrange the classroom for collaborative support learning environment, rather her classroom space was supportive for observation learning (e.g., luminous space, a widespread board placed at the center of the front wall to visible for the whole class, availability of resources, internet facilities etc.). It is found that the teacher used different teaching approaches (e.g., connecting math with real context and prior knowledge, providing a variety of problems, providing scope to explain students' thoughts with proper justification, exploring misconceptions etc.) to make the learning meaningful. Besides, the teacher not only provided feedback by herself, but also encouraged her students to get feedback fromtheir peer and the ICT tools. It is also found that the teacher applied different types of instrumental orchestration (e.g., link-screen-board, explain-the-screen, technical-support etc.) while applying the different strategies in the class.

It is found that initially the students' productive disposition and procedural fluency about mathematics were good but the other three strands of MP (i.e. conceptual understanding, adaptive reasoning and strategic competence) were very low. But, after the intervention, their MP increased. From the classroom observation and FGD responses, it is found that students' feel more motivated to learn mathematics with technology when they engage into the lesson actively (e.g., work with collaboration, directly work with technology etc.). By analyzing the data, few roles of students (e.g., engage in collaborative work, willingly engage into the lesson, work directly with ICTs etc.) and ICTs (e.g., visualize the math with real situation, make the complex topic easier and sustainable etc.) were identified while main concern of teaching-learning would be to develop students' MP with the help of ICTs.

Similar to Case-I, it is also found that some factors affect integration of ICTs in the teaching-learning process. Under this case several factors related to teachers, students, school and national context were identified. Teachers' attitude, preparation and TPACK were identifiedas teacher related factors, whereas students' attitude, interest, misuse of ICTs and parents' attitude are identified as students related factors that influence ICT integration. In addition,technical support, physical facilities and departmental ethos are identified as influencing factors to integrate ICTs in school context while curriculum, professional development, financial support, course duration and assessment policy are identified as factors related tonational context.

4.3 Findings of the Study by Cross Triangulation of Two Cases

By analyzing the similarities and dissimilarities among the findings of the two cases, it is observed that the pedagogical considerations applied by both the teachers T1 & T2 (Case-I and Case-II) are similar to some extent. The major difference observed is that the main intention of the teacher of Case-I was to conduct the class interactively, involve students to learn with collaboration such as peer work, group work and whole class discussions, whereas the teacher of Case-II, conducted the classes by focusing on the combinations of both traditional (lecture-based) and modern approach (classroom interaction). She emphasized more on students' individual learning rather than collaborative learning. That is why she did not rearrange her classroom set up. Besides, T2 did not rearrange classroom setup claiming short duration of class time, whereas T1 rearranged the classroom amenities prior to start the class (e,g., arranging portable board, flexible learning space, adequate extra chairs etc.) and sometimes within the class (e.g., sitting rearrangement for group work). Besides, while T2 teacher conducted most of the classes in the traditional classroom where some facilities (e.g., variability of multimedia and internet support) and hardness (e.g., aspect ratio problem in multimedia setting, inappropriate lighting to visible the display of the screen etc.) exists, T1 conducted class in the ICT Lab room where students got the facility to directly use the assigned PC for them according to the teacher's direction. However, the teacher did not allow students to work with the assigned PC for them in every class, rather he involved students directly to work at his computer very often which provided a flavor of how students can be directly involved in the traditional classroom.

Though, in the ICT lab room, most of the facilities for conducting class with ICT were available, teachers faced some difficulties (e.g., network problem and turning on, un-functioning remote for power on/off multimedia, log on/off computers etc.). It is also found that T1 frequently tried to make students work directly or indirectly with technology wherever possible. On the contrary,T2 rarely engaged students directly with technology, though she argued for its importance. However, both of the teachers ensured technology accessibility by themselves and used ICTs effectively. The study shows that both the teachers have the experience to conduct class with technology, and they were very enthusiastic to use technology in their class, however, T1 was more experienced than T2 and he applied more effective pedagogical approaches than T2. Moreover, T1 received several national and international training related to pedagogy and ICT. It reveals that training programs have a great influence on teachers' professional development. It is found that the teachers adopted various strategies to make the learning meaningful (e.g. linking math with real-life, exploration of prior knowledge, providing multiple-ways to solve a problem etc.) and offered multi-channel feedback (e.g., feedbackby teacher, peer, ICT tools etc.). Exploration of students' misconception, identification of mistakes and work with counter-example are also stressed by both the teachers. Both of them were found giving emphasis to engage students through motivation and adopted different strategies to motivate them (e.g., praising the learner, valuing students' opinion, providing systematic and attractive lessons etc.). Both of the teachers applied all those aforementioned strategies with the assistance of ICT tools and by support of different types of orchestrations. Comparing their orchestration attempts, it is found that T1 applied more orchestration techniques (e.g. link-screen-board, monitor-and- guide, Sherpa-at-work etc.) than that of T2. The comparison between pedagogical approaches applied by T1 & T2 is shown in Table 4.16.

Table 4.16: Comparison between pedagogical considerations by T1 & T2

Category/ theme	Similar pedagogical approaches under each theme	Case-I	Case-II
Rearranging classroom amenities	Flexible and adaptable learning space	√	
	Physical space support- collaboration learning	√	
	Physical space support- observation learning	√	√

Ensuring Technology Accessibility and Its Appropriate Usage	Selection of tools	√	√
	Access to technology	√	√
	Involving learners directly to ICT	√	√ (rarely)
	Using ICT (screen) to perform the task accurately	√	
Adopting different strategies to make the learning meaningful	Linking and connecting math with real context	√	√
	Linking and connecting math with prior knowledge	√	√
	Providing scope to apply acquired knowledge in a new situation	√	√
	Exploring prior knowledge	√	
	Providing multiple ways of representation and strategies	√	√
	Providing scope of- peer discussion, group work, whole class discussion	√	√ (rarely)
	Encouraging for individual work/thought		√
	Encouraging to check the solution using variety of methods	√	√
	Encourage to apply math language	√	
	Offering challenging tasks	√	√
	Providing variety of several examples	√	√
	Providing scope to explain students' thought with proper justification	√	√
Offering multi-channel feedback	feedback by peer	√	√
	student's self-reflection	√	
	Teacher provides feedback	√	√
	ICT provides feedback	√	√
Offering opportunities to identify error/ imprecision	Exploring misconception	√	√
	Emphasizing on counter example	√	√
	Identify mistakes (by peer, by learner's own)	√	√
Engaging students through motivation	Praise the learner	√	
	Providing attractive picture	√	
	Providing well organized and systematic lesson		√
	Valuing learners' opinion	√	
	Facilitating to get the correct path	√	√
Performing Instrumental Orchestration	Technical-demo	√	
	Link-screen-board	√	√
	Discuss-the –screen	√	√
	Guide-and-explain /Explain-the screen	√	√
	Technical-support	√	√
	Work- and- walk-by	√	√
	Discuss-tech-without-it	√	
	Sherpa-at-work	√	
	Not-use-tech	√	√
	Monitor-and-guide	√	

During the ICT orchestration process, some specific roles of ICTs and also of the students were identified from both cases as shown in Table 4.17 below. Among those roles, most of them are explicitly discussed in Case-I while some are in case-II.

Table 4.17: Identified roles of ICTs and students while ICTs are used in TL process

Role of ICTs	Role of Students
Help to visualized the real meaning of math	Engage actively in collaboration
Helps to deal with problem with minimum error	Work willingly /directly with ICT
Encourage collaboration	Provide peer feedback
Provide instant feedback	Identify own mistakes/ self-reflection
Add fun factor in learning and motivate	Engage lesson willingly
Make the learning sustainable	Attentively follow teacher's instructions
Prepare students for the future	
Time saver	
Make the complex topic easier	

The study also found that the pedagogical approaches used by the two teachers ultimately increased students' mathematical proficiency. Since mathematical proficiency consists of five inter-linked components- "*conceptual understanding, procedural fluency, adaptive reasoning, strategic competence and productive disposition*" and students' ability on all those components cannot be developed by a single approach, it is found that some of the approaches adopted by teachers, directly enhance specific attribute of mathematical proficiency while some have indirect influence. For instance, according to the teachers, while students engage in collaborative work, they develop their strong conceptual understanding, thus the pedagogical approach- "*Providing scope of- peer discussion, group work, whole class discussion"* has direct influence on developing conceptual understanding whereas the rearrangement of classroom setup to "*support collaborative learning space"* ultimately open up scope for smooth collaboration and has indirect effect on students' conceptual development. Table 4.18 below shows the pedagogical approaches adopted by the teachers and combination of approaches that contributed to the development of the five components of MP of the students.

Table 4.18: Pedagogical approaches for developing five components of MP

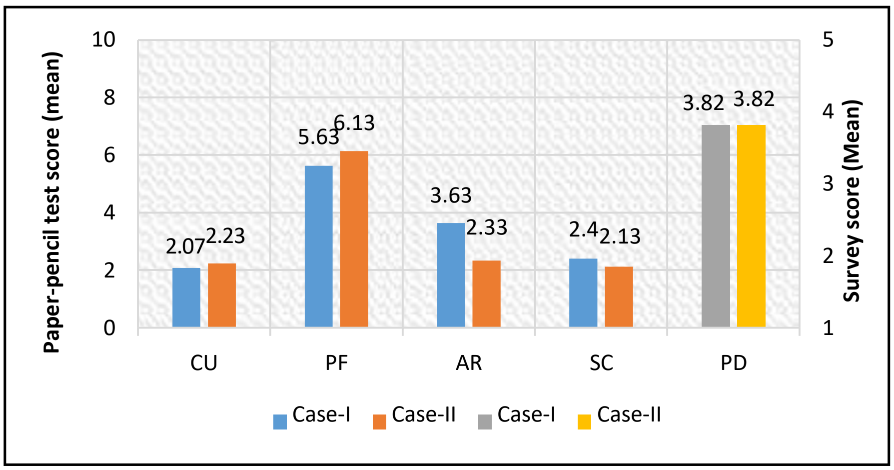
Strands of MP	Applied Pedagogical considerations
Conceptual Understanding	*Rearranging classroom amenities* • Physical space support- collaborative learning *Ensuring Technology Accessibility and Its Appropriate Usage* • Selection of tools- presentation, Geogebra, spread sheet, Desmose • Involving learners directly to ICT • Using ICT (screen) to perform the task accurately *Adopting different strategies to make the learning meaningful* • Linking and connecting math with real-life • Providing scope to apply acquired knowledge in a new situation • Exploring linking math with prior knowledge • Providing multiple ways of representation • Providing scope of- peer discussion, group work, whole class discussion • Providing the opportunity to speak/ use mathematical language • Offering challenging tasks • Providing variety of several examples
Conceptual Understanding	*Offering multi-channel feedback* • feedback by the teacher • feedback by peer • student's self-reflection *Error/ imprecision* • Exploring misconception • Providing counter example • Identify mistakes (by peer, by learner's own)
Procedural Fluency	*Rearranging classroom amenities* • Physical space support- observation learning *Ensuring Technology Accessibility and Its Appropriate Usage* • Involving learners directly to ICT • Using ICT (screen) to perform the task accurately *Adopting different strategies to make the learning meaningful* • Encouraging rapid recall • Providing variety of several examples • Providing Homework for practice *Offering multi-channel feedback* • ICT provides feedback

Adaptive Reasoning	*Rearranging classroom amenities* • Physical space support- collaborative learning *Adopting different strategies to make the learning meaningful* • Providing scope of- peer discussion, group work, whole class discussion • Providing variety of several examples • Offering challenging tasks • Providing scope to explain students' thought with proper justification *Offering multi-channel feedback* • feedback by the teacher • feedback by peer • Self-reflection
Strategic Competence	*Rearranging classroom amenities* • Flexible and adaptable learning space *Adopting different strategies to make the learning meaningful* • Providing scopes to apply multiple strategies • Exploring prior knowledge *Offering multi-channel feedback* • ICT provides feedback
Productive Disposition	*Rearranging classroom amenities* • Flexible and adaptable learning space *Ensuring Technology Accessibility and Its Appropriate Usage* • Involving learners directly to ICT *Adopting different strategies to make the learning meaningful* • Linking and connecting math with real context • Providing scope of- peer discussion *Offering multi-channel feedback* • feedback by teacher • feedback by peer *Engaging students through motivation* • Praise the learner • Valuing learner's opinion • Well organized and systematic lesson • Providing Attractive picture

The analysis of quantitative data (from survey and paper pencil test) shows that every component of students' MP for the both cases have increased after the intervention except procedural fluency. However, in case of Case-I all the four components of MP (CU, AR, SC and PD) increased significantly whereas for Case-II, students' PD has not increased significantly. Comparing the quantitative data for both the cases before intervention (Figure 4.46(a)), it is seen that students' level of mathematical proficiency for each individual strand was not so different. Whereas, the mean scores of all components of the

MP for both cases shows that the students who participated in the Case-I perform better than that of the participants of Case-II after the intervention (Figure 4.46 (b)). Again, the qualitative analysis (FGDs and classroom observations) shows that students' every component of mathematical proficiency developed through the experimental classes in both the cases. More specifically, in case of Case-II, students showed their high productive disposition while they engaged in interactive learning. It reflects that ICT-enabled teaching-learning process promotes students' MP and teaching approaches (interactive teaching) have a great influence on students' productive disposition.

(a) Before intervention



(b) After intervention

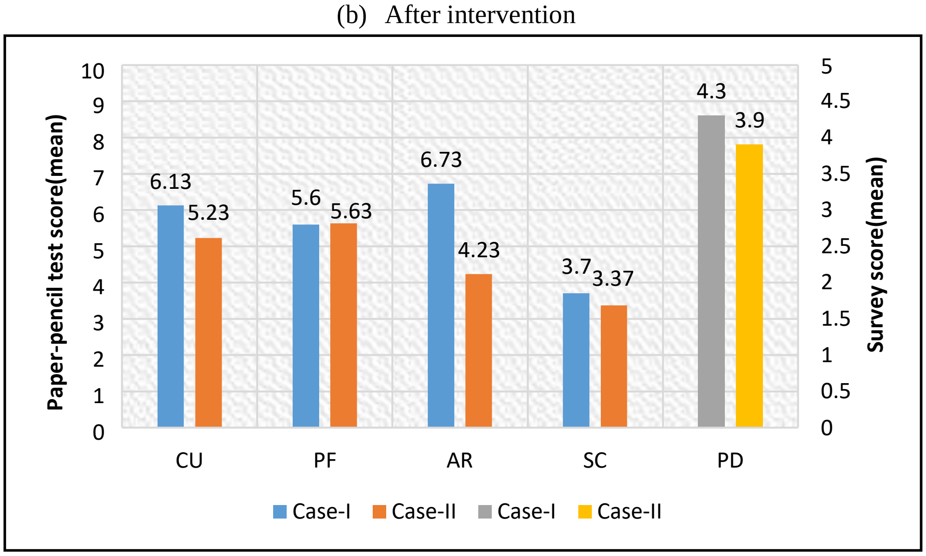


Figure 4.46: Comparison between the students' MP for Case-I and Case-II

Table 4.19: Comparison between the influencing factors identified in Case-I and Case-II

Category/ them	Identified factors	Case-I	Case-II
Teacher factors	Teachers’ attitude	√	√
	Teachers’ perceived usefulness	√	
	Teachers’ interest	√	
	Teachers’ TPACK	√	√
	Teachers’ confidence	√	
	Teachers’ preparation	√	√
	Teachers’ experience	√	
	Teachers’ class load	√	
Student factors	Students’ attitude	√	√
	Students’ interest	√	√
	Students’ misuse of ICTs	√	√
	Parents’ attitude	√	√
	Home environment	√	
School contexts	Large size class	√	
	Departmental ethos	√	√
	Physical facilities	√	√
	Technical support	√	√
National Context	Curriculum	√	√
	Professional development	√	√
	Financial support	√	√
	Course duration		√
	Assessment policy		√

It is found that both the teachers of Case-I and Case-II, identified some factors which influenced their use of ICTs. The identified factors emerged under the four themes (Teacher factors, Student factors, School context and National context) and their influence was found to vary in two cases. It is found that T1 identified nine factors on the sides of *Teacher factors* while T2 claimed about three (teachers’ attitude, TPACK and preparation). In case of *Student factors*, both the teachers T1 and T2 claimed that the students’ attitude, interest, parents’ attitude and misuse of ICTs are the influencing factors to integrate ICTs in the TL process. However, other than that, T1 talked about students' home environments which affect ICT integration. Again, departmental ethos, technical support and physical facilities are identified as affecting factors by both T1 and T2 in case of *School context*. Other than those three factors, the teachers T1 claimed about large class size. Again, curriculum, professional development, financial support are identified as influencing factors by both the teachers whereas the factor course duration and assessment policy are identified by teacher T2. All these factors emerged under the theme *National context*. Head teachers of both schools also support some of the factors which are identified by the teachers.

Chapter Five

DISCUSSIONS

This chapter summarizes and discusses findings regarding three research questions (RQ) that I aimed to address in this study. The research question 1 (RQ1) explores how teachers apply pedagogical considerations in an ICT-facilitated teaching-learning environment. The research question 2 (RQ2) identifies whether the applied pedagogical considerations promote students' mathematical proficiency or not and if yes, then also discusses how the applied pedagogical considerations promote students' mathematical proficiency. The final research question (RQ3) focuses on the factors which influence the integration of ICTs in the teaching-learning process. Finally, a process framework is proposed at the end of this chapter.

5.1 RQ-1. How do teachers apply pedagogical considerations in an ICT facilitated teaching-learning environment?

The finding of the study shows that there are several pedagogical considerations applied by the teachers in the ICT-facilitated teaching-learning (TL) environment. In this section, those pedagogical considerations are discussed in line with the extant literature and organized around the two distinct phases- *Didactical Configuration* and *Exploitation Mode* of the theoretical framework (Instrumental Orchestration framework) of the study.

5.1.1 Pedagogical consideration in Didactical Configuration phase

This section discusses how teachers in the didactical configuration phase, chose their setup for the classroom, arranged students in the class, selected different sorts of tasks and used various artifacts (tools) for a suitable ICT-enabled TL environment**.**

This study found that the classroom setup for Case-I is suitable for both observation and collaborative learning whereas for Case-II, classroom space supports observation learning. Though both teachers tried to apply some strategies to involve students' in collaboration, the teacher T1 in Case-I rearranges the classroom learning environment a bit flexible and adaptable (arranging extra chairs, one extra table and one portable board) to make it more suitable and helpful for collaboration. Findings of the study reveals that both the teachers are concerned about classroom context more specifically about physical space. T1 prefers more spacious classroom space whereas the teacher T2 is unpleasant about the lighting arrangement since these are crucial for conducting class fruitfully while ICT is used in the teaching-learning process. These findings conform to the existing knowledge (Li & Dawley, 2019) that physical space is one of the important factors to implement ICTs in the teaching-learning process effectively. The finding shows, the projector screens and the white board for both the cases are placed in front of the students and at the center of the class. As the board length is a bit longer for Case-II, T2 does not bring any extra board, whereas T1 brought a portable white board. According to Li and Dawley, to conduct classes with ICT, it is mandatory to have the facility of both projector screen and white board to link the screen to the board as well as to perform the task other than what is shown on the screen. This finding conforms to the works of Koyuncu et al. (2014) where they claimed about the importance of linking technology environment with the conventional context.

While almost in every class T1 prefers to engage students in peer discussions, group activities or whole class discussions, T2 emphasizes on individual learning. However, sometimes T2 was also found to apply whole class discussions and group work but not so regularly like T1. The study found that while reorganizing the sitting arrangement of the students, both the teachers prefer a sitting arrangement where students having high and low ability (ability based on the performance of both the content and technological knowledge) sit together to ensure students' maximum participation and solid learning. The findings also reveal that though none of the teachers rearrange the sitting arrangement in a round shape pattern for regular classes, T1 emphasizes such a sitting arrangement for effective collaboration (e.g., group work) only. Thus, classroom culture is found as a major concerning issue for TL-environment which is consistent with the finding of Li and Dawley (2019) where they reported that while teachers teach with technology, the issue of *classroom culture* needs to be taken under consideration as it shapes teaching-learning experiences.

While teaching mathematics with ICTs, both the teachers prefer the tasks to be non-routine, challenging, open-ended and real-life oriented problem-based. They also claim that the students should be given a combination of both easy and complex tasks, and the difficulty level of the tasks should be sequenced from simple to complex. They emphasize on providing several tasks with different dimensions as these sorts of problems help students to solve the problem by thinking in different angles/from different perspectives and different ways with proper logic. This study finds that such sorts of tasks increase students' ability to perform the tasks fluently with maximum correctness and prepare students with the capability of dealing with unfamiliar situations. Thus, non-routine and challenging tasks get students ready for this purpose and make their mathematical understanding stronger. Besides, real-life oriented problem-based tasks help students to internalize the concept and enable them to apply the task in new situations and also make the learning meaningful and interesting to them. Similar findings were reported in the work of Sultana and Khan (2017) where they discussed that teachers need to provide unfamiliar and challenging tasks as it will help students to develop their concepts and motivate them to learn with new experience.

It is also found that both T1 and T2 use different sorts of ICT tools such as multimedia projector, PowerPoint presentation, calculator, GeoGebra software and Desmos apps for mathematics teaching-learning purposes. However, teachers added that content related video tutorials, google search, IWB, websites (e.g., Khan academy) related to mathematics teaching-learning may be considered as effective ICT tools for mathematics TL. The study shows that both the teachers have easy access to technology. Both of them use a laptop which is connected with a multimedia projector whereas the projected screen is placed at the center of the front wall of the class. Unlike the Case-II, the students of Case-I have the facility to directly use the assigned PC for them according to the teacher's direction. Due to the limited number of PCs, two or three students have to share one PC and perform group wise. However, both of the teachers express their positive view on students' one-to-one interaction with technology. This viewpoint is well reported in the works of Li and Zheng

(2018) where they claimed that when students work directly with technology, they can enhance their learning performance by adapting and experiencing individual learning experience.

5.1.2 Pedagogical consideration in Exploitation Mode

This section discusses how the teachers decide to exploit the didactical configuration in the exploitation mode. This includes decisions on the approach for a task to be introduced and worked through, on the possible roles of the artifacts to be played, and on the schemes and techniques to be developed by the teachers and the role of students in those situations.

The study shows that most of the time T1 in Case-I facilitates the teaching-learning process rather than instructing. It is observed that a major part of his class was student- centered rather than teacher-centered. On the other hand, T2 in Case-II, proceeds the class combining both traditional teaching (e.g. lecture method) and modern teaching (e.g. interactive way) approach. In most of the classes, both T1 and T2 introduce the lessons by exploring students' prior knowledge and linking that to the topic as this technique helps teachers to understand students' level and plan for how the lessons will proceed. Besides, when students can learn a topic linking to their existing knowledge, they become motivated and learning becomes meaningful. The findings also reveal that T1 often introduces the lesson linking with real-life events and familiar contexts. This technique helps students to be involved in the lesson willingly and develop the realization that math is not only an abstract subject, it is not isolated from their lives. Similar findings were reported in the work of Sultana and Khan (2017) where they reported that connecting math with real-life phenomena is essential to develop students' math concepts and to motivate them in learning mathematics.

The study shows that ICT tools (e.g. simulation programs) create an environment more effective for learning as students can visualize the real meaning of mathematics through it. Moreover, the maximum accuracy in teaching-learning can be achieved with the support of technology as ICT opens the scopes to deal with problems with minimum error (e.g., using zoom in and out option to explore the location of each and every point of the graph of a linear function). The study also shows that both the teachers believe that ICT opens the scope to conduct the TL process with collaboration. As, due to the use of ICT, teachers can get more time to apply different TL techniques (e.g. group work, peer or whole class discussions) in the classroom than the traditional classroom. In the ICT facilitated learning environment students can collaborate not only with peers but also with technology. Students can get feedback from the technology. The findings also reveal that use of ICT not only makes the learning meaningful but also offers a fun factor in learning and motivates students to involve in the TL process willingly. The findings show that both of the teachers think that to make the learning more sustainable use of ICT is vital. Besides, not only the teachers but also the students express their positive view about use of ICT in the teaching- learning as they think that it prepares students for the future effective workforce. These roles of ICT are consistent with the findings of Das (2019) and Saravanakumar (2018). Both of them reported in their study that due to the blessings of ICT, students become skilled workforce and can build their successful career.

The study shows that though the role of teachers of two schools were almost similar in both the cases, it varied in few instances. For example, as the teacher of Case-I, the teacher of Case-II did not rearrange classroom amenities, rarely involved students working with ICTs directly, applied relatively less interactive teaching-learning strategies etc. These differences may occur due to some contextual reasons in Case-II such as disarrangement of resources and physical facilities to conduct the class using ICTs, lack of support of school authority, inadequate experience of teachers etc.

The study found, both of the teachers ensure the accessibility of technology and its appropriate use such as they emphasize on students' direct involvement with the use of ICT, though T2 rarely provides scope to the students to directly interact with ICT. The study found that despite the willingness to involve students directly with their assigned PC in the ICT Lab room, Case-II teacher was unable to do that due to the unsupportive behavior of school authority, thus she took all classes (except one) in the traditional classroom. This finding conforms with the finding of Turgut and Aslan (2021) where they reported that teachers' intention to integrate ICT in his/her practice highly depends on school authority's support.

However, the pedagogical approaches adopted in the ICT lab room by the teacher in Case-I (where most of the facilities to conduct class with ICTs were available) could be applied in the traditional classroom. As in the context of developing country like Bangladesh, most of the classes are conducted in traditional classroom where multimedia facilities may or may not be present, to conduct class effectively with ICTs the availability of multimedia facility in the classroom must be mandatory along with ensuring some physical facilities (e.g., confirming uninterrupted internet, luminous space for collaborative work and flexible learning, appropriate lighting and board arrangement for linking virtual context to conventional context etc.). This finding conforms with the existing finding of Roehl et al. (2013) where they argued that to create active learning, collaborative support environment, in traditional classroom setting, more optimal arrangements need to be adapted such as flexible learning space that allow for group work and many different activities at the same time.

According to both the teachers, while students are directly involved in ICT tools, their fear about technology becomes less and they can extend their knowledge. The study shows that while students directly work with technology, the teacher's role is to act as a facilitator and scaffold students where necessary. Teachers also provide the technical support when students face problems in the technical issue. The study shows that none of the teachers initially provides the freedom to work with technology by the students without any instruction or demonstration. Moreover, T1 discusses the importance of technology for the specific lesson so that students get interested in working with the tools. This finding is in line with the previous study of Sultana and Khan (2017) where they stated that a teacher needs to familiarize students with the ICTs clearly while he/she tends to work with them (students) with the collaboration of ICTs.

It is also found that teachers use a projected screen and white board at the same time to link what is shown in the projected screen in the other setting. They also use white boards for explaining the topic more elaborately. On the one hand, the finding of the study reveals that teachers often explain what is projected on the screen for the whole class, on the other hand, they invite students to come in front of the class and explain what is projected on the screen and ask to clarify their opinion with proper logic. Similar findings were reported in the work of Drijvers et al. (2010) where they emphasized that in an ICT- enrich classroom environment, it is necessary to create a relationship between what happens in the technological environment and how this is represented in conventional settings like paper-pencil, board etc. Besides, T1 in Case-I, invites one student to present the task with the help of ICT and opens the floor for discussion. Such teaching strategies are very effective as it ensures the participation of all students' arguments and cross-arguments deepen their mathematical understanding. This finding is consistent with the findings of (DBE, 2018) where it is reported that students' mathematical concepts become solid if they are involved in debate. It is found that teachers are not always stuck with a single method rather they adopt different strategies to make the learning meaningful such as they proceed the lesson connecting with prior knowledge and create such an environment so that students can apply their acquired knowledge in the new context. Besides they provide the scopes to represent and solve the problem in multiple ways. It is also found that while conducting class in ICTs enabled environment, teachers offer challenging and a variety of different dimensional tasks so that students can increase their multi-dimensional thinking. The findings of the study show that along with the individual work; pair work, group work and whole class discussions are also encouraged. The finding also shows that while students work individually or group wise, teachers walk throughout the classroom and try to understand whether students are on the right track or not and facilitate them to get the correct path. Finding of the study also shows that exploring misconception, providing counter examples and identifying mistakes by their peers or by their own are also considered to be effective pedagogical considerations. It is also found that both the teachers are not depended on only one-way feedback by themselves rather they offer multi-channel feedback (e.g. feedback by peer, feedback by ICT and student's self-reflection). The findings also show that teachers apply different techniques to motivate the students in the learning such as praising the learner, valuing learners' opinion and preparing the lesson with relevant attractive pictures to motivate students as motivation to learn is an important factor to engage into the lesson willingly. This finding is consistent with the finding of Filgona et al. (2020). It is found that teachers apply the above mentioned strategies by orchestrating different sorts of instrumental orchestrations (such as Technical-demo, Link-screen-board, Discuss-the –

screen, Guide-and-explain, Technical-support, Work- and- walk-by, Discuss-tech-without-it, Sherpa-at-work and Not-use-tech) with the help of ICTs.

The study also discusses that during the teachers' orchestration with the help of ICTs, students perform varied roles such as, involving actively in the collaboration, providing constructive feedback to their peers, concerning and identifying their own mistakes, willingly get involved in the lessons and work directly with ICTs and the most vital role is attentively follow what the teacher explains or instructs.

5.2 RQ-2. Whether and how does the ICT facilitated teaching-learning process promote students' mathematical proficiencies?

5.2.1 Assessing students' mathematical proficiency

Findings of the study conform to the existing knowledge (Sudiarta & Widana, 2019) that students' mathematical proficiency increases if ICTs are used in the TL process.

The analysis (qualitative data: FDG and classroom observation) shows that the overall mathematical proficiency of students for both cases increased when the teacher conducted class in an ICT facilitated teaching-learning environment. Though the classroom observation and FGD data shows clear indication about the development of procedural fluency for both cases, the paper-pencil test (quantitative data) provides evidence that a student's procedural fluency does not increase for Case-I and decrease for Case-II. This opposite picture may have occurred due to the question structure in the post-test. It is found that initially students' overall mathematical proficiency was not so mentionable for both the cases. Though they were good at the specific component "procedural fluency" of mathematical proficiency, their math conceptual understanding, reasoning skills and ability to solve math problems by multiple strategies were very poor. Besides, students' overall productive disposition was high for both the cases. One of the reasons for that could be selection of participants. The students who chose higher mathematics as a subject were selected as participants (as the planned task contents were suitable for higher mathematics). The study shows that students' PD increased as they experienced learning in ICT-facilitated learning environments. Specially for the Case-I, this positive change is significant. It is found that they can make better sense of mathematics, become more persistent, confident, curious and cooperative after the intervention. Since, initially students perceived mathematics as *useful & worthwhile* and showed *enthusiasm*, their views on these factors have increased but not so notably. Surprisingly, the confidence and curiosity of students of Case-II slightly decreased. This study also found that after experiencing classes in the ICT-facilitated environment, students' mathematical concept, reasoning ability and ability to formulate, solve math in multiple strategies significantly increased. This finding is commensurate with the findings of Granberg and Olsson (2015) who reported that ICT tools assist students to engage in creative reasoning to develop a solid conceptual understanding and solve problems using multiple strategies.

The study shows that ICT-enabled teaching-learning processes promote students' mathematical proficiency in both the schools, but the proficiency of students in one school (Case-I) increased more than the other school (Case-II). This might be attributed to the differences in pedagogical approaches the two teachers adopted in their classes (details are in section 4.3).

5.2.2 Effect of pedagogical approaches on students' mathematical proficiency

The findings of the study show that teachers apply multi-dimensional pedagogical techniques which foster the development of students' mathematical proficiency. It is seen that the ICT-facilitate teaching-learning environment promotes students' strong mathematics conceptual understanding, ability to engage in creative reasoning, skill in procedure as well as strategic competence and productive disposition. This finding is consistent with the observations of multiple researchers who reported that ICT enriched learning environment engage students in relevant and meaningful learning contexts, develop connections among their mathematical ideas and real world context (Kafai et al. 1998), assist students to engage in creative reasoning to develop a solid conceptual understanding, help to verify their strategies (Granberg & Olsson, 2015) and develop mathematical resilience (Lugalia et al., 2015).

The study found different sorts of pedagogical considerations promote students'

Mathematical Proficiency (MP). It is found that all the pedagogical considerations applied in both the cases do not directly enhance every strand of MP. The pedagogical considerations which enhance the particular stands of the MP that is conceptual understanding, procedural fluency, adaptive reasoning, strategic competence and productive dispositions are discussed in the subsequent sections below.

5.2.2.1 Pedagogical considerations for enhancing Conceptual Understanding (CU)

The study finds that classroom rearrangement is one of the important pedagogical considerations to enhance student's conceptual development in mathematics. If teachers' intention is to create the learning environment interactive and collaborative, all the features (e.g. portable board to link with the projected screen, round shape or face to face sitting arrangement, certain space among the groups, placement of board, projector screen and lighting arrangement etc.) are considered to be vital. Such a supportive learning environment creates scope to engage in constructive discussions. Thus, this sort of learning environment helps to develop students' CU. This finding is supported by the findings of Ozdemir and Pape (2012) that while students work with collaboration, they get the opportunity to explore the limits of their own understanding by dialogic talk (Wegerif, 2010).

Selection of appropriate ICT tools and its proper utilization for math teaching-learning is also found to be crucial for developing students' mathematical concepts. With the support of ICT, teachers can present and discuss mathematical topics in-depth which ultimately deepen and extend students' mathematical understanding.

The study also shows that while students learn mathematics connecting with real situations, learning becomes more solid. To connect mathematics with real situations, teachers provide familiar contextual examples and use ICT so that learners can visualize the concept in real-life. In addition, learners have to provide the scope to use mathematical language to make sense of the connection between mathematics and real life. This viewpoint is well reported in the works of (DBE, 2018) that ICT helps to visualize and connect math with the real world. Besides, *exploring students' prior knowledge, linking math with the prior* *knowledge* and *providing scopes to apply the acquired knowledge in the new situations* are considered as effective strategies to develop students' conceptual understanding. Similar findings were reported by Balka et al. (2010) where they claimed that if teachers intend to develop students' solid understanding in math concepts, they need to construct new knowledge with the assistance of prior knowledge and utilize the new knowledge to solve problems in a new situation. The findings of this study also shows that students need to introduce or experience several examples from various dimensions. Working with problems sequencing from easier to harder ones, help learners to inter-link among the contents which ultimately enhances their mathematical concepts. This is consistent with the findings by Wolfram (2010) where he found that harder problems along with the simpler ones could develop students' conceptual understanding. In this study, *engaging learners in peer discussion, group work and whole class discussion* are also found as effective approaches for developing conceptual understanding. It is found that when students get involved in discussion and collaborative work, the concepts become clearer to them and learners can develop their math understanding. This finding conforms to the findings by researchers (DBE, 2018; Brousseau, 1997; Ozdemir & Pape, 2012) who showed that teachers should encourage and create the environment such that students can involve themselves into the discussion and progress with a solid understanding. This study also shows that *offering unfamiliar, non-routine, challenging tasks* are considered to be effective strategies to develop math *conceptual understanding* about mathematics. In line with the work of Sultana et al. (2017), this study found that by dealing with unfamiliar, non-routine and challenging tasks, students will be ready for realistic obstacles that exist in the real world.

Findings of this study shows that multi-channel feedback (e.g. Feedback by teacher, Peer and Students' self-reflection) can be applied in ICT-facilitated teaching-learning environment to increase conceptual understanding. While teachers can assist students to reflect on their performed task and establish dialogue to guide them to the correct path rather than directly mentioning the right or wrong answer, scope to open feedback by peers also enhance their concept as this approach urges them to think more. Besides, students' self-reflection helps them to identify their own mistakes. In addition, exploration of students' misconceptions, encouragement to deliver counter-examples and identifying mistakes are also found effective for developing conceptual understanding in this study. An ICT-facilitated teaching-learning environment opens up the scope to apply these strategies effectively. Many other studies support this finding (e.g. Fuglestad, 1997; Granberg & Olsson, 2015; Ogwel, 2008) where it is argued that ICT offers challenging tasks, alleviates students' misconceptions and provides the opportunity to show counter examples.

5.2.2.2 Pedagogical considerations for enhancing Procedural Fluency (PF)

As for conceptual understanding, this study found several pedagogical considerations which enhance procedural fluency. This study found that classroom rearrangement which is supportive for observation learning is effective for developing students' procedural fluency since such an environment ensures that available resources and tools are easily visible and accessible to the students. This finding complements the findings by Van Lent and Laird (2001) where they demonstrated that observation learning supports students to acquire procedural knowledge more efficiently than standard knowledge acquisition.

This study also reveals that direct involvement with ICTs helps students to develop the ability to select or appropriately use the commands which ultimately lead to their procedural fluency. As the ICT tools open the scope to perform a task with minimum error and maximum accuracy, it gradually increases students' fluency in math (i.e., procedural fluency) along with technology. This finding is consistent with the findings of (DBE, 2018) which claimed that ICT helps the learners to perform quickly and accurate calculations, and constructions, and eventually enhance their skill in mathematical procedure by repeating and practicing (DBE, 2018).

Providing homework for practice and *encouragement for quick recall* are found to be effective strategies that increase students' math fluency ability. Besides, to solve several diversified problems, learners need to think in different dimensions which ultimately increase students' capacity to recall and to solve a problem quickly. As a result, they develop their procedural fluency which is in line with the previous study of (DBE, 2018) that while students deal with several types of examples with diversity, they develop the ability to solve problems promptly.

As feedback from ICT provides the output with maximum accuracy with proper steps, it helps students to understand how to apply the processes correctly. This finding conforms with the findings by Granberg and Olsson (2015) where they argued that when students get feedback from ICT, they can perform the task more precisely. Besides, in line with the findings of Lim and Chai (2004), this study found that when feedback is provided using ICT, teachers need to encourage students to reflect on what they see, evaluate the evidence, make predictions and explain their conclusions.

5.2.2.3 Pedagogical considerations for enhancing Adaptive Reasoning (AR)

The study found that classroom rearrangement which is suitable for collaboration indirectly increases students' adaptive reasoning, since during group work, peer work, whole class discussions, students engage in argument and explain their ideas to the group members or peers with proper logic, resulting in their reasoning skills. This is well supported by Fang (2021) where he reported that group discussions is a fruitful instructional design for enhancing students' reasoning ability. Though extant literature does not give stress to provide diverse dimensional problems for building adaptive reasoning, this study argues that a variety of problems foster students' multidimensional thinking as students attempt to solve the problem by proper logic rather than rote learning. Again, challenging, non-routine and a variety of problems create the scope to attempt multi-dimensional tasks with a logical point of view. This finding is consistent with the work of (Kusumah et al. 2016) where they stated that students' ability to think logically will be formed by dealing with non-routine tasks. In this situation students apply logical thinking ability to make connections between concepts and context. Besides, learners need to get involved in creative reasoning and critical thought so that they can explain their thought with proper justifications. This viewpoint is well reported in the works of (DBE, 2018) that teachers should encourage students to use mathematical language and explain their own ideas with logic. Besides, while teachers provide feedback, the instructions should be clear and lead students to think about the reason behind the mistakes and what needs to be done. Similar findings were reported in the study by Shute (2008) that feedback is more effective when it not only provides information about answer correctness, but also elaborates on qualities of student work or how to improve. It is also found that feedback provided by peers makes the students logical and constructive. The study shows that students' self-reflection on their work also enhances their reasoning skill as this approach insists them to re-check their performed tasks and to think more with proper logic.

5.2.2.4 Pedagogical considerations for enhancing Strategic Competence (SC)

The study found that suitable arrangement of classroom amenities (e.g. portable board, availability of extra chairs and extra table if required for flexible learning etc.) are one of the vital issues to boost students' strategic competence. The classroom setup which is suitable for learning with collaboration, helps to develop students' strategic competence. This finding conforms with Ozdemir and Pape (2012) who reported that while students work in collaboration, they exercise strategic competence. The study also found that providing the scope to use a variety of techniques for doing math is another effective strategy for developing strategic competence. In line with the previous study by Bramald et al. (2000), the finding suggests that use of ICT creates the environment more convenient to represent a math task in multiple ways. Besides, the viewpoint of encouraging learners to solve a task in different approaches is well reported in the works of (DBE, 2018) that teachers should always allow students to try out many different strategies for doing calculations so that the learners become comfortable to deal with non-routine problems with a variety of strategies. This study also found that by exploring prior knowledge, teachers know the learners' level and based on that they can apply different strategies, which indirectly enhance students' strategic competence. Conforming with the findings of Granberg and Olsson (2015), the study also found that feedback that is provided by ICT, helps students to verify their strategies and such types of action assist students to enhance their capacity to perform a task in multiple ways.

5.2.2.5 Pedagogical considerations for enhancing Productive Disposition (PD)

The study found that flexible and adaptable learning arrangements (e.g. portable board, availability of extra chairs and extra table, lighting, availability of resources etc.) increase students' productive disposition. When students directly get involved with technology, their fear regarding technology diminishes and they show enthusiasm to engage in the lesson. Besides, this study also found that while students attempt to solve problems by discussing with their peers and can see the connection of mathematics with real-life phenomena, they enjoy and use ICT to create a more enjoyable environment. This finding is consistent with the work by García-Valcárcel et al. (2014) where they argued that when students collaboratively learn with the support of ICT, they become motivated and can keep attention.

In addition, the study shows that while clear, timely and instant feedback provided by the teachers helps students to hold their attention in the learning, on the other hand, getting feedback from peers makes their learning interesting. The scope to provide feedback to their peers, help them to develop their ability to make decisions. Again getting feedback from peers makes an interesting environment and inspires them as they think that they are prioritized by the teachers. Here both of the students have the scope to improve. The findings of the study also reveal that students' productive disposition elevates while learners are appreciated for their work, their opinions are valued. Similar findings are reported in the work of Lai (2011) where he claimed that teachers need to provide autonomy to students and allow them to be involved in a collaborative or cooperative learning supportive environment. Besides, an ICT- facilitated environment enables students to present attractive, well organized and systematic lessons which develops students' productive disposition as well.

5.3 RQ-3. What are the factors that affect integration of ICT in mathematics teaching-learning process?

The finding of the study shows that there are several enablers and inhibitors which influence the integration of ICTs in mathematics teaching-learning process. In this section, those enablers and inhibitors under four distinct aspects i.e., teacher factors, student factors, school context and national context are discussed in line with the extant literature.

5.3.1 Teacher factors

The study found that teachers' attitude, perceived usefulness, interest, TPACK, confidence, preparation, experience and class load are teacher related factors that influence the use of ICT in their practice.

It is found that teachers' attitude is a prime factor to integrate ICTs in the teaching-learning process. If teachers hold the positive thought regarding ICTs, they will be willing to use ICTs in their practice. On the contrary, if they possess a negative view, they will not be interested in applying ICTs in their practice. This finding is consistent with the findings of Kaleli-Yilmaz (2015) where he discussed that the teachers with adverse attitudes towards ICT are less confident and skilled on technology, as a result they do not accept and familiarize with technology willingly and try to avoid technology use in their teaching practice.

The study shows that if the teachers perceive that use of ICT in teaching-learning enhances students' learning, then they are interested to use ICT in their practice. Similar findings were reported in the study by Davis (1989) where he discussed that if teachers believe that use of ICT in teaching is effective for students' learning, they feel interest to work with technology. The study found that if teachers have to proceed with a class using ICT without having any interest, the class will be ineffective. Thus teachers' interest in ICTs is vital for ICT integration in teaching. This observation conforms to the works of (Sokku & Anwar, 2019) where they reported that the teachers who have good vision and perception of the use of ICT in learning, they believe learning with ICT is interesting and they are interested to use ICTs in their teaching-learning process.

The study also reveals that to integrate ICTs in the teaching-learning process, teachers must have solid knowledge on content, technology and pedagogy. It is found that teachers' attitude is affected by their TPACK. Similar findings were reported in a study (e.g., Tay, 2013) that teachers need relevant technological, pedagogical and content knowledge to perform their teaching practice with the help of ICTs.

The study shows that teachers' confidence directly influences ICT integration in their practice. This finding is consistent with the findings of Kaleli-Yilmaz (2015) where he argued that, if teachers lack confidence, it seems that they feel reluctant to use ICT. The study found that sometimes teachers seem too unconfident to use technology due to the reliability issue of technology. It is found that since technology sometimes creates troubles (e.g. network problems, require much time to log on –log off of computers or certain apps) in the class without prior notice, it may be reluctant for teachers to use technology in their practice.

The study also found that teacher's confidence not only depends on teacher's TPACK, but also depends on some other factors such as teacher's preparedness, skills and experiences on technology. In case of teacher's preparedness, the study found that teachers' preparation is affected by teachers' class load and to conduct class using ICTs, teachers need very sound preparation and plan the lesson very systematically, otherwise the class will be ineffective. This finding conforms to the observations of the researcher Gikundi (2016) who argued that teachers cannot utilize the benefit of technology in their classes due to the inadequate preparation to use technology. On the other hand, while several studies (Gorder, 2008; Lawrence & Tar, 2018) claim that teaching experience influence the successful use of ICT in classrooms, this study complements to those literature by showing that not only teacher's teaching experience but also teacher's experience to work with technology influence integrating ICTs in TL process.

The study also found that since integration of ICT in teaching practice requires extra time to take sound preparation and teachers are loaded by so many classes, they are not enthusiastic to accept ICTs in their teaching-learning process. Thus, to integrate ICTs effectively in the teaching-learning process, teachers' workload is suggested to be reduced in this study. Similar findings were also reported in the study of Fullan (2007), where the researcher argued that for implementing new initiatives it is necessary to lessen the workload of teachers.

5.3.2 Student factors

This study found that students' attitude towards ICTs, their interest to learn with the help of ICTs, Misuse of ICTs, home support (i.e., parents' attitude towards technology and home environment) are the influencing factors associated with students for integrating ICTs in the teaching-learning purpose.

In case of students' interest, the study reveals that if students are interested to learn with ICTs, it is quite easier for the teacher to continue the class with the assistance of ICTs. As students' are already enthusiastic to learn with ICTs, the teacher doesn't need to give extra effort to motivate them focusing on ICT issues. This finding is consistent with the finding of Deryakulu et al., (2008) where they reported that the satisfying aspects of ICT teaching depend on how students are interested in learning with technology.

The study found that students' attitude regarding the learning with technology is also a crucial factor to integrate ICTs in the teaching-learning process. It is found that when students believe that use of ICT in teaching enhances their learning and hold a positive attitude on learning with ICT, they are interested in working with technology and willing to engage in the session. Similar findings were reported in several studies (Cope & Ward, 2019; Parker et al. 2008)) where they suggested that students' perception regarding ICT supported teaching influences the effective use of ICTs in education.

It is found that students' home environment has an effect on ICT integration. If the family atmosphere is not supportive for learning with technology, students are not interested in working with it. The study also reveals that students' negative attitude is somewhat influenced by the attitude of family members. It is found that if family members such as parents hold negative thoughts about the integration of ICTs for teaching-learning purposes, it ultimately affects students' beliefs. This finding complements the earlier findings of Lin and Muenks (2023) where they claimed that family members (parents and siblings) contribute to shaping the mind-set of the students.

The study found that there is a chance to misuse ICTs by students and this sort of thought influences parents to hold negative attitudes regarding use of ICTs for teaching-learning purposes. Moreover, this sort of thought sometimes constrains teachers to use ICTs in their teaching-learning process. Thus, teachers and parents should monitor carefully while students work with ICTs so that students could not misuse the technology. This study recommends that school authorities can organize a discussion meeting to inform teachers, students as well as parents regarding the benefits of using ICTs in education so that their negative thoughts diminish. This is consistent with the study by Tedla (2012) where he suggested a public awareness campaign about the importance of ICT as a catalyst to facilitate the teaching-learning process.

5.3.3 School context

Considering the context of school, large size class, departmental ethos, physical facilities and technical support are found influential factors to integrate ICTs in the teaching-learning process.

Class size is found to be an influencing factor for introducing ICTs in the TL process. While Davis (2018) found that class size has no effect on the quality of classroom interaction in the developing country's context (e.g. Ghana), this study shows that when classes are conducted using ICTs, class size has an influence on the quality of TL process. It may be attributed to the fact that in ICT enabled classrooms different approaches need to be used to make TL engaging and fruitful which would be quite difficult in a large size classroom. This finding is consistent with the finding of Bate (2010), where he showed that large class size (students above 25) as a barrier to implement ICT in the classroom.

The study reveals that departmental ethos such as the attitude of the head of the institute and other teachers is another vital factor to integrate ICTs in the teaching-learning process. It is found that if the head of the institutions holds a positive attitude regarding ICT use and encourages teachers to use, all the teachers of the institute will be motivated to apply ICTs in their practice. In addition, the study shows that teachers may refuse to use ICTs in their practice due to the adverse behavior and discouraging attitude from their departmental head and colleagues. This finding is consistent with the finding of Razak (2019); Turgut and Aslan (2021) where they claimed that school leadership and authority have a great impact on successful integration of ICTs in the school. On the one hand, this study claims that teachers' practice with ICTs depends on institutional authorities' attitude. On the other hand, the study shows that despite school's authorities holding a positive attitude, they cannot implement due to several backlashes such as teachers, parents' negative mindset.

The study found that physical facilities such as availability of resources, appropriate classroom setup for TL with ICTs, uninterrupted internet facilities etc. are other affecting factors to integrate ICTs. The study reveals that if the overall classroom infrastructure is not appropriate to work with ICTs, teachers will not be interested to apply them in their practice. Besides, teachers may face technical problems (e.g. adjusting aspect ratio, proper configuration, troubleshooting etc.) during operating technology in the classroom. Thus the finding of the study suggests the importance of technical support/ technical operators to assist the teacher. The challenges identified conform to the findings by Tay et al. (2013) where they pointed out that technological infrastructure and support are vital to integrate ICTs in teaching. They argued that a technical team to set up and assist technical requirements and troubleshooting and technological infrastructure directly affected the usage rate of ICT in the classrooms.

5.3.4 National context

Other than the teachers, students and school context, this study found some other factors which affect ICTs integration. They are curriculum, professional development, financial support, course duration and assessment policy which are considered under the 'national context' theme.

The study found that curriculum is one of the crucial factors to incorporate ICTs in the TL process. Though there is a mixed opinion among the participant teachers about the appropriateness of existing math curriculum for ICT use, it is clearly found from the study that curriculum should have adequate contents and each content should be linked with ICTs and there should be a clear suggestion of how to use technology for the teacher. Besides, there should be a specific indication so that teachers and students are obliged to apply technology in their teaching-learning. This viewpoint is well reported in a study by Tay et al. (2013) where they suggested that use of ICT needs to be explicitly spelled out in the curriculum plans and schemes of work on how ICT would be used in the classroom.

Different sorts of professional development programs such as- ICT training, in-house training, training abroad etc. are found vital for integrating ICTs in education. Since teachers' TPACK and confidence are two prime factors for integrating ICTs in education, these two can be improved by attending various types of ICT based training programs. The study shows that Case-I teacher applied various innovative pedagogical approaches due to his experiences and skills achieved from several national and international training related to pedagogy and ICT. It reflects that the training program has a great impact on teachers' professional development. The study suggests that the main criteria for training should be to enhance teachers' knowledge on contents and pedagogy with the aid of ICTs rather than to support technical issues. Besides, enhancement of teachers' confidence should be another focus of the professional training programs. These findings above are similar to the findings of several researchers where they depicted that professional training program will be an excellent program if the training program focuses on use of ICT in the pedagogical aspect rather than technical issues and technical supports and helps teachers to shift their traditional teaching practice into a new paradigm (Brinkerhoff, 2006; Diehl, 2005) and to gain confidence in ICT usage (Peralta & Costa, 2007).

Financial issues are found to be a major concerning factor to implement ICTs in the TL process. The study shows that despite the very positive attitude of teachers as well as school authorities about the use of ICTs in education, its execution cannot be done properly due to the lack of adequate financial support. For ICT-enabled teaching learning, there are no alternatives of all sorts of logistics support (e.g. availability of resources, multimedia classroom, IWB, technical support etc.) which requires sufficient funds.

Course duration and assessment policy are found influencing factors to integrate ICTs in the TL process. It is found that teachers are very compacted with the schedule of their classes, so it is a bit difficult for them to manage classes where they can apply ICTs for TL purpose. Thus, while preparing the class routine, there could be a specific schedule for classes where ICTs will be used so that both the teachers and students cannot avoid using ICTs for TL purpose. In addition, despite receiving training, teachers are often reluctant to use ICTs in their practice due to the traditional structure of examination. To assess students, a blending approach of examination such as traditional examination and technology assisted examination (e.g. use of google form) could be applied.

5.4 Developing a process framework

On the basis of the findings discussed in research questions 1, 2 and 3, I have proposed a process framework (Figure 5.1) of effective pedagogical approaches to develop students' mathematical proficiency in the ICT-facilitated learning context.

The process framework illustrates how ICTs can be orchestrated in the ICT-facilitated teaching-learning environment so that students' overall mathematical proficiency develops. The orchestration has been done in two phases (Didactical Configuration and Exploration Mode) where in Didactical Configuration phase, teacher plans to select appropriate tasks as well as artifacts and rearrange the students' and classroom setup so that he/ she can properly implement his/ her intended plan in the Exploitation Mode phase.

The framework points out that to develop students' mathematical proficiency, tasks should be non-routine, challenging, open-ended, diversified and simple to complex. Different types of ICT tools such as computer/laptop, power-point presentation, calculator etc. can be used. Besides, mathematical software (e.g., GeoGebra, MATHEMATICA, Drill and practice), simulation program, Desmos apps, Graphics Tab, interactive white board (IWB) are suggested. For classroom setup, teachers need to arrange multimedia projector with projected screen and white/ black board for linking screen to other settings or further discussions other than the screen, movable desk and chair to prepare effective sitting arrangement for collaboration (e.g., group-work, peer work etc.). Finally, classroom lighting should be adjustable to create a proper learning environment. All these arrangements are emphasized in the *didactical configuration* phase in the process framework. In the *exploitation mode*, the process framework highlights how a task should be introduced (e.g., linking mathematics with real-life situation or familiar context, exploring prior knowledge etc.) and what would be the functions of artifacts (tools) (e,g,, helps to visualize real meaning of math, provides instant feedback, make the learning sustainable etc.) and students (e.g., provide peer feedback, engage willingly in the lesson and collaboration, identify their own mistakes etc.) while teacher conducting class with ICTs. Though the teacher facilitates the whole orchestration process by applying various types of orchestrations (e.g., Discuss-the-screen, technical –support, not-use-tech etc.), the teacher’s role is specified in the exploitation mode explicitly.

As during the orchestration, all components (task introduction, teacher, students and tools) of the exploitation mode have to be performed, their roles are clearly mentioned in the process framework. All the arrangement and contribution of each component (teacher, students and tools) have been done to develop students’ five strands of mathematical proficiency. The framework also shows the influencing factors in terms of teachers, students, school and national contexts that affects the overall orchestration process.

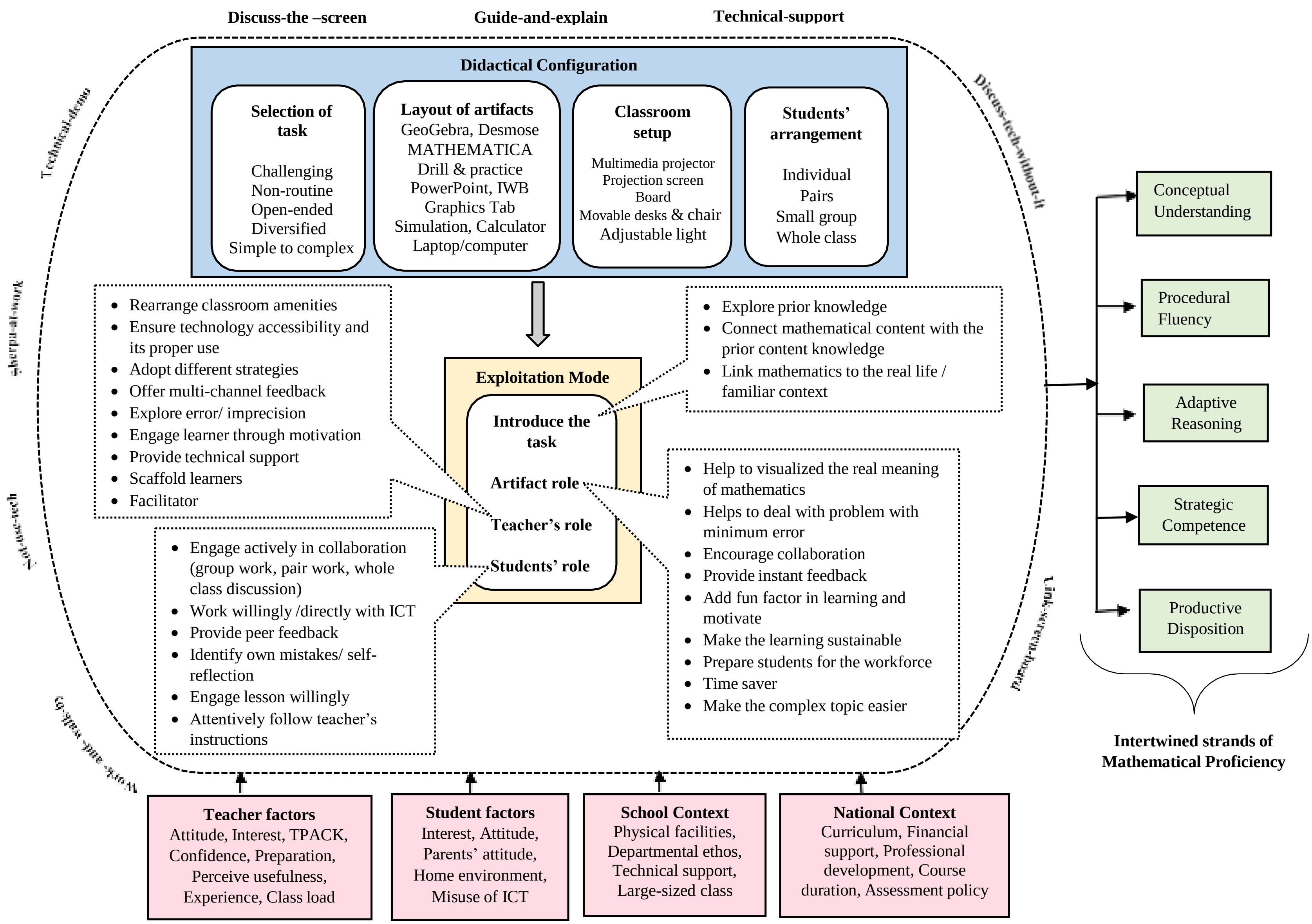


Figure 5.1: Proposed framework for ICT orchestration in TL process to promote students' MP

Chapter Six

CONCLUSION

The broad research objective of this study was to develop a better understanding of how ICTs can be orchestrated in mathematics teaching-learning (TL) process to enhance students' mathematical proficiency. With this objective in mind, this thesis explored the use of ICTs with appropriate pedagogical approach under two cases. This in-depth exploration provides useful insights into how teachers can adapt their teaching practices integrating ICTs to develop students' mathematical proficiency and what factors influence to implement ICTs effectively in TL process. The findings of the study were discussed in detail in chapter five. Before moving on to discuss implication of these findings, a summary of key findings with respect to the research questions are presented below:

6.1 Key Findings

RQ1: How do teachers apply pedagogical considerations in an ICT-facilitated teaching-learning environment?

Teachers apply different pedagogical considerations with the help of ICTs to make the lesson effective. These pedagogical considerations are, *rearranging classroom amenities, ensuring technology accessibility and its appropriate usage, adopting different strategies to make the learning meaningful, offering multi-channel feedback, offering opportunity to identify error/ imprecision, engaging students through motivation.* ICT-orchestrated learning isn't a one-person show. It involves a collaborative effort between teachers, students, and ICT tools. Some roles (e.g., help to visualize real meaning of math, provide instant feedback, add fun factor to motivate students etc.) are found as the role of ICTs whereas various roles (e.g., involving actively in the collaboration, providing constructive feedback to their peers, concerning and identifying their own mistakes etc.) are performed by the students. The study also shows that during the whole orchestration process, teachers apply different types of instrumental orchestration (e.g., link-screen-board, Technical-support, Sherpa-at-work etc.).

RQ-2. Whether and how does the ICT-facilitated teaching-learning process promote students' mathematical proficiencies?

The study shows that teaching approaches have a great influence on students' development of mathematical proficiency (MP). When teachers orchestrate ICTs in their teaching-learning process, students' four strands of mathematical proficiency (i.e., conceptual understanding, adaptive reasoning, strategic competence and productive disposition) increase. However, it needs to be noted that though the classroom observation and FGD reflect students' improvement on Procedural fluency, the evidence from paper-pencil tests shows no development of procedural fluency. It is also found that students' productive disposition increases if they learn mathematics interactively.

The study shows, while variety of pedagogical considerations promote students' MP, all the pedagogical considerations do not directly enhance every strands of MP. Certain strategies (e.g., connecting math to real-world situations, providing difficult tasks, giving opportunity for peer and whole class discussions, group work, delving into misconceptions, etc.) improve conceptual understanding while other strategies (e.g., giving practice assignments, offering a range of examples, promoting quick recall, etc.) improve procedural fluency. Again, some strategies work well for developing adaptive reasoning skills, such as providing challenging tasks, giving scope for discussion with appropriate justification, and providing multi-channel feedback. Similarly, strategies that work well for developing strategic competence include giving students opportunities to apply multiple strategies, creating a flexible and adaptable learning environment, and providing multi-channel feedback (using ICT to provide feedback). Finally, several strategies (e.g., feedback by peer, involving learners directly to ICT, flexible and adaptable learning space etc.) are found to be effective for developing productive disposition.

RQ-3. What are the factors that affect integration of ICT in mathematics teaching-learning process?

The study shows that several factors related to teachers, students, school and national context affect ICT integration in teaching-learning process. It shows that few teachers related factors like teachers' interest, attitude, TPACK and confidence directly influence while few factors (e.g., perceive usefulness, preparation, experience, class-load) influence indirectly to use ICT in their practice. This study also shows that for integrating ICTs in the teaching-learning purpose, students' attitude towards ICTs, their interest to learn with the help of ICTs, Misuse of ICTs, home support (i.e., parents' attitude towards technology and home environment) are the affecting factors associated with students. Besides, large size class, departmental ethos, physical facilities and technical support are found influential factors related to school context and curriculum, professional development, financial support, course duration and assessment policy are found influential factors associated with national context to integrate ICTs in the teaching-learning process.

Based on the answers of the research questions, I propose a process framework for orchestrating ICT in Mathematics teaching-learning in order to enhance development of students' MP. In the subsequent sections, the contributions to the existing body of knowledge and theory, implications to policy and practice, and scopes to future research have been presented relating to the broad objective of the study.

6.2 Contributions and Implications

6.2.1 Contribution to theory

The most important theoretical implication of this study is to offer a new framework (discussed in chapter 5, section 5.4) on ICT-orchestration for mathematics teaching to develop students' mathematical proficiency.

The developed framework provides a holistic view of how the orchestration needed to be in conducting mathematics class in an ICT-facilitating environment. In this study, I have used instrumental orchestration framework (Trouch, 2004) as the base theoretical framework for the orchestration of ICTs in the TL process. In addition to the Instrumental Orchestration framework, other frameworks like the Mathematical Proficiency Framework and the Technology Integration Panel (TIP) are used to identify the best options for pedagogical approaches that use ICTs to develop mathematical proficiency in the context of a developing country like Bangladesh. In line with the findings of the study, I have added *‘selection of tasks’* in the didactical configuration phase, since to enhance students’ mathematical proficiency, it is necessary to select appropriate tasks prior to the class during the planning session. The framework, a new addition to the theory, explicitly includes all possible configurations (i.e., task selection, artifacts, classroom setting, and student arrangement) in the didactical phase and the role of each element (teacher, students, artifacts) in the exploitation phase.

While existing literature discuss the potentiality of ICTs to develop students’ ability on individual strand of mathematical proficiency (i.e., developing reasoning ability (Granberg & Olsson, 2015), conceptual understanding, procedural fluency (Laswadi, 2016) and interest (Sarifah, 2022)) separately, this study undertakes all of those strands in a combined way and contributes in the theory that appropriate orchestration with ICTs to directly enhance each and every intertwined strands of mathematical proficiency. That is, in order to improve students’ mathematical proficiency across all strands (i.e., conceptual understanding, procedural fluency, adaptive reasoning, strategic competence, and productive disposition), it is important to clearly articulate in the study how ICTs should be used in the classroom, how students should be engaged, how teachers should introduce the material and tasks, and what their roles should be. In certain situations, a mixture of these tactics may work well, but in others, it might need to be adjusted due to the context and the existence of influencing factors. My claim in this regard is supported by a study that suggests there is no particular comprehensive set of classroom strategies (Hativa et al., 2001) rather, the teacher can excel and teach effectively to achieve his/her excellence in a different way using a different combination of classroom strategies.

6.2.2 Implication to policy

To become a Smart Bangladesh, the government highly emphasizes on integration of ICT in education and has taken several initiatives such as, reforming national curriculum, developing e-repository, modifying content and resources etc. The findings of this study have some implications for the educationalist and the policy makers. The study recommends that the policy maker should take the necessary initiatives to redesign the curriculum and provide adequate financial supports to create the ICT friendly teaching-learning environment such as providing specific mathematics software (e.g. GeoGebra, MATHEMATICA, FORTRAN etc.) and necessary resources (e.g. Graphics tab, IWB, internet facilities etc.) in the mathematics classrooms. Similarly, the number of computers needs to increase in every school so that the teachers can conduct their mathematics class in a one-one setting when necessary to ensure students' development both in content and technology. Besides, the findings of the study might be helpful to the policy makers to take necessary steps to enhance teachers' capability of teaching with ICTs such as providing adequate training to the teachers and monitor intensely whether teachers could apply their gained knowledge in actual teaching-learning setting after getting the training. Since, large number of class size and teachers' class load are also two vital factors to implement ICTs in TL, policy makers should take these issues under consideration and bring notable changes in the policy to make the teaching mathematics with ICTs feasible for all the teachers and students. Curriculum developer can consider these findings in revising the mathematics curriculum by aligning each possible content with ICTs and provide proper guideline to effectively use ICTs in mathematics teaching-learning process.

6.2.3 Implication to practice

This study can be utilized by the teacher trainers to develop the ICT-based professional skills of the teachers. Training should emphasize effective ICT pedagogy as well as helping instructors adopt a positive mentality about using ICT to teach mathematics. Above all, the study's conclusions will benefit educators by offering a comprehensive manual for using ICT in the classroom outside of the conventional framework. Based on the study's findings, school administrators and the institute's head can make informed decisions about their role in promoting favorable attitudes among teachers, parents, and students about the use of ICTs for teaching and learning. For instance, organizing meeting with students, parents and teachers to inform the possible benefits of the use of ICT in teaching-learning process, creating awareness to prevent abuse and misuse of technology, encouraging teachers to use ICTs in their practice (e.g., proving incentives, ensuring physical facilities etc.).

6.3 Suggestions for Future Research

This study offers numerous scope for further investigations. While only Grade-10 Science students were included in this study- a typically select group of high achievers who choose Higher Mathematics to bolster their mathematical skills- further research may be conducted to verify the viability of the suggested framework for secondary level students, where mathematics is now required for all students under the new curriculum. It is my belief that there may be performance discrepancies between pupils who are ordinary in mathematics and those who excel in the subject. As a result, evaluating the created framework in the recently adopted mathematics curriculum might offer an alternative perspective and bring a new depth to the theory. In addition, as algebra was the study's unit of teaching, more research concentrating on other mathematical content areas (such as geometry, trigonometry, etc.) may be conducted to determine whether the study's conclusions could be applied to those subjects as well. Additionally, the study offers room for modification and reconsideration by taking certain factors into account. For example, just two schools from Bangladesh's urban areas- a government and a non-government Bengali-medium school—are taken into account in this study. Therefore, more research can be conducted to test the effectiveness of the proposed framework in other situations (such as English-medium schools, high-tech or low-tech schools, schools in rural regions, etc.) both inside this country and in other nations with limited resources. Furthermore, I think that teachers who are proficient in technology might develop and employ ICTs in various methods. Consequently, in future studies, studying with students of varying ability and/or teachers who are proficient in technology may offer further insights into the mathematical practices of the teachers. Again, since the study offered an ICT orchestration framework for TL process focusing on secondary level, each and every component of the framework may not be applicable for other levels of education (e.g., early grade, primary, tertiary level etc.). Thus, further study can be done to see the applicability of the findings for other levels of education.

6.3 Limitations of the Study

While the findings of the study offer rich insights for theory and practice, the study had a few limitations. First of all, the study was carried out in two Bengali-medium schools in Dhaka, the capital city of Bangladesh, which possessed the bare minimum of ICT infrastructure needed to teach mathematics. It would have strengthened the study's conclusions more if it had included cases from various contexts, such as urban and rural areas, Bangla- and English-medium schools, and high-tech and low-tech educational institutions. However, this convenient selection is justified since the main objective of the study is to see how pedagogical approaches in an ICT-facilitated TL environment can be applied to promote students' MP. I had to take into account schools that have ICT facilities and where teachers could use ICTs to conduct classes in order to make sure that the primary goal of the study is not impeded. Once more, I looked at two instructors for this study (the Case-II teacher from a non-government school and the Case-I teacher from a government school) and attempted to identify the useful pedagogical aspects from their practice using ICTs. Additional samples would increase the study's credibility, even if I have gathered information from a variety of sources (such as semi-structured interviews, FGDs, post-lesson interviews, and classroom observations) to gain a thorough understanding of the situation. Furthermore, the study's data is restricted to teaching linear functions, slope and graphs, linear equations, and their practical applications to students enrolled in Grade-10 Higher Mathematics courses. The responder students in this study are not typical of all students because they are Grade-10 students who chose higher mathematics as their subject of choice and are typically more adept in the subject than other students. This represents another limitation of this study.

6.4 Concluding remark

In summary, this thesis sought to expand the understanding of effective pedagogical approaches in an ICT-facilitated teaching-learning environment. Focusing on ways to enhance students' mathematical proficiency, this study explores what should be the overall setting of classroom, students' arrangement, selection of tools and tasks, teacher, students and technology roles. The study demonstrates how students' mathematical proficiency increases when ICT is properly integrated into the classroom and effective pedagogical approaches are used, based on two examples in settings with limited resources. To improve students' mathematical ability in an ICT-facilitated classroom, the study presents an ICT-orchestration framework that gives a comprehensive set of guidelines. There have also been recommendations for additional research, along with the implications for theory and practice, which, in my opinion, will contribute to raising the standard of mathematics education in Bangladesh and elsewhere.

REFERENCES

Abdullah, M. (2023, May 05). Why such poor performance in English and Maths. *Dhaka Tribune.* https://www.dhakatribune.com/bangladesh/310489

Afshari, M., Bakar, K., Luan, W. S., Samah, B. A., & Fooi, F. S. (2009). Factors affecting teachers' use of information and communication technology. *International Journal of Instruction*, *2*(1), 77–104.

Alam, K. M. N., & Morgan, C. (2017). Why do few children at rural secondary madrasas in Bangladesh choose to study an optional course in Higher, *BSRLM Proceedings: 37*(1), Birkbeck College, University of London, London.

Alam, K. N., & Morgan, C. (2017, May). Why do few children at rural secondary madrasas in Bangladesh choose to study an optional course in Higher Mathematics?. In *Proceedings of the British Society for Research into the Learning of Mathematics, 37*(1). BSRLM.

Alexander, R. J. (2008). *Towards dialogic teaching: rethinking classroom talk*. (4th ed.) Thirsk: Dialogos.

Ali, Z., Busch, M., Qaisrani, M. N., & Rehman, H. U. (2020). The influence of teachers' professional competencies on students' achievement: a quantitative research study. *American Research Journal of Humanities & Social Science, 3*(6), 45-54.

Al-Mutawah, M. A., Thomas, R., Eid, A., Mahmoud, E. Y., & Fateel, M. J. (2019). Conceptual Understanding, Procedural Knowledge and Problem-Solving Skills in Mathematics: High School Graduates Work Analysis and Standpoints. *International journal of education and practice*, *7*(3), 258-273.

Al-Oteawi, S. M. (2002). *The perceptions of administrators and teachers in utilizing information technology in instruction, administrative work, technology planning and staff development in Saudi Arabia* [Doctoral thesis, Ohio University].

Aminu, M., & Samah, N. (2019). Teachers' perception on the use of Technology in teaching and learning in associate schools Zamfara state, Nigeria. *Education, sustainability and society*, *2*(2), 01-04.

Anigbo, L. C., & Ekene, I. (2015). Factors Affecting Students' Interest in Mathematics in

Secondary Schools in Enugu State. *Journal of Science and Computer Education (JOSCED), 3*(3),17-26.

Anthony, G., & Walshaw, M. (2009). Effective Pedagogy in Mathematics. Educational Practices Series-19, UNESCO International Bureau of Education.

Artigue, M. (2002). Learning mathematics in a CAS environment: The genesis of a reflection about instrumentation and the dialectics between technical and conceptual work. *International Journal of Computers for Mathematical Learning*, *7*(3), 245-274. doi:10.1023/a:1022103903080

Aspire to Innovate. (2023). *How Bangladesh's largest Professional Learning Community (PLC) is creating SMART TEACHERS*. https://a2i.gov.bd/wp-content/uploads/2023/10/Teachers-Portal-Innovation-Brief-2023.pdf

Atkinson, J. M., & Heritage, J. (Eds.). (1984). *Structures of social action: studies in conversational analysis*. Cambridge: Cambridge University Press.

Ausubel, D.P. (2000). *The acquisition and retention of knowledge: a cognitive view*. Kluwer Academic Publishers, ISBN 9780792365051

Bahr, D. L., & DeGarcia, L. A. (2008). *Elementary mathematics is anything but elementary: Content and methods from a developmental perspective*. Cengage Learning.

Balka, D. S., Hull, T. H., & Miles, R. H. (Eds.). (2009). *A guide to mathematics leadership: Sequencing instructional change*. Corwin Press.

Bakhurst, D. (2023). On the Concept of Mediation. In *The Heart of the Matter* (pp. 238-246). Brill.

Bakker, A., & van Eerde, D. (2015). An introduction to design based research with an example from statistics education. In A. Bikner-Ahsbahs, C. Knipping & N. Presmeg (Eds.), *Doing qualitative research: Methodology and methods in mathematics education* (pp. 429-466). New York: Springer.

Bangladesh Bureau of Educational Information and Statistics. (2016). Educational Structure of Bangladesh. Dhaka: BANBEIS, Ministry of Education.

Bangladesh Bureau of Educational Information and Statistics. (2022). Bangladesh Education Statistics 2021. BANBEIS. GoB

Bangladesh Bureau of Educational Information and Statistics. (2023). Bangladesh Education Statistics 2022. BANBEIS. Ministry of Education. GoB

Barnes, B. R. (2019). Transformative mixed methods research in South Africa: Contributions to social justice. *Transforming research methods in the social sciences: Case studies from South Africa*, 303-316. https://doi.org/10.18772/22019032750.24

Baroody, A. J. (1993). *Problem Solving, Reasoning, and Communicating (K-8): Helping Kids Think Mathematically*. New York, NY: Macmillan.

Barua, L., Zaman, M. S., Omi, F. R., & Faruque, M. (2020). Psychological burden of the COVID-19 pandemic and its associated factors among frontline doctors of Bangladesh: a cross-sectional study. *F1000Research*, *9*. https://doi.org/10.12688/f1000research.27189.3.

Bate, F. (2010). Class sizes: The elephant under the carpet of ICT integration.

Baumert, J., Kunter, M., Blum, W., Brunner, M., Voss, T., Jordan, A., ... & Tsai, Y. M. (2010). Teachers' mathematical knowledge, cognitive activation in the classroom, and student progress. *American educational research journal*, *47*(1), 133-180.

Baxter, P., & Jack, S. M. (2015). Qualitative case study Methodology: study design and implementation for novice researchers. *The Qualitative Report*, *13*(4), 544-556. https://doi.org/10.46743/2160-3715/2008.1573

Beauchamp, G. K., & Kennewell, S. (2010). Interactivity in the classroom and its impact on learning. *Computers & Education*, *54*(3), 759–766. https://doi.org/10.1016/j.compedu.2009.09.033

Becta (2008). *Secondary mathematics with ICT: A pupil's entitlement at Key Stages 3 and 4*. Ontario.

Becta, O. (2003). What the research says about using ICT in maths. *British Educational Communications and Technology Agency.*

Bell, J. (1987). *Doing Your Research Project. A Guide for First Time Researchers in Education and Social Science*, Open University Press, Buckingham.

Bell, J. (2005). *Doing Your Research Project: A Guide for First-Time Researchers in Education, Health and Social Science* (4th ed.). Berkshire: Open University Press.

Bhattacherjee, A. (2019). *Social Science Research: Principles, Methods and Practices* (Samara, Rowling, Ed.) (Revised edition). University of Southern Queensland Press.

Bianco, S., Gasparini, F., & Schettini, R. (2015). Color coding for data visualization. In *Encyclopedia of Information Science and Technology*, (3rd ed., pp. 1682-1691). IGI Global.

BISE (2014). Board summary of the secondary school certificate examination-2014. Ministry of Education, Dhaka, Bangladesh.

Bramald, R., Miller, J., & Higgins, S. (2000). ICT, Mathematics and Effective Teaching. *Mathematics Education Review*, 12, 1-6.

Brinkerhoff, J. (2006). Effects of a long-duration, professional development academy on technology skills, computer self-efficacy, and technology integration beliefs and practices. *Journal of research on technology in education*, *39*(1), 22-43.

Brousseau, G., & Warfield, V. (2020). Didactic situations in mathematics education. *Encyclopedia of mathematics education*, 206-213.

Broussard, S. C., & Garrison, M. E. B. (2004). The Relationship Between Classroom Motivation and Academic Achievement in Elementary-School-Aged Children. *Family and Consumer Sciences Research Journal*, *33*(2), 106-120. doi: 10.1177/1077727x04269573

Bryman, A. (2016). *Social research methods (5th ed.)*. Oxford University Press.

Buabeng-Andoh, C. (2019). Factors that influence teachers' pedagogical use of ICT in secondary schools: A case of Ghana. *Contemporary educational technology*, *10* (3), 272-288.

Burkhardt, H. (2007). Mathematical proficiency: What is important? How can it be measured? In A. H. Schoenfeld (Ed.), *Assessing Mathematical Proficiency* (pp. 77-97). New York: Cambridge University Press.

Burns, B. A., & Hamm, E. M. (2011). A comparison of concrete and virtual manipulative use in Third- and Fourth-Grade mathematics. *School Science and Mathematics*, *111*(6), 256–261. https://doi.org/10.1111/j.1949-8594.2011.00086.x

Cedillo, T., & Kieran, C. (2003). Initiating students into algebra with symbol-manipulating calculators. In J. T. Fey, A. Cuoco, C. Kieran, L. McMullin & R. M. Zbiek (Eds.), *Computer algebra systems in secondary school mathematics education* (pp. 219–240), Reston: NCTM.

Chen, A. Y., & Looi, C. K. (1999). Teaching, learning and inquiry strategies using computer technology. *Journal of computer assisted learning*, *15*(2), 162-172.

Cobb, P., Zhao, Q., & Dean, C. (2009). Conducting design experiments to support teachers' learning: a reflection from the field. *Journal of the Learning Sciences*, *18*(2), 165–199. https://doi.org/10.1080/10508400902797933

Cobb, P., & Gravemeijer, K. (2014). Experimenting to support and understand learning processes. In A. E. Kelly, R. A. Lesh & J. Y. Baek (Eds.), Kelly, A. E., Lesh, R. A., & Baek, J. Y. (2008), *Handbook of Design Research Methods in Education: Innovations in Science, Technology, Engineering, and Mathematics Learning and Teaching* (pp. 68-95). Routledge.

Cohen, J.W. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cope, C., & Ward, P. (2019). Integrating learning technology into classrooms: The importance of teachers' perceptions. *Educational Technology & Society*, *5,* 67-74.

Cox, M. J., & Marshall, G. (2007). Effects of ICT: Do we know what we should know? *Education and information technologies*, *12*, 59-70.

Creswell, J.W. (2009). *Research Design: Qualitative, Quantitative and Mixed Method Approaches* (3rd ed.). London: Sage.

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Boston, MA: Pearson.

Creswell, J. W. (2014). *Research Design: Qualitative, Quantitative, And Mixed Methods Approaches* (4th ed.). *Thousand Oaks*. CA: Sage publications. https://library.umw.ac.id/index.php?p=show_detail&id=1755&keywords=

Creswell, J.W. (2007). *Qualitative Inquiry & Research Design: Choosing Among Five Approaches* (2nd ed.). Thousand Oaks, London: Sage

Crisan, C., Lerman, S., & Winbourne, P. (2007). Mathematics and ICT: a framework for conceptualising secondary school mathematics teachers' classroom practices. *Technology, Pedagogy and Education, 16*(1), 21- 39.

Cuban, L. (2001). *Oversold and Underused: Computers in the Classroom*. Cambridge, MA: Harvard University Press.

Cunska, A., & Savicka, I. (2012). Use of ICT Teaching-Learning Methods make School Math Blossom. *Procedia - Social and Behavioral Sciences*, *69*, 1481–1488. https://doi.org/10.1016/j.sbspro.2012.12.089

Das, K. (2019). The Role and Impact of ICT in Improving the Quality of Education: An Overview. *International Journal of Innovative Studies in Sociology and Humanities (IJISSH), 4*(6), 97-103.

Davis, E. K. (2018). Mathematics classroom discourse in typical Ghanaian public school: how does it look like? Mathematics classroom discourse in typical Ghanaian public school: how does it look like? *The Oguaa Educator, 12*, 1-27.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340.

Değerli, M., & Uygan, C. (2023). Examination of Mathematics Teachers' Orchestration Types Specific to Their Dynamic Geometry Software-Based Emergency Remote Teaching. *The Universal Academic Research Journal*, *5*(3), 211-231.

Ramírez-Rueda, M. D. C., Gutiérrez, R. C., Colmenero, M. J. R., & González-Calero, J. A. (2021). Towards a coordinated vision of ICT in education: A comparative analysis of Preschool and Primary Education teachers' and parents' perceptions. *Teaching and Teacher Education, 100*, 103300. https://doi.org/10.1016/j.tate.2021.103300

Department for Education and Employment (DfEE). (1999). The National Numeracy Strategy: Framework for Teaching Mathematics from Reception to Year 6. London.

Department of Basic Education (DBE). (2018). Mathematics teaching and learning framework for South Africa: Teaching mathematics for understanding.

Government of South Africa.

Denscombe, M. (2010). *The Good Research Guide for small-scale social research projects* (4th ed.). Maidenhead: Open University Press

Department for Education and Skills (DfES). (2003). Integrating ICT into mathematics in Key Stage 3. London.

Department for Education and Skills (DfES). (2004). ICT in Mathematics Key Stage 3, *National Strategy: ICT Across the Curriculum*. London.

Deryakulu, D., Buyukozturk, S., Karadeniz, S., & Olkun, S. (2008). Satisfying and frustrating aspects of ICT teaching: A comparison based on self- efficacy. *International Journal of Social, Management, Economics and Business Engineering*, *2*(10), 202-205.

Diehl, D. E. (2005). *A study of faculty-related variables and competence in integrating instructional technologies into pedagogical practices* (pp. 1-108). Texas Southern University.

Dillenbourg, P., Zufferey, G., Alavi, H., Jermann, P., Do-Lenh, S., Bonnard, Q., Cuendet, S., & Kaplan, F. (2011). Classroom orchestration: The third circle of usability. In H. Spada, G. Stahl, N. Miyake & N. Law (Eds.), *Connecting Computer-Supported Collaborative Learning to Policy and Practice: CSCL2011 Conference Proceedings, 1* (pp. 510-517). Hong Kong, China: International Society of the Learning Sciences.

Diknas, P (2008). *Pengembangan Perangkat Penilaian Afektif* www.dikmenum.go.id. http://indraelbuguri.blogspot.com/2009/04/rangkuman-pendidikan-matematika-i.html

Dong, C., & Newman, L. (2018). Enacting pedagogy in ICT-enabled classrooms: conversations with teachers in Shanghai, Technology. *Pedagogy and Education*, *27*(4), 499-511. DOI: 10.1080/1475939X.2018.1517660

Donnelly, D. F., McGarr, O., & O'Reilly, J. (2011). A framework for teachers' integration of ICT into their classroom practice. *Computers & Education*, *57*(2), 1469–1483. https://doi.org/10.1016/j.compedu.2011.02.014

Doorman, M., & Drijvers, P. (2011). Algebra in function. In P. Drijvers (Ed.), *Secondary Algebra Education* (pp. 119–135). https://doi.org/10.1007/978-94-6091-334-1_6

Drijvers, P., Doorman, M., Boon, P., Reed, H. C., & Gravemeijer, K. (2010). The teacher and the tool: instrumental orchestrations in the technology-rich mathematics classroom. *Educational Studies in Mathematics*, *75*(2), 213–234. https://doi.org/10.1007/s10649-010-9254-5

Drijvers, P. (2012). Teachers Transforming Resources into Orchestrations. In: G. Gueudet, B. Pepin & L. Trouche (Eds.), *From Text to 'Lived' Resources. Mathematics Teacher Development* (pp. 265-281). Springer, Dordrecht. https://doi.org/10.1007/978-94-007-1966-8_14

Drijvers, P., Tacoma, S., Besamusca, A., Doorman, M., & Boon, P. (2013). Digital resources inviting changes in mid-adopting teachers' practices and orchestrations. *ZDM – Mathematics Education*, *45*(7), 987–1001. https://doi.org/10.1007/s11858-013-0535-1

Drijvers, P. (2015). Digital technology in mathematics education: Why it works (or doesn't). In *Selected regular lectures from the 12th international congress on mathematical education* (pp. 135-151). Springer International Publishing.

Directorate of Secondary and Higher Education. (2015a). Semi-annual Monitoring Report.

Monitoring and Evaluation Wing, DSHE. Ministry of Education. GoB

Directorate of Secondary and Higher Education. (2015b). Learning Assessment of Secondary Institutions 2015. Monitoring and Evaluation Wing, DSHE. Ministry of Education. GoB

Easterby-Smith, M., Thorpe, R., & Jackson, P.R. (2008). *Management Research* (3rd ed.). London: Sage.

Erbas, A. K., & Yenmez, A. A. (2011). The effect of inquiry-based explorations in a dynamic geometry environment on sixth grade students' achievements in polygons. *Computers & Education. 57* (4), 2462-2475. https://doi.org/10.1016/j.compedu.2011.07.002

Erfjord, I. (2011). Teachers' initial orchestration of students' dynamic geometry software use: Consequences for students' opportunities to learn mathematics. *Technology, Knowledge, and Learning*, *16*(1), 35–54. https://doi.org/10.1007/s10758-011-

9176-z

Ernest, P. (1989). The knowledge, beliefs, and attitudes of the mathematics teacher: A model, *Journal of Education for Teaching*, *15*, 13-33.

Faizi, R. (2018). Moroccan higher education students' and teachers' perceptions towards using Web 2.0 technologies in language learning and teaching. *Knowledge Management & E-Learning: An International Journal*, 86–96. https://doi.org/10.34105/j.kmel.2018.10.005

Fang, S. C. (2021). Towards scientific inquiry in secondary earth science classrooms: Opportunities and realities. *International Journal of Science and Mathematics Education*, *19*, 771-792.

Feng, W., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development*, *53*(4), 5–23. https://doi.org/10.1007/bf02504682

Filgona, J., Sakiyo, J., Gwany D. M., & Okoronka A. U. (2020). Motivation in Learning. *Asian Journal of Education and Social Studies, 10* (4), 16-37.

Fives, H., & Buehl, M. M. (2012). Spring cleaning for the "messy" construct of teachers' beliefs: What are they? Which have been examined? What can they tell us? In *American Psychological Association eBooks* (pp. 471–499). https://doi.org/10.1037/13274-019

Flyvbjerg, B. (2011). Case Study. In N. K. Denzin & Y. S. Lincoln (Eds.), *The Sage Handbook of Qualitative Research*, 4, 301-316. Thousand Oaks: SAGE Publications.

Foster, C. (2014). Minimal interventions in the teaching of mathematics. *European Journal of Science and Mathematics Education, 2* (3), 147- 154.

Foster, C. (2018). Developing mathematical fluency: comparing exercises and rich tasks. *Educational Studies in Mathematics, 97*(2), 121-141.

Fried, L., & Konza, D. (2013). Using self-determination theory to investigate student engagement in the classroom. *International Journal of Pedagogy and Curriculum*, *19*(2), 27–40.

Fuglestad, T. G. (1997). The Teaching of Decimals using Spreadsheets: A Support for Diagnostic Teaching. In L. Rico & A. Sfard (Eds.), *Proceedings of the 8th International Congress on Mathematics Education*, 21-32. Sevilla.

Fullan, M. (2007). *The new meaning of educational change* (4th ed.). London: Routledge Falmer.

Gadanidis, G., & Geiger, V. (2010). A social perspective on technology-enhanced mathematical learning: from collaboration to performance. *ZDM*, *42*, 91-104.

Gamage, S. H., Ayres, J. R., & Behrend, M. B. (2022). A systematic review on trends in using Moodle for teaching and learning. *International Journal of STEM Education*, *9*(1), 1-24. https://doi.org/10.1186/s40594- 021-00323-x

García-Valcárcel-Muñoz-Repiso, A., Basilotta-Gómez-Pablos, V., & López-García, C. (2014). ICT in collaborative learning in the classroom of elementary and secondary education. *Comunicar*, *21*(42), 65-74.

Gebhardt, E., Thomson, S., Ainley, J., & Hillman, K. (2019). Teacher Gender and ICT. In: Gender Differences in Computer and Information Literacy. *IEA Research for Education*, *8*. Springer, Cham. https://doi.org/10.1007/978-3-030-26203-7_5

Ghavifekr, S., & Rosdy, W. A. W. (2015). Teaching and Learning with Technology: Effectiveness of ICT Integration in Schools. *International Journal of Research in Education and Science*, *1*(2), 175-191. https://doi.org/10.21890/ijres.23596

Gikundi, Z. (2016). *Factors Influencing Integration of Information and Communication Technology In Learning And Teaching In Public Secondary Schools: A Case Of Tigania West Sub County, Meru County, Kenya* [Doctoral thesis, University of Nairobi].

Glover, D., & Miller, D. (2007). Leading changed classroom culture — the impact of interactive whiteboards. *Management in Education*, *21*(3), 21-24. https://doi.org/10.1177/0892020607079988

Goldkuhl, G. (2012). Pragmatism vs interpretivism in qualitative information systems research. *European Journal of Information Systems, 21*, 135–146. DOI: 10.1057/ejis.2011.54

Gorder, L. M. (2008). A study of teacher perceptions of instructional technology integration in the classroom. *Delta Pi Epsilon Journal, 50*(2), 63-76.

Granberg, C., & Olsson, J. (2015). ICT-supported problem solving and collaborative creative reasoning: Exploring linear functions using dynamic mathematics software. *The Journal of Mathematical Behavior, 37*, 48–62. https://doi.org/10.1016/j.jmathb.2014.11.001

Gravemeijer, K. P. E., & Cobb, P. (2001, April 13). Designing classroom-learning environments that support mathematical learning. In *Paper presented at the Design experiments, or engineering prototypes of interactive learning environments in science and mathematics* [Symposium]. American Educational Research Association (AERA), Seattle, USA.

Gravemeijer, K., Bowers, J., & Stephan, M. (2003). A hypothetical learning trajectory on measurement and flexible arithmetic. *Journal for Research in Mathematics Education*, *12*, 51–66. doi:10.2307/30037721

Gravier, C., Fayolle, J., Noyel, G., Leleve, A., & Benmohamed, H. (2006). Distance Learning: Closing the Gap between Remote Labs and Learning Management Systems, *Proceedings of IEEE First International Conference on E-Learning in Industrial Electronics, Hammamet, Tunisie*, 130-134.

Groth, R. E. (2017). Classroom Data Analysis with the Five Strands of Mathematical Proficiency. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, *90*(3), 103–109. https://doi.org/10.1080/00098655.2017.1301155

Guetterman, T. C., & Fetters, M. D. (2018). Two methodological approaches to the integration of mixed methods and case study designs: A systematic review. *American Behavioral Scientist*, *62*(7), 900-918.

Guetterman, T.C., & Mitchell, N. (2016). The Role of Leadership and Culture in Creating Meaningful Assessment: A Mixed Methods Case Study. *Innovative Higher Education*, *41* (1), 43–57. https://doi.org/10.1007/s10755-015-9330-y

Gunpinar, Y., & Pape, S. (2018). Teachers' Instructional Practices within Connected Classroom Technology Environments to Support Representational Fluency. *Journal of Computers in Mathematics and Science Teaching, 37*(1), 27- 52.

Hajjar, S. T. (2018). Statistical analysis: Internal-consistency reliability and construct validity. *International Journal of Quantitative and Qualitative Research*

Methods, *6*(1), 27-38.

Haji, S., Yumiati, Y., & Zamzaili, Z. (2019). Improving Students' productive disposition through realistic mathematics education with outdoor approach. *JRAMathEdu (Journal of Research and Advances in Mathematics Education)*, *4*(2), 101-111.

Halidi, H. M., Husain, S. N., & Sahrul, S. (2015). Pengaruh Media Pembelajaran Berbasis TIK Terhadap Motivasi dan Hasil Belajar IPA Siswa Kelas V SDN Model Terpadu Madani Palu, *e-Jurnal Mitra Sains, 3*(1), 53-60.

Hansson, H., Sultana, S., Sarwar, A. H., Ahmed, F., Uddin, R., Saha, P., ... & Islam, M. R. (2018). The Teachers' Portal as a Tool for Teachers' Professional Development in Bangladesh: Facilitating Nationwide Networking and Digital Multimedia Content for 40,000 Schools. *International Journal of Education and Development using Information and Communication Technology*, *14*(3), 113-130.

Hativa, N., Barak, R., & Simhi, E. (2001). Exemplary university teachers: Knowledge and beliefs regarding effective teaching dimensions and strategies. *The journal of higher education*, *72*(6), 699-729.

Harel, I., & Papert, S. (1991). Software design as a learning environment. In I. Harel & S. Papert. (Eds), *Constructionism*, 41- 83. Norwood, New Jersey: Ablex Publishing.

Harrison, A. W., & Rainer, R. K. (1992). The Influence of Individual Differences on Skill in End-User Computing. *Journal of Management Information Systems, 9*(1), 93-111.

Hartman, R. J., Townsend, M. B., & Jackson, M. (2019). Educators' perceptions of technology integration into the classroom: a descriptive case study. *Journal of Research in Innovative Teaching & Learning*, *12*(3), 236–249. https://doi.org/10.1108/jrit-03-2019-0044

Hennessy, S., Ruthven, K., & Brindley, S. U. E. (2005). Teacher perspectives on integrating ICT into subject teaching: commitment, constraints, caution, and change. *Journal of curriculum studies, 37*(2), 155-192.

Hiebert, J. (1999). Relationships between Research and the NCTM Standards. *Journal for Research in Mathematics Education*, *30*(1), 3. https://doi.org/10.2307/749627

Hill, H. C., Ball, D. L., & Schilling, S. G. (2008). Unpacking Pedagogical Content

Knowledge: Conceptualizing and Measuring Teachers' Topic-Specific Knowledge of Students. *Journal for Research in Mathematics Education*, *39*(4), 372–400. http://www.jstor.org/stable/40539304

Hohenwarter, M., & Fuchs, K. (2004, July). Combination of dynamic geometry, algebra and calculus in the software system GeoGebra. In *Computer algebra systems and dynamic geometry systems in mathematics teaching conference* (pp. 1-6).

Hollebrands, K. (2007). The role of a dynamic software program for geometry in the strategies high school mathematics students employ. *Journal for Research in Mathematics Education*, 38(2), 164–192.

Holz-Clause, M., Guntuku,D., Koundinya,V., Clause, R., & Singh, K. (2015). Current and Future Trends in Higher Education Learning: Implications for Curriculum Design and Delivery. In N. P. Ololube, P.J. Kpolovie & L.N. Makewa (Eds.), *Handbookof Research on Enhancing Teacher Education with Advanced Instructional Technologies* (pp. 277-292). IGI Global. https://doi.org/10.4018/978-1-4666-8162-0.ch015

Hossain, A. (2018). The Implementation of Learning Together in Improving Students' Mathematical Performance. *International Journal of instruction*, *11*(2), 483-496.

Hoyles, C., Healy, L., & Pozzi, S. (1994). Learning Mathematics in Groups with Computers: reflections on a research study. *British Educational Research Journal*, *20*(4), 465- 483. https://doi.org/10.1080/0141192940200408

Hsu, S. (2010). The Relationship between Teacher's Technology Integration Ability and Usage. *Journal of Educational Computing Research*, *43*(3), 309–325. https://doi.org/10.2190/ec.43.3.c

Hwang, W., Chen, N., Dung, J., & Yang, Y. (2007). Multiple Representation Skills and Creativity Effects on Mathematical Problem Solving using a Multimedia Whiteboard System. *Journal of Educational Technology & Society*, *10*(2), 191–212. http://www.jstor.org/stable/jeductechsoci.10.2.191

Imms, W., Mahat, M., Byers, T., & Murphy, D. (2017). Type and Use of Innovative Learning Environments in Australasian Schools. ILETC Survey 1. *Online Submission*.

Imon, M.M. I.I (2017). *ICT integration in Secondary Education in Bangladesh: A study of Policy and Practice* [MPhil thesis, University of Oslo]. Retrieved from https://www.duo.uio.no/bitstream/handle/10852/61350/1/Imran-Thesis-CIE--17

International Society for Technology in Education (ISTE) (2008). Essential conditions: Necessary conditions to effectively leverage technology for learning. https://www.iste.org/standards/for-educators

Islam, M. R., & Ferdosh, J. (2019). ICT in Education for sustainable development and preparing human resource for future Bangladesh. Retrieved from http://a2i.gov.bd/wp- content/uploads/2019/11/ICT-in-Edication.pdf

Ismail, S. A. M. M., Jogezai, N. A., & Baloch, F. A. (2020). Hindering and enabling factors towards ICT integration in schools: A developing country perspective. *Elementary Education Online*, *19*(3), 1537-1547.

Jane-Jane Lo, J., & Kratky, J. L. (2012). Looking for Connections between Linear and Exponential Functions. *The Mathematics Teacher*, *106* (4), 295-301 https://doi.org/10.5951/mathteacher.106.4.0295

Jones, S. (2017). Technology in the Montessori Classroom: Teachers' beliefs and technology use. *Journal of Montessori Research*, *3*(1), 16. https://doi.org/10.17161/jomr.v3i1.6458

John, P. D., & Sutherland, R. (2004). Teaching and learning with ICT: New technology, new pedagogy?. *Education, Communication & Information*, *4*(1), 101-107.

Kafi, M. A. (2015). *Challenges of Teaching and Learning Mathematics at Secondary Level in Bangladesh* [Doctoral thesis, University of Rajshahi] http://rulrepository.ru.ac.bd/handle/123456789/267

Kabir, S., & Jalali, T. K. (2021). Linking Real-Life Situation with Content of School Mathematics at Secondary Level: Exploring Current Practice and Challenge in Bangladesh. *Journal of Education and Practice, 12* (3), 162-173.

Kafai, Y. B., Franke, M. L., Ching, C. C., & Shih, J. C. (1998). Game design as an interactive learning environment for fostering students' and teachers' mathematical inquiry. *International Journal of Computers for Mathematical Learning*, *3*, 149-184.

Kaleli-Yilmaz, G. (2015). The Views of Mathematics Teachers on the Factors Affecting the Integration of Technology in Mathematics Courses. *Australian Journal of Teacher Education, 40*(8). https://doi.org/10.14221/ajte.2015v40n8.8

Karatza, Z. (2019). Information and communication technology (ICT) as a tool of differentiated instruction: An informative intervention and a comparative study on educators' views and extent of ICT use. *International Journal of Information and Education Technology*, *9*(1), 8-15.

Karpuzcu, S. Y. (2017). *Middle school mathematics teachers' mathematical practices in teaching slope, linear equations, and graphs in technology enhanced classroom environments* [Doctoral thesis, Middle East Technical University].

Kearney, M., & Treagust, D. F. (2001). Constructivism as a referent in the design and development of a computer program using interactive digital video to enhance learning in physics. *Australasian Journal of Educational Technology*, *17*(1), 64-79. https://doi.org/10.14742/ajet.1773

Kendal, M., & Stacey, K. (2002). Teachers in transition: Moving towards CAS-supported classrooms. *ZDM*, *34*(5), 196-203.

Kenedi, A. K., Helsa, Y., Ariani, Y., Zainil, M., & Hendri, S. (2019). Mathematical Connection of Elementary School Students to Solve Mathematical Problems. *Journal on Mathematics Education*, *10*(1), 69-80.

Khalid, M., Khan, M. S. H., & Gregory, S. (2023). Contextual variation on teachers' conceptions of ICT-enhanced teaching in engineering education. *Heliyon, 9*(3).

Khan, M. S. H., Hasan, M., & Clement, C. K. (2012). Barriers to the Introduction of ICT into Education in Developing Countries: The Example of Bangladesh. *International Journal of Instruction*, *5*(2), 61–80. http://e-iji.net/dosyalar/iji_2012_2_4.pdf

Khan, S.H. (2014). A Model for Integrating ICT into Teacher Training Programs in Bangladesh. *International Journal of Education and Development using Information and Communication Technology*, 10(3), 21 -31.

Khanna, P. (2019). Positivism and Realism. In: P. Liamputtong (Ed.), *Handbook of Research Methods in Health Social Sciences.* Springer, Singapore. https://doi.org/10.1007/978-981-10-5251-4_59

Kilpatrick, J., Swafford, J., & Findell, B. (2001). *Adding it up: Helping how children learn mathematics*. Washington, DC: National Academy Press.

Kim, H. S., & Kamil, M. L. (2002). Successful Uses of Computer Technology for Reading

Instruction. In M. L. Kamil, H. Walberg & J. Manning, (Eds.), *Successful Reading Instruction* (pp. 11-22).

Kilpatrick, J., & Swafford, J. (2002). *Helping children learn mathematics*. Washington, DC: National Academy Press.

Koyuncu, I., Akyuz, D., & Cakiroglu, E. (2014). Investigating Plane Geometry Problem Solving Strategies of Prospective Mathematics Teachers in Technology and Paper and Pencil Environments. *International Journal of Science and Mathematics Education*, 1–26.

Kratky, J. L. (2013). *One teacher's instrumental orchestrations* [Paper presentation]. North American Chapter of the International Group for the Psychology of Mathematics Education (PME-NA), Chicago, IL

Kratky, J. L. (2016). *Pedagogical moves as characteristics of one instructor's instrumental orchestrations with tinkerplots and the ti-73 explorer: a case study* [Doctoral thesis, Western Michigan University]. https://scholarworks.wmich.edu/dissertations/2480

Kurt, S. (2014). Creating technology-enriched classrooms: implementational challenges in Turkish education. *Learning, Media and Technology*, 39(1), 90-106. DOI: 10.1080/17439884.2013.776077

Kurtz, K. (2019). Project-Based Learning in High School Mathematics. *Learning to Teach Language Arts, Mathematics, Science, and Social Studies Through Research and Practice*, *8*(1).

Kusumah, Y. S., Darwis, S., & Afgani, J. D. (2016). Developing Conceptual Understanding and Procedural Fluency for Junior High School Students through Model-Facilitated Learning (MFL). *European Journal of Science and Mathematics Education*, *4*(1), 67-74.

Kvale, S. (1996). *Interviews*. Thousand Oaks, CA: Sage.

Laal, M., & Ghodsi, S. M. (2012). Benefits of collaborative learning. *Procedia - Social and Behavioral Sciences*, *31*, 486–490. https://doi.org/10.1016/j.sbspro.2011.12.091

Laborde, C. (2001). Integration of technology in the design of geometry tasks with CABRI - Geometry. *International Journal of Computers for Mathematical Learning*, *6*(3), 283-317.

Lai, E. R. (2011). Motivation: A Literature Review. *Pearson*, 1-43.

Langford, P. (1989). *Children's thinking and learning in the elementary school*. https://openlibrary.org/books/OL2063955M/Children's_thinking_and_learning_in_the_elementary_school

Laswadi, Kusumah, Y.S., Darwis, S., Afgani, J.D. (2016). Developing conceptual understanding and procedural fluency for junior high school students through model-facilitated learning (MFL). *European Journal of Science and Mathematics Education*, *4*(1)

Lasky, S. (2005). A sociocultural approach to understanding teacher identity, agency and professional vulnerability in a context of secondary school reform. *Teaching and Teacher Education*, *21*(8), 899–916. https://doi.org/10.1016/j.tate.2005.06.003

Lawrence, J. E., & Tar, U. A. (2018). Factors that influence teachers' adoption and integration of ICT in teaching/learning process. *Educational Media International*, *55*(1), 79-105. DOI: 10.1080/09523987.2018.1439712

Lee, C., & Johnston-Wilder, S. (2014). Mathematical resilience: what is it and why is it important? In: Chinn, Steve (Ed.), *The Routledge International Handbook of Dyscalculia and Mathematical Learning Difficulties* (pp. 337-345), Abingdon: Routledge.

Lerís, D., Sein-Echaluce, M. L., Hernández, M., & Bueno C. (2017). Validation of indicators for implementing an adaptive platform for MOOCs. *Computers in Human Behavior*, *72*, 783–795.

Lestari, K. E., & Yudhanegara. (2015). Penelitian Pendidikan Matematika. Bandung: PT Refika Aditama.

Li, S., & Zheng, J. (2018). The relationship between self-efficacy and self-regulated learning in One-to-One computing environment: the mediated role of task values. *The Asia-Pacific Education Researcher*, *27*(6), 455–463. https://doi.org/10.1007/s40299-018-0405-2

Li, S., Yamaguchi, S., Sukhbaatar, J., & Takada, J. I. (2019). The influence of teachers' professional development activities on the factors promoting ICT integration in primary schools in Mongolia. *Education Sciences*, *9*(2), 78.

Li, Y., & Dawley, L. (2019). Technology Integration Panel (TIP): A Classroom Observation Tool to Measure the Capacity of Using Technology to Support Student-Centered Learning in the K12 Classroom. Annual meeting of the International Society for Technology in Education, Philadelphia.

Lim, C. P., & Chai, C. S. (2004). An activity-theoretical approach to research of ICT integration in Singapore schools: Orienting activities and learner autonomy. *Computers & Education*, *43*(3), 215–236. https://doi.org/10.1016/j.compedu.2003.10.005

Lim, C. P., Pek, M. S., & Chai, C.S. (2005). Classroom Management Issues in ICT-Mediated Learning Environments: Back to the Basics. *Journal of Educational Multimedia and Hypermedia*, 14(4), 391-414.

Lin, S., & Muenks, K. (2023). Family context of mindset matters: Students' perceptions of parent and sibling math mindsets predict their math motivation, behavior, and affect, *Applied Developmental Science.*1-28
DOI: 10.1080/10888691.2023.2177163

Lozano, M.D. (2017). Investigating task design, classroom culture and mathematics learning: an enactivist approach. *ZDM Mathematics Education*, 49, 895–907. https://doi.org/10.1007/s11858-017-0890-4

Lugalia, M. (2015). *Pupils learning algebra with ICT in Key Stage 3 mathematics classrooms.* [Doctoral thesis, University of Warwick].
https://webcat.warwick.ac.uk/record=b2827363~S1

Lugalia, M., Johnston-Wilder, S. And Goodall, J. (2015). Using ICT and Dialogic Teaching: Impact on Mathematical Resilience and Attainment in Algebra of a Kenyan School Year Group. EDULEARN15 Proceedings, 5069-5078

Made, W. (2011). Strategi Pembelajaran Inovatif Kontemporer, Suatu Tinjauan Konseptual Operasional. Jakarta: Bumi Aksara.

Maher, C. A. (2002). How students structure their own investigations and educate us: what we've learned from a fourteen year study. In: A. D. Cockburn, & E. Nardi (Eds.), Proceedings of the Twenty-Sixth Conference of the International Group for the Psychology of Mathematics Education, 1, 31-46. Norwich, UK: School of Education and Professional Development, University of East Anglia.

Marasabessy, R. (2021). Study of mathematical reasoning ability for mathematics learning in schools: A literature review. *Indonesian Journal of Teaching in Science*, *1*(2), 79-90.

Mareschal, S., & Delaney, S. (2019). *Using FOCUS GROUP DISCUSSIONS with children and adolescents: a practical guide for maximizing their effectiveness IM Resource Portal*. https://www.im-portal.org/help-library/using-focus-group-discussions-children-adolescents-guide

McGilvray, D. (2021). *Executing data quality projects: Ten Steps to Quality Data and Trusted Information (TM)*. Academic Press.

McKenney, S., Nieveen, N., & Van Den Akker, J. (2006). Design research from a curriculum perspective. In *Routledge eBooks*. https://doi.org/10.4324/9780203088364-14

McGrath, C., Palmgren, P. J., & Liljedahl, M. (2019). Twelve tips for conducting qualitative research interviews. *Medical Teacher*, 41(9), 1002–1006. https://doi.org/10.1080/0142159x.2018.1497149

Mertala, P. (2019). Teachers' beliefs about technology integration in early childhood education: A meta-ethnographical synthesis of qualitative research. Computers in Human Behavior. 101. 334-349. 10.1016/j.chb.2019.08.003.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative Data Analysis: An Expanded Sourcebook* (2nd ed.), Thousand Oaks, LA: Sage.

Milgram, R. J. (2007). What is Mathematical Proficiency? In Alan H. Schoenfeld (Ed.), Assessing Mathematical Proficiency, (pp. 31-58). Cambridge University Press.

Min, L. (2019). How Does Teachers' Workload Affect Their Utilization of Information and Communication Technology: Research Results by Cluster Analysis on Primary and Secondary Teachers in China, *International Symposium on Educational Technology (ISET)*, Hradec Kralove, Czech Republic, 2019, 97-102, doi: 10.1109/ISET.2019.00029.

Ministry of Education. (2013). *Master Plan for ICT in Education 2012-2021*. Dhaka: MoE.

Ministry of Education. (2010). *National education policy 2010.* Dhaka: MoE

Ministry of Post, Telecommunication and Information Technology. (2018). *National Information and Communication Technology policy 2018*. Dhaka: MoPTIT.

Miranda, H., & Russell, M. (2011). Understanding factors associated with teacher-directed student use of technology in elementary classrooms: A structural equation modeling approach. *British Journal of Educational Technology*, *43*(4), 652–666. https://doi.org/10.1111/j.1467-8535.2011.01228.x

Mishra, P., & Koehler, M. J. (2006). 'Technological pedagogical content knowledge: a framework for teacher knowledge', Teachers College Record, 108(6): pp.1017-1054

Moon, J. (2001) How to improve the impact of short courses and workshops. Training & Professional Development. London: Kogan Page.

Mora-Cruz, A., Saura, J. R., & Palos-Sanchez, P. R. (2022). Social Media and User-Generated Content as a Teaching Innovation Tool in Universities. In J.R. Saura (Eds), Teaching Innovation in University Education: Case Studies and Main Practices, 52-67. IGI Global. https://doi.org/10.4018/978-1-6684-4441-2.ch004

Morshed, M. M. (2013). Math anxiety and math achievement in rural junior-secondary students of Bangladesh. Proceedings from the Annual meeting of the 57th Annual Conference of the Comparative and International Education Society. New Orleans, LA.

Moyer, P. S., Bolyard, J. J., & Spikell, M. A. (2002). What are virtual manipulatives? Teaching Children Mathematics, 8(6), 372–377.

Mumtaz, S. (2000) Using ICT in Schools: a review of the literature on learning. Teaching and software evaluation. Coventry: University of Warwick Centre for New Technologies Research in Education.

Mundy, M., Kupczynski, L., & Kee, R. (2021). Teacher's Perceptions of Technology Use inSchools. *SAGE Open*, *2*(1), 1–8.

Mwendwa, N. K. (2017). Perception of teachers and principals on ICT integration in the primary school curriculum in Kitui County, Kenya. *European Journal of Education Studies*. https://doi.org/10.46827/ejes.v0i0.875

Nandhakumar, J., & Jones, M. (1997). Too close for comfort? Distance and engagementin interpreting information system research. Information Systems Journal, 7, pp. 109-137

National Council of Teachers of Mathematics. (2011). Technology in Teaching and Learning Mathematics, Online at: https://www.nctm.org/Standards-and-Positions/Position-Statements/Technology-in-Teaching-and-Learning Mathematics

National Council of Teachers of Mathematics. (2014). Procedural fluency in mathematics: A position of the National Council of Teachers of Mathematics. Reston, VA: NCTM.

National Curriculum and Textbook Board. (2012). National Curriculum 2012. http://www.nctb.gov.bd/sites/default/files/files/nctb.portal.gov.bd/files/6d9b9671_f815_460c_b8ef_c58a1b829f55/Maths%20&%20Higher%20Math.pdf

National Curriculum and Textbook Board. (2013). Higher Mathematics: Classes Nine-Ten.

National Curriculum and Textbook Board. (2021). National Curriculum Framework 2021. https://shed.portal.gov.bd/sites/default/files/files/shed.portal.gov.bd/page/0b8eda3f_ce40_46c5_9e98_1ccda2ec348b/English.pdf

National Research Council. (2001). Adding It Up: Helping Children Learn Mathematics. Washington, DC: National Academy Press.

Noss, R. and Hoyles, C. (1996). Windows on mathematical meanings: learning cultures and computers. Dordrecht; London: Kluwer Academic Publishers.

Ogwel, A. (2008). Integrating ICT in Mathematics Education: Curricula Challenges in the Kenyan System of Education. Regional Conference on e-Learning: Increasedaccess to education, diversity in applications and management strategies, 1-11.

Ostler, E., (2011). Teaching Adaptive and Strategic Reasoning Though Formula Derivation Beyond Formal Semiotics Department of Teacher Education University of Nebraska at Omaha United States, *International Journal of Mathematics Science Education*, *4*(16)

Ottenbreit-Leftwich, A., Glazewski, K., Newby, T. J., & Ertmer, P. A. (2010). Teacher value beliefs associated with using technology: Addressing professional and student needs. *Computers & Education, 55*(3), 1321–1335. https://doi.org/10.1016/j.compedu.2010.06.002

Ozdemir, İ. E. Y., & Pape, S. J. (2012). Supporting students' strategic competence: a case of a sixth-grade mathematics classroom. *Mathematics Education Research Journal*, *24*(2), 153–168. https://doi.org/10.1007/s13394-012-0033-8

Özkaya, A., & Yetim, K. (2017). The effects of Realistic Mathematics Education on students' achievements and attitudes in fifth grades mathematics courses. International Online Journal of Education and Teaching (IOJET), 4(2), 185–197.

Parhizgar, Z., Dehbashi, A., Liljedahl, P., & Alamolhodaei, H. (2022). Exploring students' misconceptions of the function concept through problem-posing tasks and their views thereon, *International Journal of Mathematical Education in Science and Technology*, 53(12), 3261-3285, DOI: 10.1080/0020739X.2021.1937732

Parker, R. E., Bianchi, A., & Cheah, T. Y. (2008). Perceptions of instructional technology: Factors on influence and anticipated consequences. Educational Technology & Society, vol. 11, no. 2, pp. 274-293.

Parvin, M. S. (2013). Integrations of ICT in Education Sector for the Advancement of the Developing Country: Some Challenges and Recommendations-Bangladesh Perspective. *International Journal of Computer Science and Information Technology*, *5*(4), 81–92. https://doi.org/10.5121/ijcsit.2013.5406

Pear, J. J., & Crone-Todd, D. E. (2002). A social constructivist approach to computer-mediated instruction. *Computers & Education, 38*(1–3), 221–231. https://doi.org/10.1016/s0360-1315(01)00070-7

Pedersen, M. K., Bach, C. C., Gregersen, R. M., Højsted, I. H., & Jankvist, U. T. (2021). Mathematical representation competency in relation to use of digital technology and task design—a literature review. *Mathematics*, *9*(4), 444.

Peralta, H., & Costata, F. A. (2007). Teachers' competence and confidence regarding the use of ICT. *Sísifo-Educational Sciences Journal*, 75-84.

Pierce, R., & Stacey, K. (2010). Mapping pedagogical opportunities provided by mathematics analysis software. *International Journal of Computers for Mathematical Learning*, *15*, 1-20.

Plano Clark, V. L., & Creswell, J. W. (2015). Understanding research: A consumer guide. Merrill: New Jersey, USA.

Plomp, T. (2007). Educational design research: An introduction. In T. Plomp, & N. Nieveen (Eds.), An introduction to education design research: Proceedings of the seminar conducted at the East China Normal University, Shanghai (PR China), November 23-26, 2007. (3rd print ed.) (pp. 9-35). Enschede: SLO.

Powell, A. B., Francisco, J. M., & Maher, C. A. (2003). An analytical model for studying the development of learners' mathematical ideas and reasoning using videotape data. *The Journal of Mathematical Behavior*, *22*(4), 405–435. https://doi.org/10.1016/j.jmathb.2003.09.002

Preiner, J. (2008). *Introducing dynamic mathematics software to mathematics teachers: The case of GeoGebra.* [Doctoral Thesis, University of Salzburg]. https://doi.org/10.13140/RG.2.2.15003.05921

Ratnayake, I. G., Adler, J., & Thomas, M. (2023). Relating chains of instrumental orchestrations to teacher decision-making. *Journal of Mathematics Teacher Education*, 1-28.

Razak, N., Ab Jalil, H., & Ismail, I. (2019). Challenges in ICT integration among Malaysian public primary education teachers: The roles of leaders and stakeholders. *International Journal of Emerging Technologies in Learning(iJET)*, *14*(24), 184-205.

Reeves, T. (2006). Design research from a technology perspective. In J. Van Den Akker, K. Gravemeijer, S. McKenney & N. Nieveen (1st ed.), *Educational Design research*. 52-66. Routledge.

Reezan, D. (2013). *The effects of teaching linear equations with Dynamic Mathematics Software (GeoGebra) on seventh grade students' achievement* [Master's thesis, Middle East Technical College]

Redecker, C., & Johannessen, Ø. L. (2013). Changing Assessment — Towards a New Assessment Paradigm Using ICT. *European Journal of Education*, *48*(1), 79–96. https://doi.org/10.1111/ejed.12018

Reiten, L. (2018). Teaching WITH (not near) Virtual Manipulatives. In E. Langran & J.

Borup (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference* (pp. 1826-1835). Washington, D.C., United States: Association for the Advancement of Computing in Education (AACE).

Rezigalla, A. A. (2022). Item analysis: Concept and application. In *IntechOpen eBooks*. https://doi.org/10.5772/intechopen.100138

Ropum, S. K., Islam, M. M., & Rabbi, M. F. (2022). Multimedia classrooms of the secondary schools in Bangladesh: A Situation analysis. *Journal of Research in Instructional*, *2*(2), 175-196.

Roschelle, J., Rafanan, K., Bhanot, R., Estrella, G., Penuel, B., Nussbaum, M., & Claro, S. (2010a). Scaffolding group explanation and feedback with handheld technology: Impact on students' mathematics learning. *Educational Technology Research and Development*, *58*, 399-419.

Roschelle, J., Shechtman, N., Tatar, D., Hegedus, S., Hopkins, B., Empson, S., ... & Gallagher, L. P. (2010b). Integration of technology, curriculum, and professional development for advancing middle school mathematics: Three large-scale studies. *American Educational Research Journal*, *47*(4), 833-878.

Rubin, C., & Babbie, S. (2019). *Research Methods for Social Work* (9th ed.). Cengage Learning: Boston, MA, USA.

Ruthven, K. (2014). Frameworks for analysing the expertise that underpins successful integration of digital technologies into everyday teaching practice. *The mathematics teacher in the digital era: An international perspective on technology focused professional development*, 373-393.

Salam, A., Hossain, A., & Rahman, S. (2015). Effects of Using Teams Games Tournaments (TGT) Cooperative Technique for Learning Mathematics in Secondary Schools of Bangladesh. *Malaysian Online Journal of Educational Technology*, *3*(3), 35-45.

Saravanakumar, A. R. (2018). Role of ICT on Enhancing Quality of Education, *International Journal of Innovative Science and Research Technology*, *3*(12), 717-719.

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research Methods for Business Students* (5th ed.). London: Pearson Education Limited.

Schiller, J. (2003). The elementary school principal as a change facilitator in ICT integration. *The technology source*, *26*(1), 12-22.

Schoenfeld, A. H. (2007). Issues and tensions in the assessment of mathematical proficiency. In A. H. Schoenfeld (Ed.), *Assessing Mathematical Proficiency* (pp 3-15). New York: Cambridge University Press.

Seel, N.M., Lehmann, T., Blumschein, P., Podolskiy, O.A. (2017). What is Instructional Design? In *Instructional Design for Learning* (pp.1-17). Sense Publishers, Rotterdam. https://doi.org/10.1007/978-94-6300-941-6_1

Serin, H. (2015). The Role of technology in whole-class teaching. *International Journal of Social Science Education Studies*, *2*, 25-27.

Shen, L. (2010). Mitigating Psychological reactance: The role of Message-Induced Empathy in Persuasion. *Human Communication Research*, *36*(3), 397–422. https://doi.org/10.1111/j.1468-2958.2010.01381.x

Shohel, M. M. C., & Power, T. (2010). Introducing Mobile Technology for Enhancing Teaching and Learning in Bangladesh: Teacher Perspectives. *Open Learning: The Journal of Open and Distance Learning*, 25(3), 201-215.

Shute, V. J. (2008). Focus on formative feedback. *Review of educational research*, *78*(1), 153-189.

Siddiqui**,** K. (2023, July 28). SSC pass rate drops to 80.39% amid poor performance in Math, English. *The Business Standard.* https://www.tbsnews.net/bangladesh/education/8039

Siegfried, Z. J. M. (2012). *The Hidden Strand of Mathematical Proficiency: Definingand Assessing for Productive Disposition in Elementary School Teachers' Mathematical Content Knowledge* [Doctoral thesis, University of California].

Smith, M., Bill, V., & Raith, M. L. (2018). Promoting a conceptual understanding of mathematics. *Mathematics Teaching in the Middle School*, *24*(1), 36-43.

Sokku, S. R., & Anwar, M. (2019). Factors Affecting the Integration of ICT in Education. *Journal of Physics,* 1-6. https://doi.org/10.1088/1742-6596/1244/1/012043

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.

Sudiarta, I. G. P., & Widana, I. W. (2019). Increasing mathematical proficiency and students character: lesson from the implementation of blended learning in junior high school in Bali. *Journal of Physics, 1317,* 012118. https://doi.org/10.1088/1742-6596/1317/1/012118

Sultana, T. (2016). Comparative Study on Effective Teaching Strategies in Mathematics Classrooms Using ICT: UK vs Bangladesh [Master's dissertation, University of Bristol]

Sultana, T., Khan, R. H., & Sultana, R. (2016). ICT-Based Teaching Strategies for Mathematics Classroom: A Comparative Study between UK and Bangladesh. *Teacher's World: Journal of Education and Research, 43*, 193-207.

Sultana, T., & Khan, R.H. (2017). Developing a Framework for Effective Teaching Strategies in ICT-Mediated Mathematics Classroom: Context Bangladesh. *Teacher's World*, *44*, 73-88.

Sultana, M., & Haque, M.S. (2018). The Cause of Low Implementation of ICT in the Education Sector Considering Higher Education: A Study on Bangladesh. *Canadian Social Science, 14*(12), 67-73.

Sultana, T., & Khan, R. H. (2019). Investigating University Students‟ Satisfaction on Online Class: Bangladesh Perspective. *Bangladesh Education Journal, 18*(2), 23-32.

Sultana, T., Farhana, Z. & Jahanara, Q. A. (2020). Assessing Mathematical Literacy of Students at Secondary Level in Bangladesh, *Teacher's World: Journal of Education and Research*, *46*, 79-90.

Sumartini, T. S. (2015). Peningkatan Kemampuan Penalaran Matematis Siswa Melalui Pembelajaran Berbasis Masalah. *Jurnal pendidikan matematika, 5*,1

Sutherland, R., Robertson, S., & John, P. (2009). *Improving Classroom Learning with ICT*. London and New York: Routledge Taylor & Francis Group.

Sutherland, W., Pullin, A., Dolman, P., & Knight, T. (2004). The need for evidence-based conservation. *Trends in Ecology & Evolution, 19,* 305–308

Suurtamm, C., Thompson, D. R., Kim, R. Y., Moreno, L. D., Sayac, N., Schukajlow, S., Silver, E. A., Ufer, S., & Vos, P. (2016). *Assessment in mathematics education:*

Large-Scale assessment and classroom assessment. Springer Nature. https://library.oapen.org/bitstream/20.500.12657/27856/1/1002148.pdf

Suurtamm, C. (2018). Enhancing Mathematics teaching and learning through sound assessment practices. In A. Kajander, J. Holm & E. J. Chernoff (Eds.), *Teaching and Learning Secondary School Mathematics* (pp.473-482). Cham, CH: Springer International Publishing AG.

Swan, M. (2008). Designing a Multiple Representation Learning Experience in Secondary Algebra. *Educational Designer*, *1*(1), 1-17

Sze Ming Loh, R., Kraaykamp, G., & van Hek, M. (2023). Do students' ICT skills pay off in math performance? Examining the moderating role of countries' ICT promotive environment. *In European Educational Research Journal*. SAGE Publications. https://doi.org/10.1177/14749041231201197

Tabach, M. (2011). A Mathematics Teacher's Practice in a Technological Environment: A Case Study Analysis Using Two Complementary Theories. *Tech Know Learn, 16*, 247–265. https://doi.org/10.1007/s10758-011-9186-x

Tabach, M. (2013). Developing a general framework for instrumental orchestration. In *Jana Trgalova & Hans-Georg Weigand (Eds.), Conference on European Research on Mathematics Education, CERME8.* Available from http://cerme8. metu. edu. tr/wgpapers/wg15_papers. html.

Tang, K., Hsiao, C., Tu, Y., Hwang, G., & Wang, Y. (2021). Factors influencing university teachers' use of a mobile technology-enhanced teaching (MTT) platform. *Educational Technology Research and Development*, *69*(5), 2705–2728. https://doi.org/10.1007/s11423-021-10032-5

Tay, L. Y., Lim, S. K., & Lim, C. P. (2013). Factors affecting the ICT integration and implementation of one-to-one computing learning environment in a primary school–A sociocultural perspective. In *Creating holistic technology-enhanced learning experiences* (pp. 19-37). Brill.

Tavakol, M., & Dennick, R. (2011). Post examination analysis of objective tests. *Med Teach*, *33*(6), 447-58.

Tedla, B. A. (2012). Understanding the importance, impacts and barriers of ICT on teaching and learning in East African countries. *International Journal for e-*

Learning Security (IJeLS), *2*(3/4), 199-207.

Tinio, V. L. (2003). *ICT in Education*.

Tomlinson, C. A. (1999). *The differentiated Classroom: responding to the needs of all learners*. http://eric.ed.gov/?id=ED429944

Trouche, L. (2004). Managing the complexity of human/machine interactions in computerized learning environments: Guiding students' command process through instrumental orchestrations. *International Journal of Computers for Mathematical Learning, 9*(3), 281- 307. doi:10.1007/s10758-004-3468-5

Trouche, L. (2005). Instrumental genesis, individual and social aspects. In D. Guin, K. Ruthven & L. Trouche (Eds.), *The didactical challenge of symbolic calculators: Turning a computational device into a mathematical instrument* (pp. 197-230). Springer: New York, NY, USA.

Turgut, Y. E., & Aslan, A. (2021). Factors affecting ICT integration in TURKISH education: A systematic review. *Education and Information Technologies*, *26*(4), 4069-4092.

UGWU, N. P., & Nnaekwe, K. (2019). The concept and application of ICT to teaching/learning process. *International Research Journal of Mathematics, Engineering and IT*, *6*(2).

United Nations Development Programme. (2021). *Digital classrooms to narrow thedigital divide for students in remote Khagrachari.* https://www.undp.org/bangladesh/stories/digital-classrooms-narrow-digital-divide-students-remote-khagrachari

United Nations Educational, Scientific and Cultural Organization. (2014). *Information and Communication Technology (ICT) in Education in Asia: A comparative analysis of ICT integration and e-readiness in schools across Asia*, Information paper no. 22.

Valencia-Márquez, L., Escalera-Chávez, M. E., & Moreno-García, E. (2022). Mathematical Skills Demand for Financial Decision Making in Companies. *TEM Journal*, *11*(3).

Van Den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (2006). *Educational Design research*. Routledge: London, UK.

Van Lent, M., & Laird, J. E. (2001, October). Learning procedural knowledge through observation. In *Proceedings of the 1st international conference on Knowledge capture* (pp. 179-186).

van Merrienboer, J. J., McKenney, S., Cullinan, D., & Heuer, J. (2017). Aligning pedagogy with physical learning spaces. *European Journal of Education*, *52*(3), 253-267.

Vannatta, R., & Fordham, N. (2004). Teacher dispositions as predictors of classroom technology use. *Journal of Research on Technology in Education, 36* (3), 253-271

Volman, M., & van Eck, E. (2001). Gender Equity and Information Technology in Education: The Second Decade. *Review of Educational Research*, *71*(4), 613-634. https://doi.org/10.3102/00346543071004613

Von Inqvald, E. (2009). *Teachers' implementation and orchestration of Cabri: Initial use of a dynamic geometry software package in mathematics teaching.* VDM Verlag, Saarbrücken.

Wang, C. X., & Kinuthia, W. (2004). Defining Technology Enhanced Learning Environment for Pre-Service Teachers. *Society for Information Technology & Teacher Education International Conference*, *1*, 2724–2727.

Waxman, H. C., & Huang, S. L. (1998). Classroom Learning Environments in Urban Elementary, Middle, and High Schools. *Learning Environments Research*, *1*(1), 95-113.

Weaver, M. (2006). Exploring conceptions of learning and teaching through the creation of flexible learning spaces: The learning gateway—A case study. *New Review of Academic Librarianship*, *12*(2), 109-125.

Webb, M., & Cox, M. (2004). A review of pedagogy related to information and communications technology, *Technology*, *Pedagogy and Education*, *13*(3), 235-286

Wegerif, R. (2010). *Mind Expanding: Teaching for Thinking and Creativity in Primary Education*. McGraw-Hill: Open University press.

Wilson, S., Lydiah, N., & Pachomius, W. (2015). Gender Differences in Pedagogical Interaction of Information Communication Technology Among Science and Mathematics Teachers in Public Secondary Schools in Kieni West Subcounty, Nyeri County, Kenya. *Int J Educ Res, 3*(1), 443-62.

Wolfram, C. (2010). Stop Teaching Calculating, Start Teaching Math-Fundamentally Reforming the Math Curriculum.

Woodward, A., Beswick, K., & Oates, G. (2018). Positive Education and Teaching for Productive Disposition in Mathematics. In B. Rott, G. Törner, J. Peters-Dasdemir, A. Möller & Safrudiannur (Eds.), *Views and Beliefs in Mathematics Education*(pp. 161-171). Springer.

World Economic Forum. (2023). *Six elements accelerating education for a Smart Bangladesh and a Smart World*. https://www.weforum.org/agenda/2023/05/six-elements-accelerating-education-for-a-smart-bangladesh-and-a-smart-world/

Yadav, N. (2015). Technology: A tool for clearing misconceptions in mathematical concepts. *Splint International Journal of Professionals*, *2*(1), 18-28.

Yin, R.K. (2009). Case Study Research: Design and Method (3rd ed.). Sage Publications: California, USA.

Yin, R.K. (2014). Case Study Research: Design and Method (2nd ed.). Sage Publications.

Zawojewski, J. S., Chamberlin, M. T., Hjalmarson, M., & Lewis, C. (2008). Developing design studies in Mathematics Education Professional Development: Studying teachers' interpretive systems. In *Routledge eBooks*. https://doi.org/10.4324/9781315759593-23

Zengin, Y. (2017). The effects of GeoGebra software on pre-service mathematics teachers' attitudes and views toward proof and proving. *International Journal of Mathematical Education in Science and Technology*, *48*(7), 1002–1022. https://doi.org/10.1080/0020739x.2017.1298855

Zinger, D., Tate, T., & Warschauer, M. (2017). Learning and Teaching with Technology: Technological Pedagogy and Teacher Practice. *The SAGE handbook of research on teacher education* (pp. 577-593). https://doi.org/10.4135/9781526402042.n33

Zulnaidi, H., Oktavika, E., & Hidayat, R. (2020). Effect of use of GeoGebra on achievement of high school mathematics students. *Education and Information Technologies*, *25*(1), 51-72. https://doi.org/10.1007/s10639-019-09899-y

APPENDICES

Appendix A: Introductory Letter from the supervisor

শিক্ষা ও গবেষণা ইনস্টিটিউট
ঢাকা বিশ্ববিদ্যালয়
ঢাকা-১০০০, বাংলাদেশ

Institute of Education and Research
University of Dhaka
Dhaka-1000, Bangladesh
Fax: +880-2-9667222
www.du.ac.bd

11 October, 2022

To

The Principal / Headmaster

....

Subject: **Request for providing support to a PhD student of IER, University of Dhaka**

Dear Sir,

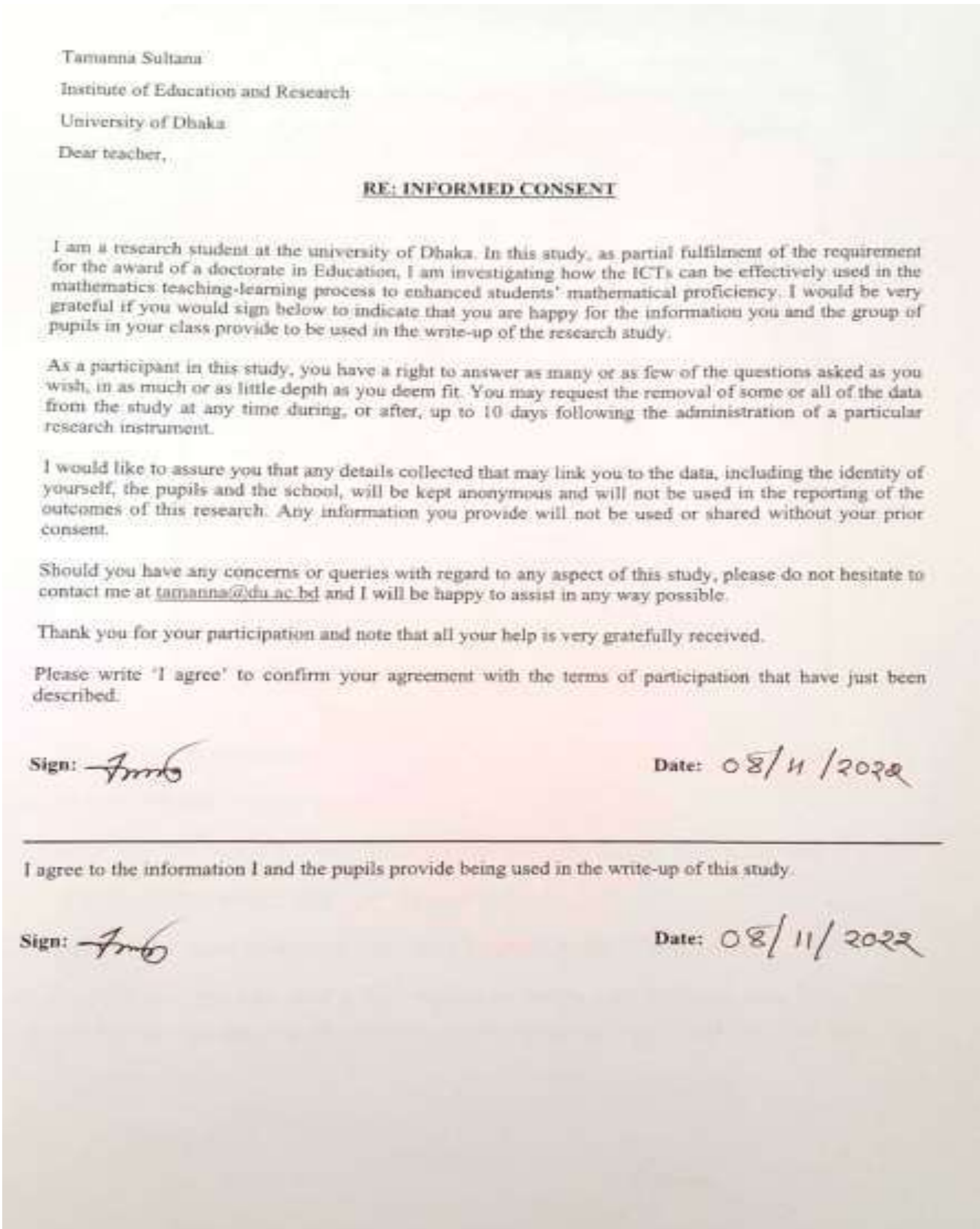
Receive greetings from the Institute of Education and Research (IER), University of Dhaka. I would like to inform you that my PhD student Ms. Tamanna Sultana, Associate Professor, Institute of Education and Research, University of Dhaka needs to collect data from your Institution for her study titled **"Orchestrating ICTs for Promoting Students' Mathematical Proficiency at Secondary Level in Bangladesh".** Ms, Sultana needs to observe Mathematics class of secondary level, interview teacher of that class and conduct a Focus Group Discussion with students. I request you and your colleagues to provide her with all kinds of support in this regard. Please feel free to contact me if you have any questions regarding her research work.

Thanking you,

Dr. Md. Abdul Halim
Professor
Institute of Education and Research, University of Dhaka
Mobile: +8801715304802
Email: halimma@du.ac.bd

Appendix B: Informed Consent Form

T1: Participant teacher of Case-I



Tamanna Sultana

Institute of Education and Research

University of Dhaka

Dear teacher,

RE: INFORMED CONSENT

I am a research student at the university of Dhaka. In this study, as partial fulfilment of the requirement for the award of a doctorate in Education, I am investigating how the ICTs can be effectively used in the mathematics teaching-learning process to enhanced students' mathematical proficiency. I would be very grateful if you would sign below to indicate that you are happy for the information you and the group of pupils in your class provide to be used in the write-up of the research study.

As a participant in this study, you have a right to answer as many or as few of the questions asked as you wish, in as much or as little depth as you deem fit. You may request the removal of some or all of the data from the study at any time during, or after, up to 10 days following the administration of a particular research instrument.

I would like to assure you that any details collected that may link you to the data, including the identity of yourself, the pupils and the school, will be kept anonymous and will not be used in the reporting of the outcomes of this research. Any information you provide will not be used or shared without your prior consent.

Should you have any concerns or queries with regard to any aspect of this study, please do not hesitate to contact me at tamanna@du.ac.bd and I will be happy to assist in any way possible.

Thank you for your participation and note that all your help is very gratefully received.

Please write 'I agree' to confirm your agreement with the terms of participation that have just been described.

Sign: Tms **Date:** 08/11/2022

I agree to the information I and the pupils provide being used in the write-up of this study.

Sign: Tms **Date:** 08/11/2022

T2: Participant teacher of Case-II

Tamanna Sultana

Institute of Education and Research

University of Dhaka

Dear teacher,

RE: INFORMED CONSENT

I am a research student at the university of Dhaka. In this study, as partial fulfilment of the requirement for the award of a doctorate in Education, I am investigating how the ICTs can be effectively used in the mathematics teaching-learning process to enhanced students' mathematical proficiency. I would be very grateful if you would sign below to indicate that you are happy for the information you and the group of pupils in your class provide to be used in the write-up of the research study.

As a participant in this study, you have a right to answer as many or as few of the questions asked as you wish, in as much or as little depth as you deem fit. You may request the removal of some or all of the data from the study at any time during, or after, up to 10 days following the administration of a particular research instrument.

I would like to assure you that any details collected that may link you to the data, including the identity of yourself, the pupils and the school, will be kept anonymous and will not be used in the reporting of the outcomes of this research. Any information you provide will not be used or shared without your prior consent.

Should you have any concerns or queries with regard to any aspect of this study, please do not hesitate to contact me at tamanna@du.ac.bd and I will be happy to assist in any way possible.

Thank you for your participation and note that all your help is very gratefully received.

Please write 'I agree' to confirm your agreement with the terms of participation that have just been described.

Sign: Nishat **Date:** 03|01|2023

I agree to the information I and the pupils provide being used in the write-up of this study.

Sign: Nishat **Date:** 03|01|2023

Appendix C: Paper-pencil test (Pre-intervention)

<u>নিচের প্রশ্নগুলোর উত্তর দাও।</u>

সময়ঃ ১ ঘন্টা　　　　　　　　　　　　　　　　　　　　　　　　পূর্ণমানঃ ৪০

প্রশ্ন১। ৪ জন শিশু ও তাদের উচ্চতা নিচের টেবিলে দেখানো হলঃ

শিশুর বয়স উচ্চতা	উচ্চতা
৫	৪০
৫	৪২
৬	৪৪
৭	৪৭

ক) কোনটি সঠিক? (সঠিক উত্তরের বক্সে টিক '√ ' চিহ্ন দিন)　　(২)

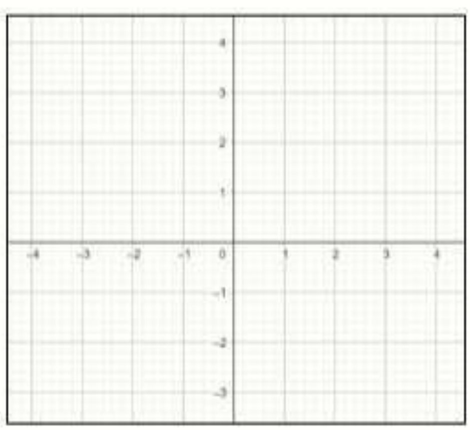
☐ বয়স হল উচ্চতার একটি ফাংশন

☐ উচ্চতা হল বয়সের একটি ফাংশন

খ) কেন ? ব্যাখ্যা করুন (অনুগ্রহ করে আপনার মতামত বক্সের ভেতরে লিখুন)　　(৪)

গ) আপনি এই ফাংশনকে কয়টি ভিন্ন উপায়ে উপস্থাপন করতে পারবেন? সেগুলো লিখুন। (অনুগ্রহ করে উত্তরটি বক্সের ভেতরে লিখুন)　　(৪)

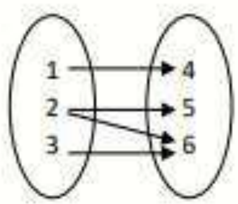
প্রশ্ন২। ক) নিচের গ্রাফে 2x-y+1=0 সমীকরণটির সরলরেখার গ্রাফটি আঁকুন।　　(৫)

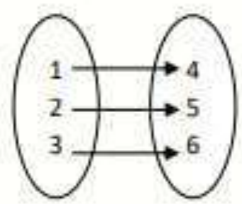


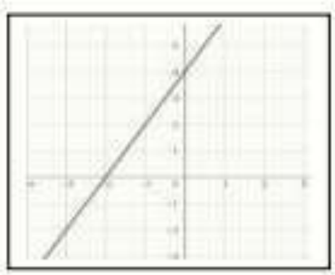
খ) গ্রাফটি আঁকার পদ্ধতিটি ব্যাখ্যা করুন। (অনুগ্রহ করে উত্তরটি বক্সের ভেতরে লিখুন) (৫)

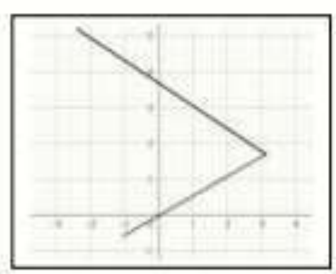
গ) আপনি কয়টি উপায়ে গ্রাফটি আঁকতে পারবেন? উপায়গুলো ব্যাখ্যা করুন। (অনুগ্রহ করে উত্তরটি বক্সের ভেতরে লিখুন) (৪)

প্রশ্ন৩। ক) ফাংশনের জন্য নিচের কোনটি সত্য নয়? (সঠিক উত্তর(গুলো) এর মধ্যে টিক '√ ' চিহ্ন দিন) (২)

i) 

ii) 

iii) 

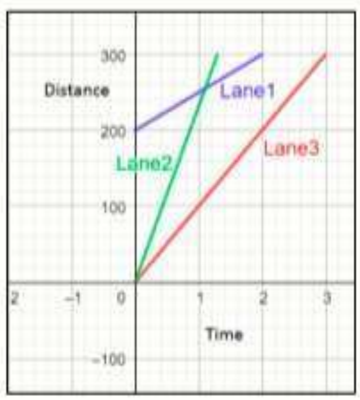
iv) 

খ) কেন ফাংশন নয় তা নিচের বক্সে ব্যাখ্যা করুন। (২)

প্রশ্ন৪। ক) একটি রেখার ঢাল -1/2 দেয়া আছে। বিন্দু (6,8) লাইনের মধ্যে আছে। লাইনটির সমীকরণ কি হবে? তার y-ইন্টারসেপ্ট কোনটি? (৩)

খ) আরও কী কী সমীকরণের মাধ্যমে লাইনটিকে দেখানো যাবে? (অনুগ্রহ করে উত্তরটি বক্সের ভেতরে লিখুন) (৩)

প্রশ্ন ৫। নিচের গ্রাফটিতে সময়ের সাথে ৩টি গাড়ির দূরত্বের সম্পর্ক দেখাচ্ছে।



সময় এবং দূরত্ব সম্পর্কিত নির্দিষ্ট বিবরণীর মাধ্যমে লেন ৩ গাড়ির যাত্রাপথ নিয়ে একটি গল্প লিখ।(অনুগ্রহ করে উত্তরটি বক্সের ভেতরে লিখ।) (৬)

(English version of the test item)

Answer all of the following

questions

Time: 1 hour Total Marks: 40

Q1: Height of 4 students are shown in the following table.

Age	Height
5	40
5	42
6	44
7	47

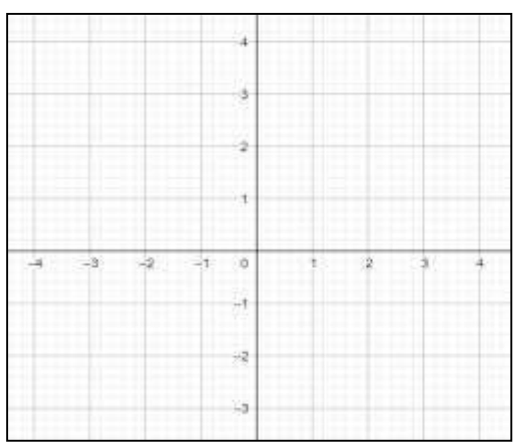
a) Which one is correct? (Please write √ inside the box of the correct one) (2)

☐ Height is a function of age
☐ Age is a function of height

b) Explain why (please write your opinion inside the box). (4)

c) How many different ways can you represent this function? Write the ways of differentrepresentation. (please write the answer inside the box). (4)

Q2: a) Sketch the graph of 2x-y+1=0 in the following graph paper. (5)

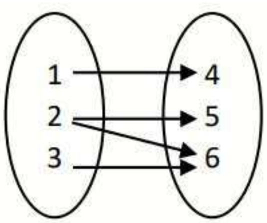


b) Explain the procedure of sketching the graph (please write the answer inside the box). (5)

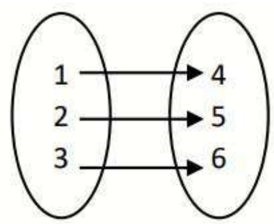
c) How many ways can you sketch the graph? Explain the ways. (please write the answer inside the box). (4)

Q3: a) Which of the following is not true for function? (Please √ the correct answer(s)) (2)

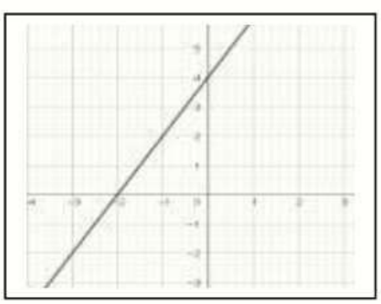
i)



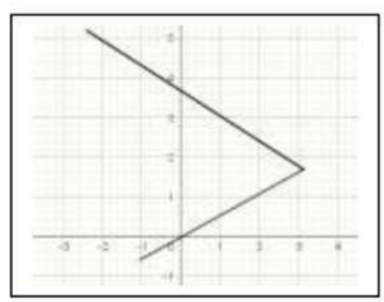
ii)



iii)



iv)

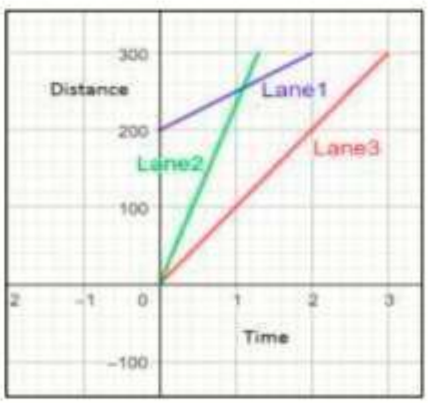


b) Why they are not function? (Please write the reasons inside the box below) (2)

Q4: a) The slope of a line is -1/2 and the point (6,8) lies on the line. Write the equation of that line. Find also y-intercept (3)

b) write all possible equations which represent the same line. (3)

Q5: The following graph shows the distance Vs time relationship about the journey of three cars.



Tell a story about the journey of those cars including specific details about time and distance. (please write the answer inside the box). (6)

Appendix D: Paper-pencil test (Post-intervention)

নিচের প্রশ্নগুলোর উত্তর দাও।

সময়ঃ ১ ঘণ্টা পূর্ণমানঃ ৪০

প্রশ্ন ১: ৪টি বই এর মূল্য তালিকা নিচে দেখানো হলো।

বই	মূল্য (টাকা)
বাংলা	৪০০
ইংরেজি	৪২০
গণিত	৪৪০
বিজ্ঞান	৪২০

ক) কোনটি সঠিক বলে তুমি মনে কর? (উত্তরের বক্সে টিক '√ ' চিহ্ন দেও।) (২)

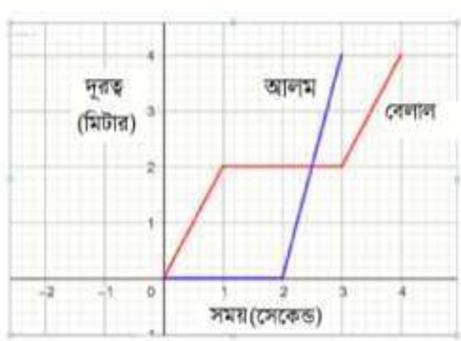
☐ বই হলো মূল্যের একটি ফাংশন

☐ মূল্য হলো বই এর একটি ফাংশন

খ) কেন ব্যাখ্যা কর (অনুগ্রহ করে তোমার মতামত বক্সের ভেতরে লিখ।) (৪)

গ) এই ফাংশনকে কী কী ভিন্ন উপায়ে উপস্থাপন করা যেতে পারে? (অনুগ্রহ করে উত্তরটি বক্সের ভেতরে লিখ।) (৪)

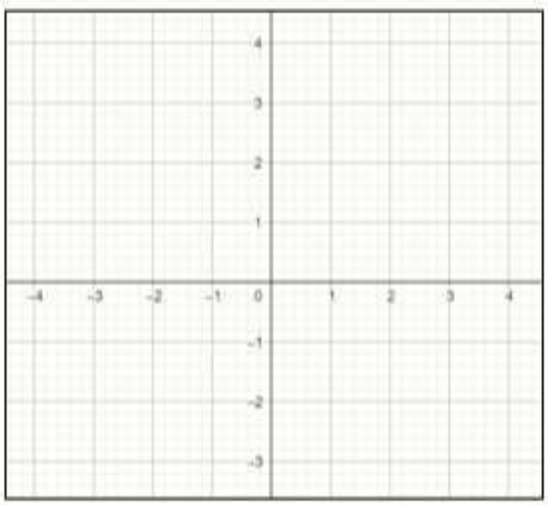
প্রশ্ন ২: নিচের গ্রাফটি আলম এবং বেলালের যাত্রার দূরত্ব বনাম সময়ের সম্পর্ক দেখাচ্ছে।



সময় এবং দূরত্ব সম্পর্কিত নির্দিষ্ট বিবরণীর মাধ্যমে বেলালের যাত্রা নিয়ে একটি গল্প লিখ।(অনুগ্রহ করে উত্তরটি বক্সের ভেতরে লিখ।) (৬)

প্রশ্ন৩: ক) একটি সরলরেখার সমীকরণের উদাহরণ দেও যেখানে $m>0$ and $c<0$ । (অনুগ্রহ করে উত্তরটি বক্সের ভেতরে লিখ।) (২)

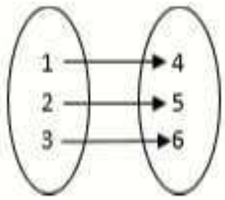
খ) নিচের গ্রাফ পেপার-এ তোমার লেখা সমীকরণটির গ্রাফ আঁক এবং আঁকার পদ্ধতিটি নিচের বক্সে ব্যাখ্যা কর। (৪+৪)



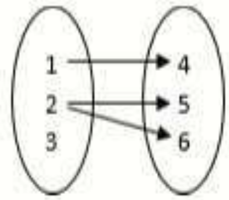
গ) কয়টি ভিন্ন ভিন্ন উপায়ে তুমি গ্রাফটি আঁকতে পার? উপায়গুলো ব্যাখ্যা কর। (অনুগ্রহ করে উত্তরটি বক্সের ভেতরে লিখ) (৫)

প্রশ্ন৪: ক) ফাংশনের জন্য নিচের কোনটি সত্য নয়? (সঠিক উত্তর(গুলো) এর মধ্যে টিক '√' চিহ্ন দেও।) (২)

i)



ii)



iii)

iv)

খ) কেন ফাংশন নয় নিচের বক্সে লিখ। (২)

গ) কেন ফাংশন নয় তা তুমি কত ভাবে ব্যাখ্যা করতে পার? (নিচের বক্সে কারণগুলো লিখ।) (৩)

প্রশ্ন৫: একটি রেখার ঢাল -1/3 দেয়া আছে। বিন্দু (-3, 2) রেখাটির উপরে আছে। নিচের কোন সমীকরণের সাহায্যে সহজেই রেখাটিকে আঁকা যাবে? (সঠিক উত্তরের বক্সে টিক '√' চিহ্ন দেও।) (২)

- ☐ $y=mx+c$
- ☐ $y-y_1=m(x-x_1)$
- ☐ $x/a+y/b=1$
- ☐ $(y-y_1)/(y_1-y_2)=(x-x_1)/(x_1-x_2)$

(English version of the paper-pencil test question).Answer all of the following questions

Time: 1 hour Total Marks: 40

Q1: The price of 4 books are shown in the following table.

Book	Price
Bangla	400
English	420
Mathematics	440
Science	420

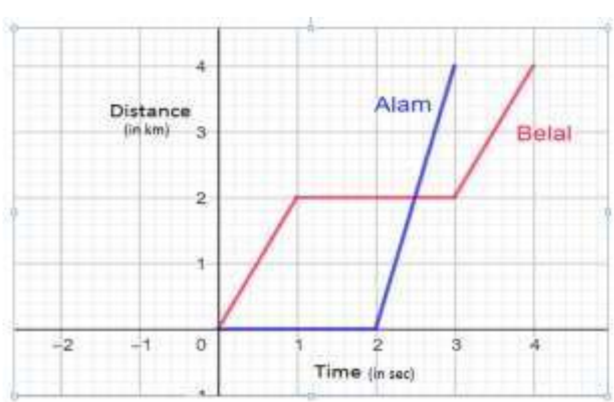
a) Which one is correct? (Please write √ inside the box of the correct one) (2)

☐ Book is a function of price
☐ Price is a function of Book

b) Explain why (please write your opinion inside the box). (4)

c) How many different ways can you represent this function? Write the ways of differentrepresentation. (please write the answer inside the box) (4)

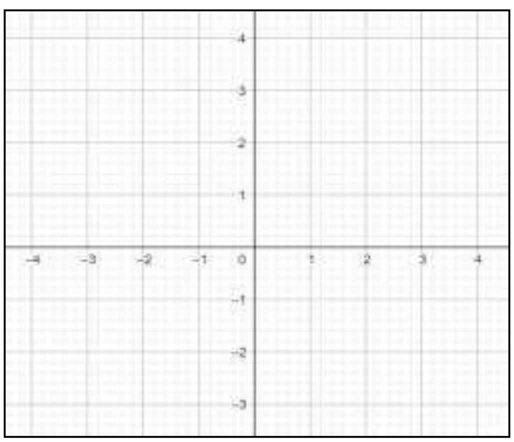
Q2: The following graph shows the distance Vs time relationship for journey of two people Alam and Belal. (6)



Tell a story about the Belal's Journey including specific details about time and distance. (please write the answer inside the box)

Q3: a) Write an example of an equation of a straight line with $m>0$ and $c<0$. (please write the answer inside the box) (2)

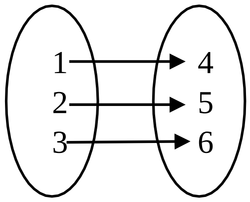
b) Sketch the graph of your written equation on the axis provided below. Explain about how have you sketched the graph in the following blank box. (4+4)



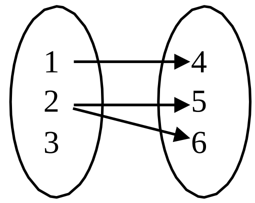
c) How many ways can you sketch the graph? Explain the ways. (please write the answer inside the box). (5)

Q4: a) Which of the following is not true for function? (Please √ the correct answer(s)) (2)

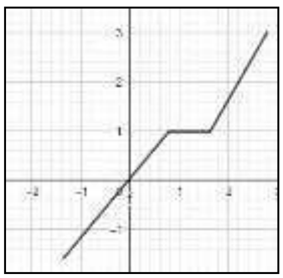
i)



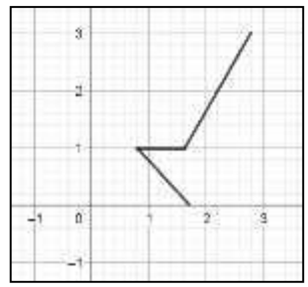
ii)



iii)



iv)



c) Why they are not function? (Please write the reasons inside the box below) (2)

d) In how many ways you can explain that they are not function? (Please write your opinion inside the box) (3)

Q5: a) The slope of a line is -1/3. The point (-3,2) is on the line. By using which of the following form, the graph of the equation can be easily drawn? (Please √ the correct answer) (2)

☐ $y=mx+c$

☐ $y-y_1=m(x-x_1)$

☐ $x/a+y/b=1$

☐ $(y-y_1)/(y_1-y_2)=(x-x_1)/(x_1-x_2)$

Appendix E: Pupil Survey Questionnaire

গবেষণার জন্য তোমার মূল্যবান সময়ের কিছু সময় ব্যয় করে ফর্মটি পূরণ কর। তোমার ব্যক্তিগত উপলব্ধি এবং সৎ উত্তর এই গবেষণার সাফল্যের জন্য অতীব গুরুত্বপূর্ণ।

সি নং.	আইটেম	১ দৃঢ়ভাবে একমত	২ একমত	৩ নিরপেক্ষ	৪ দ্বিমত	৫ দৃঢ়ভাবে দ্বিমত
১.	গণিত আমার ভবিষ্যতের জন্য অপরিহার্য					
২.	গণিতের জ্ঞান আমাকে আমার ক্ষেত্রের জটিল বিষয়গুলো বুঝতে সাহায্য করে					
৩.	আমি গণিত করতে আগ্রহ বোধ করি					
৪.	গণিত করার সময় আমি মনোযোগ ধরে রাখতে পারি					
৫.	আমরা গণিতে কি করি তা আমি স্পষ্টভাবে বুঝতে পারি					
৬.	গণিতের সমস্যা সমাধানে অসুবিধার সম্মুখীন হলেও আমি সমস্যা সমাধান করা বন্ধ করি না					
৭.	সহপাঠীদের সাহায্য করার জন্য আমি আমার গণিত দক্ষতা নিয়ে আত্মবিশ্বাসী					
৮.	বিভিন্ন উপায়ে গণিত সমস্যা সমাধান করা নিয়ে আমি আত্মবিশ্বাসী					
৯.	বাস্তব জীবনের সাথে সম্পর্কিত সমস্যার অর্থ এবং কিভাবে সেগুলো করা যায় সে ব্যাপারে জানতে আমি আগ্রহী					
১০.	সহপাঠীদের সাথে গণিতের ধারণা শেয়ার করতে এবং আলোচনা করে গণিতের সমস্যার সমাধান করতে আমি আগ্রহী					
১১.	গণিতে ভাল হওয়ার জন্য ভুল করাও গুরুত্বপূর্ণ					
১২.	আমি যদি যথাযথভাবে চেষ্টা করি তাহলে যেকোনো ধরনের গণিত শিখতে পারব					

(English version of the survey questionnaire)

Dear respondent, very good day!

Please feel free to provide your opinion and this information will be used absolutely for academic purpose. Your personal perception and honest opinion are considered vital importance for the success of this study. Your cooperation in this regard will be highly appreciable.

Sl. No.	Items	5 Strongly agree	4 Agree	3 Neutral	2 disagree	1 Strongly disagree
1.	Mathematics is essential for my future.					
2.	Having a solid knowledge of Mathematics helps me understand more complex topics in my field.					
3.	After completing these classes, I feel more interest to do math					
4.	After completing these classes, I can keep more attention whenever I do math					
5.	After completing these classes, I can make sense of what we do in math more clearly					
6.	After completing these classes, I feel that I do not stop to work on math problem even I struggle with that problem					
7.	After completing these classes, I feel more confident on my math ability skill to help my peers					
8.	These classes help me to feel confident to try to solve math problems in different ways					
9.	After completing these classes, I am more curious to know the real life oriented math problems and how to solve them					
10.	After completing these classes, my eagerness to share math ideas and solve problems by discussing with my peers has increased					
11.	These classes make my thought strong that making mistakes are necessary to be good at Mathematics.					
12.	After completing these classes, my believe become more solid that anyone can learn mathematics if appropriate effort has given					

Appendix F: Interview schedules and Focus Group Discussion (FGD)

<u>Teacher Interview</u>

Background Information

- আপনার শিক্ষাগত যোগ্যতা সম্পর্কে বলুন।
- শিক্ষকতা পেশায় আপনার অভিজ্ঞতা কত বছরের?
- আপনার পেশাগত উন্নয়নের জন্য কি কোনো ট্রেনিং গ্রহন করেছেন? ব্যাখ্যা করুন।
- ICT সম্পর্কে আপনার জ্ঞান কেমন বলে আপনি মনে করেন? আপনি আপনার শেখন-শেখানো কার্যক্রমে ICT কতটা ব্যাবহার করেন? ব্যাখ্যা করুন।

Classroom Context

1. শিখন-শেখানো উদ্দেশ্যে কোন ধরনের আইসিটি টুল ব্যাবহার করেন?/ কী আইসিটি টুল ব্যাবহার করা যেতে পারে?
2. আইসিটি ব্যাবহার করে ক্লাস পরিচালনার সময় কি ধরনের প্রযুক্তি থাকা দরকার ?
3. আপনি কি মনে করেন যে আইসিটি দিয়ে পাঠদানের সময় ক্লাসরুম সেটআপ পুনর্বিন্যাস করা দরকার? কেন এবং কিভাবে?
4. ল্যাব রুমের পরিবর্তে নিয়মিত শ্রেনিকক্ষে আইসিটি ব্যাবহার করে ক্লাস পরিচালনা করলে সেটা কি ফলপ্রসু হবে বলে মনে করেন? কেন এবং কীভাবে?
5. শ্রেনিকক্ষে আইসিটি ব্যাবহার করে ক্লাস পরিচালনা করার সময় শিক্ষার্থীদের বসার ব্যাবস্থা (যেমন একক কাজ, জোড়ায় কাজ, দলীয় কাজ) কিভাবে সংগঠিত করা উচিত? কেন?
6. যখন আইসিটির সাহায্যে ক্লাস পরিচালনা করা হবে তখন গাণিতের কাজ/গানিতিক সমস্যাগুলো কেমন হওয়া উচিত?

Teacher Context

7. আপনি কি মনে করেন যে আইসিটি টুল আপনাকে ক্লাসে বিভিন্ন পদ্ধতি প্রয়োগের সুযোগ প্রদান করে? কিভাবে এবং কেন দরকার?
8. আপনি যখন আইসিটি ব্যাবহার করে শেখন-শেখানো কার্যক্রম পরিচালনা করেন, তখন আপনি পূর্বে কী ধরনের প্রস্তুতি নেন? আপনি কি ব্যাখ্যা করতে পারবেন?
9. ছাত্রদেরকে সৃজনশীল কাজ ও যুক্তির সাথে জড়িত করতে শিক্ষকের ভূমিকা কেমন হওয়া উচিত বলে আপনি মনে করেন?

Students' Context

10. আপনি কি মনে করেন যে ক্লাসে আইসিটি টুল ব্যাবহারে শিক্ষার্থীদের শেখার আগ্রহ বৃদ্ধি পায়? কেন?
11. আইসিটি ব্যাবহার করে ক্লাস পরিচালনার সময় শিক্ষার্থীদের কিভাবে পারফর্ম করা উচিত?
12. আপনি যখন আইসিটি ব্যাবহার করে ক্লাস পরিচালনা করেন তখন কি আপনার শিক্ষার্থীরা সহযোগিতা করে? কিভাবে?

Affecting Factors

13. গণিত শেখানোর সময় আইসিটি ব্যাবহার করতে গিয়ে আপনি কি কি সমস্যার সম্মুখীন হন? আপনি কিভাবে সেগুলো সমাধান করেন?

14. আইসিটি ব্যাবহার করে গণিত শেখানোর জন্য শিক্ষকের মনোভাব, অভিজ্ঞতা, আগ্রহ বা অন্য কোন বিষয় কেমন গুরুত্বপূর্ণ? কেন?

15. আপনি কি মনে করেন যে শিখন-শেখানো কার্যক্রমে প্রযুক্তির ব্যাবহারের জন্য স্কুলের প্রেক্ষাপট গুরুত্বপূর্ণ? কেন এবং কিভাবে?

16. আপনার স্কুলের পরিবেশ কি প্রযুক্তি ব্যাবহারের জন্য সহায়ক? কিভাবে? কী কী ঘাটতি রয়েছে?

17. বর্তমান পাঠ্যক্রম কি প্রযুক্তির ব্যাবহারের জন্য উপযোগী? কীভাবে? না হলে , কেমন হওয়া দরকার ছিল? কি পরিবর্তন দরকার?

18. আপনি কি মনে করেন যে প্রযুক্তির প্রতি শিক্ষার্থীদের মনোভাব ও প্রস্তুতি প্রযুক্তির সাহায্যে শেখানোর জন্য গুরুত্বপূর্ণ? কেন?

19. আপনি কি মনে করেন যে আইসিটি ব্যাবহার করে শেখানোর সময় ছাত্রদের পূর্ব অভিজ্ঞতা এবং বাড়ির পরিবেশের কোন প্রভাব আছে? কীভাবে?

20. আইসিটি ব্যাবহার করে শিখন-শেখানোর ক্ষেত্রে আরও কোন কোন বিষয়গুলো প্রভাবিত করে বা challenge থাকতে পারে বলে আপনি মনে করেন?

Head Teacher Interview

১। আইসিটি ব্যবহার করে ক্লাস পরিচালনার জন্য কী ধরনের প্রযুক্তিগত সুবিধা থাকা দরকার বলে আপনি মনে করেন? আপনার বিদ্যালয়ে সকল ধরনের সুবিধা কি বিদ্যমান? ‘না’ হলে, কী ঘাটতি রয়েছে এবং তা কীভাবে পূরণ করা সম্ভব বলে আপনি মনে করেন?

২। শিখন-শেখানো কার্যক্রমে প্রযুক্তি ব্যবহারের জন্য বিদ্যালয় প্রধান ও সহকর্মিদের মনভাব কতটা গুরুত্বপূর্ণ বলে আপনি মনে করেন? কীভাবে?

৩। আপনার স্কুলের পরিবেশ কি প্রযুক্তি ব্যবহারের জন্য সহায়ক? কিভাবে? কী কী ঘাটতি রয়েছে?

৪। আইসিটি ব্যবহার করে গণিত শেখানোর জন্য শিক্ষকের মনোভাব/অভিজ্ঞতা/ প্রস্তুতি/ আগ্রহ কতটা গুরুত্বপূর্ণ বলে আপনি মনে করেন? এগুলো বাড়ানোর জন্য বিদ্যালয় প্রধান হিসেবে কোন পদক্ষেপ গ্রহন করেছিলেন কি? ‘হ্যাঁ’ হলে, কী কী পদক্ষেপ গ্রহন করেছিলেন? আরও কী কী পদক্ষেপ নেওয়া যেত বলে আপনি মনে করেন? ‘না’ হলে, কী কী পদক্ষেপ গ্রহন করা দরকার বলে আপনি মনে করেন?

৫। শিক্ষকদেরকে আইসিটি ব্যবহারে দক্ষ হবার জন্য কী ধরনের পদক্ষেপ গ্রহন করা দরকার বলে আপনি মনে করেন? বিদ্যালয় প্রধান হিসেবে আপনি কোন পদক্ষেপ গ্রহন করেছিলেন কি? ‘হ্যাঁ’ হলে, কী ধরনের পদক্ষেপ গ্রহন করেছিলেন? আরও কী কী পদক্ষেপ নেওয়া যেত বলে আপনি মনে করেন? 'না' হলে, কী কী পদক্ষেপ গ্রহন করা দরকার বলে আপনি মনে করেন?

৬। আইসিটি ব্যবহার করে গণিত শিখন-শেখানো কার্যক্রম পরিচালনা করার ক্ষেত্রে আর কোন কোন বিষয় প্রভাবিত করে বলে আপনি মনে করেন?

৭। আইসিটি ব্যবহার করে গণিত শিখন-শেখানো কার্যক্রম পরিচালনা করার ক্ষেত্রে আর কী কী চ্যালেঞ্জ থাকতে পারে বলে আপনি মনে করেন?

Focus Group Discussions

১। এই ক্লাসগুলোর পূর্বে ডিজিটাল টেকনোলজি ব্যবহার করে ক্লাস পরিচালনা করা হয়েছে-এমন কোন ক্লাস-এ অংশগ্রহণ করেছ কি?

২। শ্রেণিতে ডিজিটাল টেকনোলজির ব্যবহার কে কেমন মনে কর? কেন?

৩। তুমি কি মনে কর শ্রেণিতে ডিজিটাল টেকনোলজির ব্যবহার তোমার গণিত শেখার ক্ষেত্রে কোন পরিবর্তন এনেছে? ব্যাখ্যা কর।

৪। গনিতের কোন একটি বিষয়বস্তুর ধারনা তোমার পরিষ্কার হয়েছে কিনা, তা তুমি কীভাবে বুঝ?

৫। গনিতের কোন একটি বিষয়বস্তুর ধারনা পরিষ্কার করার জন্য শিক্ষক কি শ্রেণিতে বিভিন্ন কৌশল অবলম্বন করেছিলেন? তোমার কাছে কোন কৌশলগুলো কার্যকর মনে হয়েছে? এ ক্ষেত্রে টেকনোলজি কি কোনভাবে সাহায্য করেছে?

৬। তুমি কি মনে কর ক্লাসগুলো করার পর তোমার গানিতিক সমস্যা সমাধানের দক্ষতা বেড়েছে? কীভাবে? এ ক্ষেত্রে টেকনোলজি কি কোনভাবে সাহায্য করেছে?

৭। একটি সমস্যা বিভিন্ন উপায়ে সমাধানের সুযোগ কি তোমাদের ক্লাশে ছিল? এ বিষয়টিকে তোমরা কীভাবে দেখ?

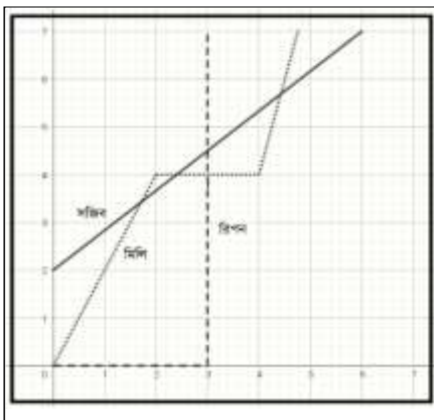
৮। বন্ধুর সাথে আলোচনার মাধ্যমে গণিত শেখাটা তুমি কেমন মনে কর? শ্রেণিতে ডিজিটাল টেকনোলজির ব্যবহারে বন্ধুর সাথে আলোচনার মাধ্যমে গণিত শেখার সুযোগ কি বেশি বলে মনে কর? কীভাবে?

৯। শিক্ষকের বাইরে আর কী ভাবে তুমি ফিডব্যাক পেয়েছ?

১০। তোমরা যে ভাবে ক্লাস করে অভ্যস্ত, সে ধরনের ক্লাসের সাথে ICT- ব্যবহারের মধ্যমে পরিচালিত ক্লাসের মধ্যে পার্থক্য আছে বলে তোমার মনে হয়েছে? সেটা কি হেল্পফুল ছিল?

১১। ক্লাসগুলো করার পর, গণিত ও গণিত শেখার ব্যপারে তোমার মধ্যে কি পরিবর্তন এসেছে বলে তুমি মনে কর? কিভাবে?

Activity task provided during FGD



মিলি এবং সজিব তাদের নিজ নিজ বাসাথেকে একই সময়ে ট্রেন ষ্টেশনের দিকে রওনা হল এবং ৩ মিনিট পর রিপন রওনা হল। নিচের গ্রাফগুলো মিলি, সজিব এবং রিপনের যাত্রার দূরত্ব বনাম সময়ের সম্পর্ক দেখাচ্ছে।

১। মিলির যাত্রার গতিপথটি ব্যখ্যা কর।

২। কে আগে পৌঁছেছিল? কি ভাবে বুঝলে?

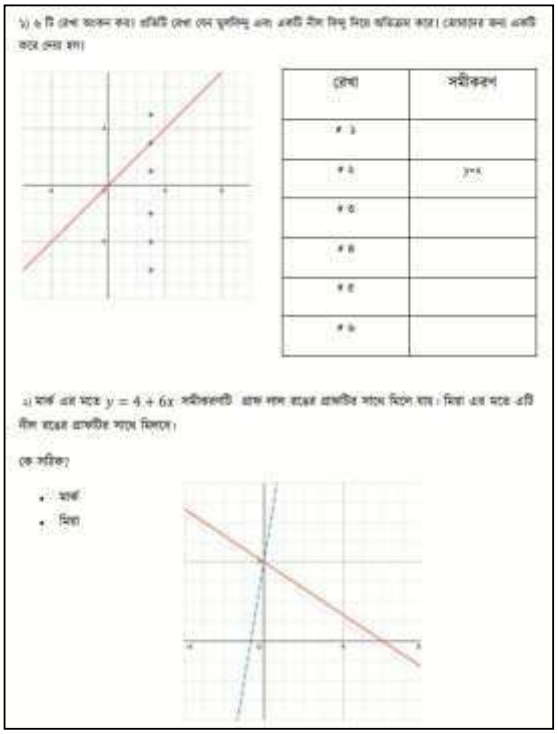
৩। শুরুতে কার গতি সবচেয়ে দ্রুত ছিল? কি ভাবে বুঝলে? আর কোন ভাবে কি ব্যখ্যা করতে পার?

৪। কার বাসা ষ্টেশনের সবচেয়ে কাছে ছিল? কি ভাবে বুঝলে?

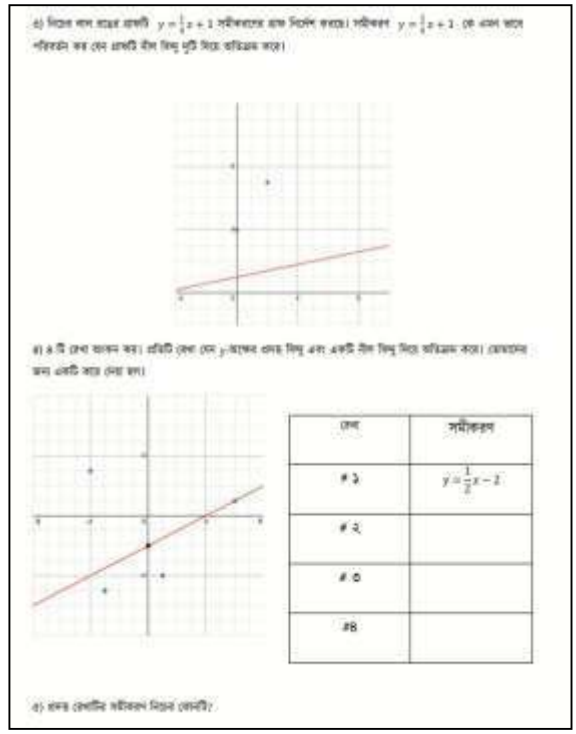
৫। এখানে সবগুলো গ্রাফই কি ফাংশনের গ্রাফ? বাস্তব উদাহরণের মাধ্যমে কী বুঝাতে পার?

৬। মিলির ভাই দিপু, মিলি রওনা হবার ১ মিনিট পর ষ্টেশনের উদ্দেশ্যে রওনা হয় এবং ৪ মিটার দূরত্বে মিলি ও সজিবের সাথে তার দেখা হয়। যদি সে কোথাও না থেমে সরাসরি ষ্টেশনে পৌঁছায়, তবে তার গ্রাফটি কেমন হবে?

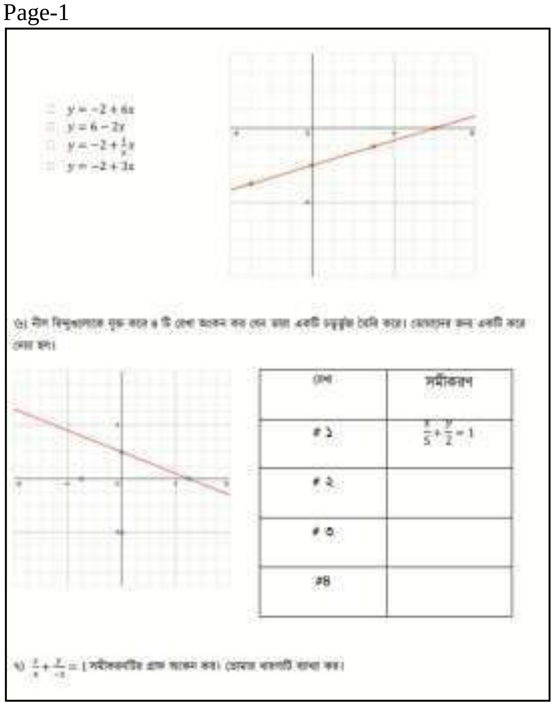
Appendix G: Activity Task-1 (Case-I)



Page-1

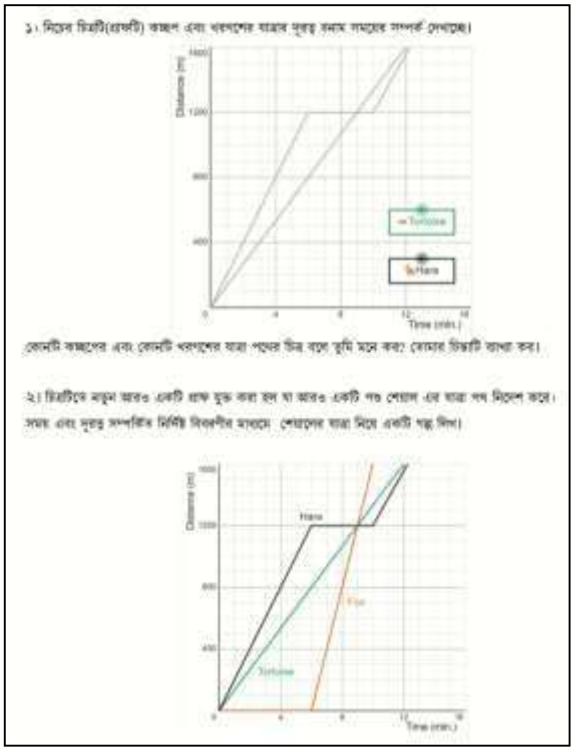


Page-2

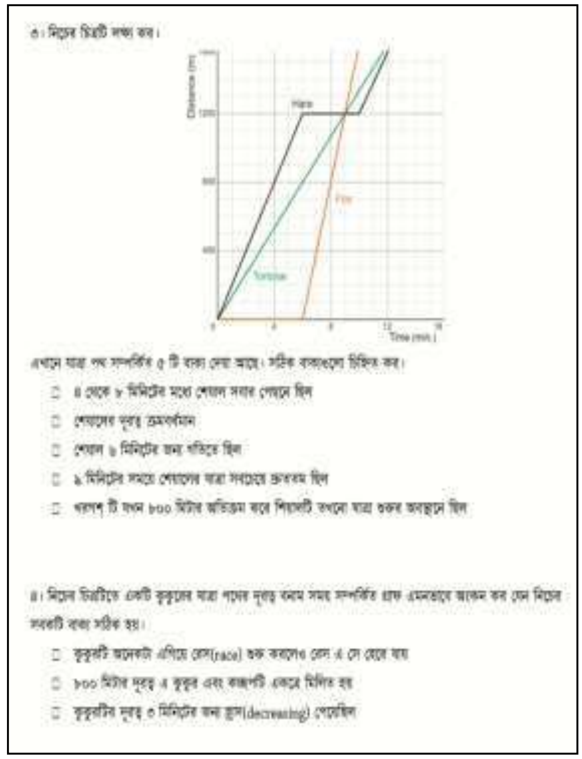


Page-3

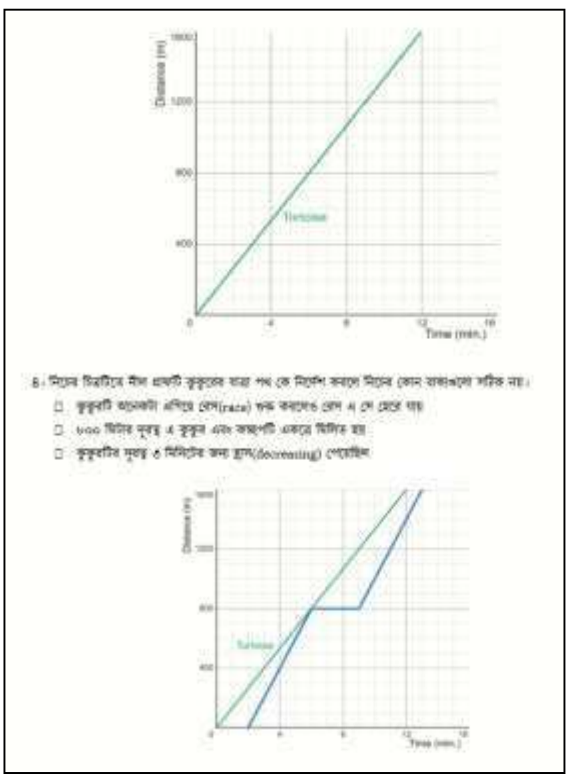
Appendix H: Activity Task-2 (Case-I)



Page-1

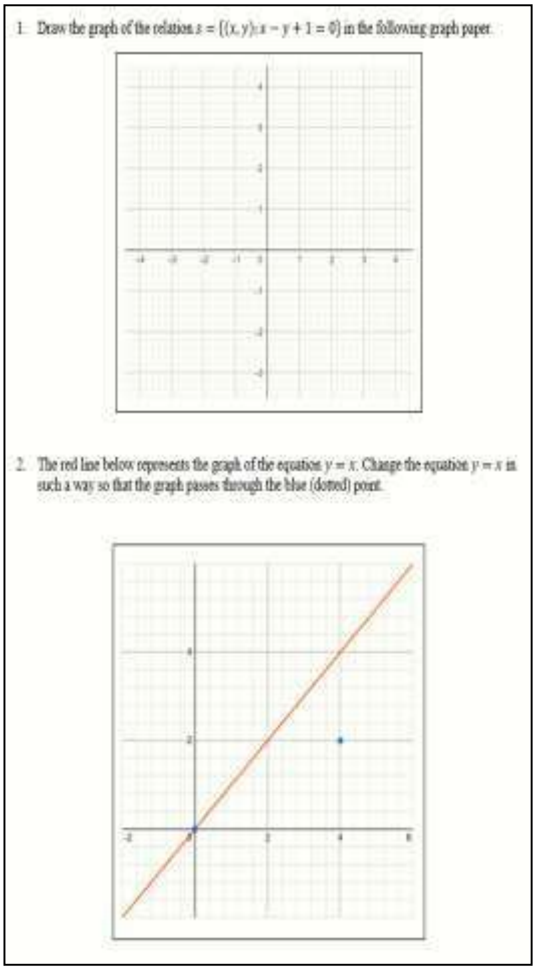


Page-2



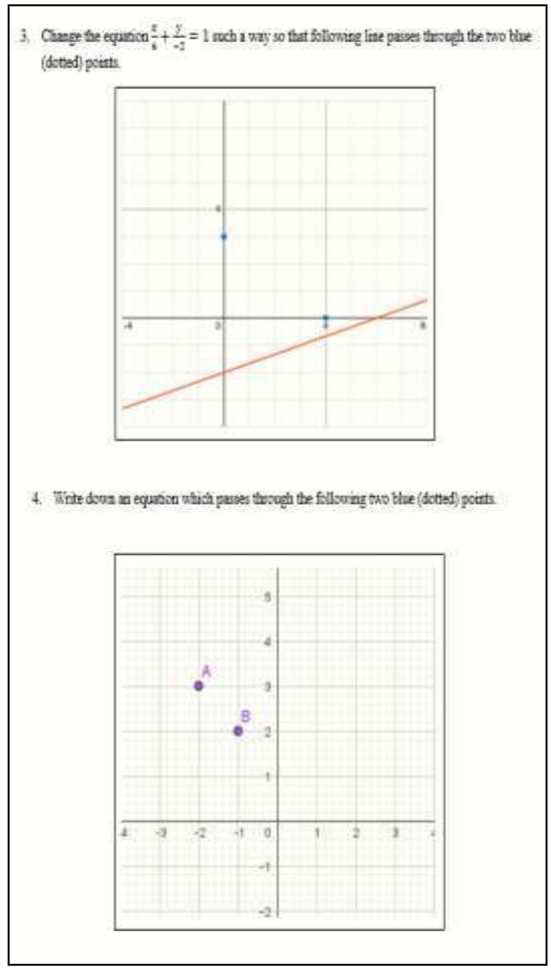
Page-3

Appendix I: Activity task-1 (Case-II)


1. Draw the graph of the relation $s = \{(x, y): x - y + 1 = 0\}$ in the following graph paper.

2. The red line below represents the graph of the equation $y = x$. Change the equation $y = x$ in such a way so that the graph passes through the blue (dotted) point.

Page 1


3. Change the equation $\frac{x}{6} + \frac{y}{-2} = 1$ such a way so that following line passes through the two blue (dotted) points.

4. Write down an equation which passes through the following two blue (dotted) points.

Page 2

Appendix J: Activity task-2 (Case-II)

১) m এর মান বাড়ার সাথে সাথে রেখার কি পরিবর্তন হয়?

উত্তরঃ

২) m এর মান যত ছোট হতে থাকে অর্থাৎ m=-1, m=-2 গ্রাফ এর কি পরিবর্তন হয়?

উত্তরঃ

৩) m এর মান (+ve), (-ve) এবং '0' পরিবর্তন করলে রেখার কি পরিবর্তন হয়?

উত্তরঃ

৪) m এর মান পরিবর্তন করলেও রেখার কোন বিন্দুটির কোন পরিবর্তন হয়না?

উত্তরঃ

৫) c এর মান বাড়ার সাথে সাথে রেখার কি পরিবর্তন হয়?

উত্তরঃ

৬) c এর মান যত ছোট হতে থাকে অর্থাৎ c=-1, c=-2 গ্রাফ এর কি পরিবর্তন হয়?

উত্তরঃ

৭) c এর মান (+vet), (-vet) এবং '0' পরিবর্তন করলে রেখার কি পরিবর্তন হয়?

উত্তরঃ

৮) C এর মান এবং y-অক্ষের cutting point এ কোন উল্লেখযোগ্য কিছু রয়েছে কি?

উত্তরঃ

Appendix K: Transcripts of a full intervention lesson

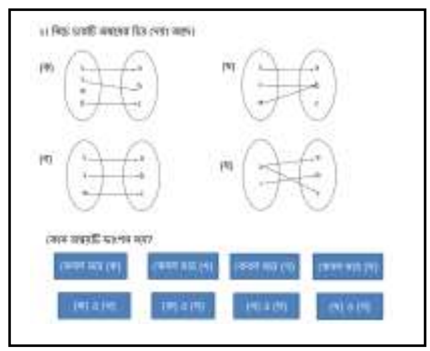
Teacher's Name: T1 (Case-I)	**Date: 21-11-2022**
Grade: 10	**Topic: Function**
Numbers of students: 30	**Class duration: 50 minutes**

(Teacher T1 entered the classroom. All students showed respect to the teacher by standing.)
T1: Sit down please. Good morning everyone!
Students: Good morning sir. *(Loudly)*
T1: How are you all?
Students: well sir. *(all loudly)*

(Teacher rearranged some sitting arrangement for a while and place the portable board at a suitable place ensuring that all students can see clearly)

T1: can you see the board and the screen clearly?
Students: yes sir.

(Teacher displayed a PowerPoint slide on the projection screen)



T1: Look at the screen. What have you seen?
Students: 4 diagrams
T1: Yes, now you have to identify which diagram(s) are not represent function. Think for a while.
T1: S11_C1, tell us which option(s) do you think?
S11_C1: Option one i.e. this one, sir.
T1: why?
S11_C1: because, to be a function, every input must have an output, here one input has no output. Which is not possible.
T1: Do you think any other option will be?
S11_C1: Um. I am not sure, sir.
T1: S7_C1, tell us S11_C1's answer is correct or not?
S7_C1: No sir. I think S11_C1 is partially correct. The 4^{th} diagram is also not a function. So the correct option will be this one. *(showing the option by using finger)*
T1: Explain us, why.
S7_C1: To be a function, every input must have exactly one output. But here, one input has two outputs 'a' and 'c', which is not true for a function.
T1: Students, what do you think?
Students: S7_C1 is correct.
T1: Ok, S7_C1, use this mouse and click on the option (in the laptop) which one you think correct.
S7_C1: ok, sir.

("Anwer is correct" showed on the projected screen)

T1: A big round of applause for S7_C1.

(All clapped for S7_C1)

T1: who can tell us about the 2nd and 3rd diagram? Raise your hand.

(all most every student raised their hand)

T1: S23_C1, stand up. Tell us about 2nd diagram.

S23_C1: it is function.

T1: why?

S23_C1: for every input there is exactly one output.

T1: look at ‘c’, is it associated with any input?

S23_C1: no sir.

T1: then, still is it a function?

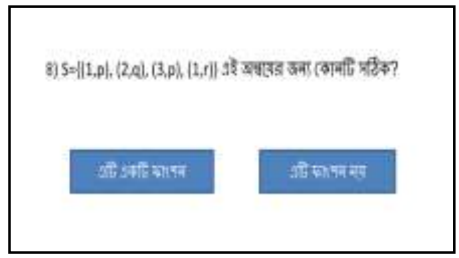
S23_C1: yes sir, to be a function each input must be associated with exactly one output. Here ‘c’ is not input and every input has one output. So it is a function.

T1: anyone want to deny S23_C1’s opinion?

Students: No sir, he is correct.

T1: very good

(teacher displayed the next slide)



T1: every one look at the screen. Which one is correct? You can discuss with your peer for 2 minutes. *(students discussed with their peer. Some of the students raised their hands. Teacher moved the whole class and tries to understand what they were discussing.)*

T1: okay, time up. S13_C1 go toward the projection screen and explain us what do you think.

S13_C1: this option is correct. *(showing by his finger)*

T1: why?

S13: sir, this is not a function because for input 1, we get output ‘p’ and for input 3, we get output ‘p’. For different input, we did not get different output, so this is not function.

T1: What do you think students?

(Some students told that “ wrong”. Some students seemed confused)

T1: Okay, S22_C1 come here and explain your opinion. S13_C1, you still standup here.

S22_C1: sir, S13_C1 told that 2nd option will be the answer, that is correct. But his explanation is wrong. Here, for input 1, we get two different outputs ‘p’ and ‘r’, which is not possible to be a function.

T1: okay, let’s see whether you are correct or not. S22_C1 use the computer and click on the option which you think is correct.

(S22_C1 went toward the computer and press on the chosen option. Correct sign (√) appeared on the screen with explanation)

T1: wonderful, the answer is correct.

(every one clapped)

T1: S13_C1, have you realized why your answer was not correct?

S13_C1: yes sir.

T1: why?

S13_C1: I told, for input 1, the output is ‘p’ and for input 3, the output is ‘p’. That is why, it is not a function. But it was wrong. To be a function for different input value, output could be same, but for unique input value, output never be more than one.

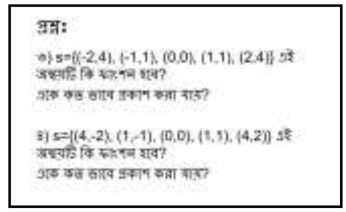
T1: students, what do you think?

Students: S13_C1 is correct sir. *(all said loudly)*

T1: good *(looking at S13_C1 and S22_C1)*, both of you can take your sits.

T1: now students, open your script.

(teacher wrote two questions on the portable white board and asked students to copy those question in their scripts)



T1: look at your 1st question. What is it?

Students: it is a relation sir.

T1: why relation? S1_C1, tell us.

S1_C1: sir, it has 5 order pairs and 1st element of each order pair is associated with the 2nd element.

T1: students, what do you think?

Students: S1_C1 is correct sir.

T1: S19_C1 stand up. Did 2 is related to any one?

S19_C1: yes sir. It is 4.

T1: what about -2?

S19_C1: it is also related to 4.

T1: can we say this relation, a function? Look at all order pair carefully.

(students was thinking, some of them were discussing with their peer, some were raising their hands.)

T1: S25_C1, what do you think?

S25_C1: function, sir.

T1: is it? *(asked with tone of doubt)*

(S25_C1 seemed a bit confused)

T1: S9_C1, what do you think?

S9_C1: it is function sir, because each input is associated with exactly one output.

T1: what about the order pair (-2,4) and (2,4)?

S9_C1: here input different but output same, so it is okay for a function.

T1: students, what do you think?

Students: S9_C1 is correct sir.

T1: very good, a big clap for S9_C1.

T1: students, can you imagine in which way we can write f(x), so that for each input value we get the output value? I will give you an example, suppose f(x)= x+1 *(teacher wrote f(x)=x+1 on the board)*. For x=1, what will be the value of f(x)?

Students: 2

T1: good. In that case, what was the order pair?

(some students said (1,2), some said (2, 1))

T1: (1,2) or (2,1), which one?

S11_C1: (1,2), sir. *(said loudly)*

T1: S11_C1, stand up. Why not (2,1)?

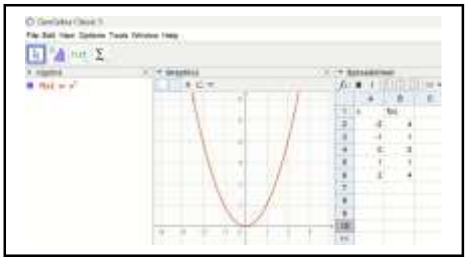
S11_C1: because x is the 1st element of a order pair. Here the value of x is 1, not 2.

T1: students, what do you think?

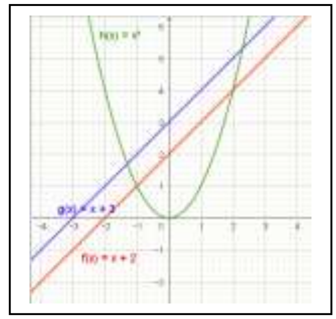
Students: S1l_C1 is correct sir.

T1: very good, sit down.

T1: now, think what should be the expression of f(x) so that all order pairs of question 1 are satisfied. You can discuss with your friend.
Students: f(x) should be x^2
T1: we can check it.



(teacher used the spread sheet window in the GeoGebra software and wrote the command of $f(x)=x^2$. He put x=*-2, then it gave output 4.)*
T1: look carefully, what we get.
T1: S7_C1 came here. Put the another input value. *(teacher asked S7_C1 to use his laptop)*
S7_C1: sir, where will I write the value?
(teacher showed him how to do it)
(S17_C1 put the value -1 for x and then pressed the button 'enter'. The output value 1 appeared.)
T1: have the result match with the order pair?
Students: yes sir.
T1: who want to come?
Students: me me. *(raising their hand)*
T1: S4-C1, come and check for 3rd order pair.
(S4_C1 put the value '0' as an input and output showed '0')
S4_C1: got '0', sir. It same as the order pair. Can I do it for the next one?
T1: okay.
S4_C1: it is '1', sir.
T1: good, thank you
S14_C1: sir, can I come?
T1: Okay, come *(teacher welcome him with a big smile)*
(S14_C1 puts the value '2' as input and gets '4' as output)
(All clapped)
T1: So, your chosen f(x) was correct.
T1: This is the tabular form to represent a function *(teacher indicated the spread sheet window in the Geogebra software)*
T1: Now, we will see what will be the graph of this function
(Teacher plotted all the list of the points and connected them on the graphical window of the GeoGebra software. A "U" shape graph appeared on the screen.)
T1: Students, look, this is the graph of x^2. You can check output for any value of x in the tabular form and can check the output on the graph as well.
T1: clear?
Students: yes sir.
T1: this is called the graphical representation of function and x^2 is the algebraic form of that function. So, how many ways we learn to represent a function?
Students: 3 ways sir.
T1: good. Try to solve the next question at your home.
(Teacher divided the students into 6 groups and 5 students were in each group. Teacher asked two students from each group to bring two extra chair so that they can discussed easily with



each other. Then teacher provided a worksheet in each group containing three graphs with their algebraic expressions).

T1: look at the graphs and their algebraic expressions. Try to find out the similarities and dissimilarities among these graphs, also the algebraic expressions. Each group will get 2 minutes.

T1: Group 1, any one from your group stand up and tell us, did you find any similarities among the graphs.

Group 1: all are graphs of function.

T1: Group 2, what do you think about Group 1's response?

Group 2: Group 1 is right. *(one student response from group 2)*

T1: why?

Group 2: For each graph, each input value has unique output.

T1: Group 3, what do you think? Can you explain it with example?

Group 3: sir, Group 1 and 2 are correct. Here for the red graph, um, if the input is 1 then the output is 3. for blue graph, if input x=2 the output is f(x)= 5 and for green graph, if the input is 2, then the output is 4. In this way, for each input, we can get unique output.

T1: very good. Thank you Group 1, 2 and 3. Now, Group 4, did you get any dissimilarities?

Group 4: Red and blue graphs are straight line and green graph is not a straight line.

T1: anything more?

(Group 4 did not respond for further).

Group 5: sir, we find more thing.

T1: okay, stand up and tell us. *(one student from Group 5 stood up)*

Group 5: sir, we get dissimilarities in algebraic expressions. In the algebraic expressions of the red and blue graphs have the power of variable '1' and has constant value, but the green one's has power 2 and no constant value.

T1: what do you think, group 6?

Group 6: he is correct sir.

T1: well done. You all are correct. Red and blue graphs are straight lines and in their algebraic expressions, the power of the variables is 1. This types of function called linear function. Constant value is not an issue here, there may be a constant value or not. We will learn about the linear function more in the next class.

That is all for today.

Hope to see you in the next class. Thank you.

Students: Thank you, sir. *(students showed their respect by standing)*

End of the lesson

Appendix L: Tests of Normality (Paper-pencil test data)

(a) Case 1:

Tests of Normality				
		Shapiro-Wilk		
		Statistic	df	Sig.
Before Intervention (Pre-test)	CU	.937	30	.077
	PF	.939	30	.084
	AR	.933	30	.059
	SC	.935	30	.067
After Intervention (Post-test)	CU	.939	30	.085
	PF	.943	30	.110
	AR	.936	30	.070
	SC	.934	30	.061

(b) Case-2

Tests of Normality				
		Shapiro-Wilk		
		Statistic	df	Sig.
Before Intervention (Pre-test)	CU	.938	30	.080
	PF	.934	30	.062
	AR	.939	30	.084
	SC	.936	30	.069
After Intervention (Post-test)	CU	.937	30	.074
	PF	.945	30	.125
	AR	.966	30	.426
	SC	.935	30	.069

Appendix M: Tests of Normality (Survey data)

(a) Case 1:

Tests of Normality				
		Shapiro-Wilk		
		Statistic	df	Sig.
Before Intervention (Pre-test)	useful & worthwhile	.741	30	<.001
	sense-making endeavor	.909	30	.014
	enthusiasm	.818	30	<.001
	persistence	.917	30	.022
	confidence	.844	30	<.001
	curiosity	.802	30	<.001
	corporation	.811	30	<.001
After Intervention (Post-test)	useful & worthwhile	.627	30	<.001
	sense-making endeavor	.860	30	.001
	enthusiasm	.681	30	<.001
	persistence	.900	30	.008
	confidence	.835	30	<.001
	curiosity	.701	30	<.001
	corporation	.628	30	<.001

(a) Case 2:

Tests of Normality				
		Shapiro-Wilk		
		Statistic	df	Sig.
Before Intervention (Pre-test)	useful & worthwhile	.730	29	<.001
	sense-making endeavor	.950	29	.184
	enthusiasm	.871	29	.002
	persistence	.941	29	.108
	confidence	.919	29	.029
	curiosity	.789	29	<.001
	corporation	.847	29	<.001
After Intervention (Post-test)	useful & worthwhile	.690	29	<.001
	sense-making endeavor	.925	29	.042
	enthusiasm	.846	29	<.001
	persistence	.933	29	.065
	confidence	.952	29	.205
	curiosity	.804	29	<.001
	corporation	.881	29	.004

Appendix N: Descriptive statistics of each indicator of the PD

(a) Case-I

Before intervention

Indicators of PD	N	Mean	Std. Deviation	Minimum	Maximum	Median
useful & worthwhile	30	4.4333	.67891	3.00	5.00	5.0000
sense-making endeavor	30	3.6007	.45866	2.67	4.67	3.6700
enthusiasm	30	4.0333	1.03335	2.00	5.00	4.0000
persistence	30	3.6000	.35505	3.00	4.33	3.6700
confidence	30	3.2667	.65302	1.00	4.00	3.5000
curiosity	30	3.8333	.74664	3.00	5.00	4.0000
corporation	30	3.9667	.76489	3.00	5.00	4.0000

After intervention

Indicators of PD	N	Mean	Std. Deviation	Minimum	Maximum	Median
useful & worthwhile	30	4.4667	.86037	1.00	5.00	5.0000
sense-making endeavor	30	4.3450	.64018	2.67	5.00	4.5000
enthusiasm	30	4.5667	.62606	3.00	5.00	5.0000
persistence	30	4.3780	.55874	3.00	5.00	4.3300
confidence	30	4.3500	.63177	2.50	5.00	4.5000
curiosity	30	4.5333	.62881	3.00	5.00	5.0000
corporation	30	4.5667	.67891	2.00	5.00	5.0000

(b) Case-II

Before intervention

Indicators of PD	N	Mean	Std. Deviation	Minimum	Maximum	Median
useful & worthwhile	30	4.2100	1.03057	1.00	5.00	4.0000
sense-making endeavor	30	3.7997	.76210	1.33	5.00	4.0000
enthusiasm	30	3.6667	.92227	2.00	5.00	4.0000
persistence	30	3.7113	.81066	.00	4.67	3.6700
confidence	30	3.2667	.90719	.00	4.50	3.5000
curiosity	30	4.2759	.79716	2.00	5.00	4.0000
corporation	30	3.8276	1.00246	1.00	5.00	4.0000

After intervention

Indicators of PD	N	Mean	Std. Deviation	Minimum	Maximum	Median
useful & worthwhile	30	4.4667	.73030	3.00	5.00	5.0000
sense-making endeavor	30	4.0010	.53913	2.67	5.00	4.0000
enthusiasm	30	3.7333	.73968	2.00	5.00	4.0000
persistence	30	3.8113	.63503	2.33	5.00	4.0000
confidence	30	3.1667	.69893	1.50	4.50	3.0000
curiosity	30	4.0667	.82768	2.00	5.00	4.0000
corporation	30	3.7667	1.04000	1.00	5.00	4.0000

Appendix O: Comparative test between pre & post intervention (Wilcoxon Signed Rank Test)

(a) Case I

	Post test-pre test	N	Mean Rank	Sum of Ranks	z-value	p-value	Effect size r
useful & worthwhile	Negative Ranks	7	10.29	72.00	-.655	.513	-0.085
	Positive Ranks	11	9.00	99.00			
	Ties	12					
sense-making endeavor	Negative Ranks	4	9.88	39.50	-3.605	<.001	-0.465
	Positive Ranks	23	14.72	338.50			
	Ties	3					
enthusiasm	Negative Ranks	5	5.00	25.00	-2.465	.023	-0.318
	Positive Ranks	11	10.09	111.00			
	Ties	14					
persistence	Negative Ranks	2	3.00	6.00	-4.226	<.001	-0.546
	Positive Ranks	23	13.87	319.00			
	Ties	5					
confidence	Negative Ranks	2	4.00	8.00	-4.481	<.001	-0.579
	Positive Ranks	26	15.31	398.00			
	Ties	2					
curiosity	Negative Ranks	5	9.00	45.00	-3.143	.002	-0.406
	Positive Ranks	19	13.42	255.00			
	Ties	6					
corporation	Negative Ranks	3	9.67	29.00	-2.753	.006	-0.355
	Positive Ranks	16	10.06	161.00			
	Ties	11					

(b) Case-II

	Post test-pre test	N	Mean Rank	Sum of Ranks	z-value	p-value	Effect Size r
useful & worthwhile	Negative Ranks	7	8.07	56.50	-.999	.318	-0.129
	Positive Ranks	10	9.65	96.50			
	Ties	13					
sense-making endeavor	Negative Ranks	10	10.60	106.00	-.977	.329	-0.126
	Positive Ranks	13	13.08	170.00			
	Ties	7					
enthusiasm	Negative Ranks	8	8.69	69.50	-.346	.730	-0.045
	Positive Ranks	9	9.28	83.50			
	Ties	13					
persistence	Negative Ranks	10	13.90	139.00	-.031	.975	-0.004
	Positive Ranks	13	10.54	137.00			
	Ties	7					
confidence	Negative Ranks	13	12.23	159.00	-.652	.515	-0.084
	Positive Ranks	10	11.70	117.00			
	Ties	7					
curiosity	Negative Ranks	14	9.86	138.00	-1.313	.189	-0.170
	Positive Ranks	6	12.00	72.00			
	Ties	9					
corporation	Negative Ranks	9	9.72	87.50	-.090	.928	-0.012
	Positive Ranks	9	9.28	83.50			
	Ties	11					

According to Cohen (1988),

Small effect: r values above 0.1
Moderate effect: r values above 0.3
Strong effect: r values above 0.5