

University of Dundee

DOCTOR OF PHILOSOPHY

**Maths and Mobile Technologies**  
**Effects on Students' Attitudes, Engagement and Achievement**

Fabian, Ma Khristin

*Award date:*  
2018

[Link to publication](#)

**General rights**

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

**Take down policy**

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Maths and Mobile Technologies:  
Effects on Students' Attitudes, Engagement and Achievement

Ma. Khristin Fabian

A thesis submitted for the degree of PhD in Education

School of Education and Social Work

University of Dundee

2018



## TABLE OF CONTENTS

Table of Contents .....	i
List of Tables.....	vi
List of Figures .....	vii
List of Appendices .....	ix
Acknowledgement.....	x
Declaration .....	xi
Abstract .....	xii
Chapter 1 Introduction .....	1
Scope of the Research .....	1
Overview of the Current Study.....	3
Outline of Chapter Content .....	4
Chapter 2 Review of Literature .....	5
Theoretical Framework .....	5
Theories of Technology Supported Mathematics Learning .....	5
Theories of Mobile Learning .....	8
Technology Acceptance Model .....	14
Critical Success Factors .....	15
Empirical Framework.....	18
Student Attitudes.....	18
Achievement .....	20
Systematic Review of Maths and Mobile Learning Studies .....	22
Maths and Mobile Learning (2003-2012).....	22
Systematic review methodology. ....	23
Searching and screening for studies. ....	23
Describing and mapping of studies. ....	25
Quality and relevance appraisal. ....	25
Synthesising study findings and data analysis. ....	26
Results. ....	26
Descriptive map of research on mobile technology uses for learning maths. ...	26
Charting the learning space.....	29
Functional pedagogical use.....	30
Learning strategies used.....	32
Student attitudes and perceptions. ....	36
Student attitudes and perceptions towards mobile technologies. ....	36
Change in student attitudes and perceptions towards mathematics. ....	37
Student engagement. ....	38
Group dynamics and collaboration. ....	38
Engagement with the mobile-supported activity. ....	39
Student achievement.....	40
Elementary studies: A meta-analysis.....	40
Middle school studies. ....	43
High school studies.....	45
Other study findings.....	46

Limitations. ....	47
Maths and Mobile Learning Studies 2013-2016.....	48
Systematic review methodology. ....	48
Results. ....	49
Descriptive map of mobile learning research for 2013-2016.....	50
Learning outcome. ....	53
Limitations. ....	56
Summary (for both systematic reviews) .....	57
Descriptive map of research. ....	57
Student attitudes and engagement. ....	58
Achievement. ....	58
Gaps in Literature .....	59
Chapter Summary .....	59
Chapter 3    General Method.....	61
Research Design .....	61
Nature of the Intervention .....	62
Ethical Considerations.....	64
Chapter 4    Study 1 – A pilot study .....	66
Introduction .....	66
Methodology .....	66
Research design .....	66
Participants.....	67
Instruments.....	68
End activity evaluation.....	68
Video recordings. ....	69
Student interviews.....	69
Teacher interviews. ....	69
Mathematics attitude inventory (MAI). ....	70
Achievement. ....	71
The mobile learning activities.....	72
Technology used. ....	72
Skitch.....	72
Mirrord Picture Reflection .....	73
Measure Map.....	73
Area and Perimeter. ....	74
InstaSurvey. ....	75
Google Sheets.....	79
Learning Activities.....	80
Sessions on Symmetry.....	80
Sessions on area and perimeter. ....	81
Session on angles.....	83
Session on information handling. ....	84
Procedure .....	87
Data Analysis .....	87
Findings .....	88
Micro-evaluation.....	88
Student evaluation.....	88
Meso-evaluation.....	90
Critical incident analysis. ....	90

Breakdowns.....	90
Breakthroughs.....	95
Student interviews.....	97
Mid-study interview.....	97
End-study interview.....	98
Teacher interview.....	99
Macro-evaluation.....	100
Mathematics attitude inventory.....	100
Mathematics achievement.....	102
Discussion.....	102
Limitations of Current Study.....	104
Summary and Next Direction.....	104
Chapter 5 Study 2 – A quasi-experimental design.....	107
Introduction.....	107
Methodology.....	108
Research Design.....	108
Participants.....	109
Instruments and Measures.....	110
End activity evaluation.....	110
Maths attitude inventory (MAI).....	110
Maths test (MT).....	110
Interviews.....	110
The mobile learning activity.....	111
Procedure.....	113
Data Analysis.....	113
Micro-evaluation.....	113
Meso-evaluation.....	113
Macro-evaluation.....	113
Results.....	114
Micro-evaluation.....	114
Meso-evaluation.....	117
Student perception of the tablet activities.....	117
Perceived advantages/disadvantages of doing tablet activities.....	117
Working in pairs and in groups.....	118
Challenges encountered.....	119
Teacher interview.....	119
Macro-evaluation.....	121
Student achievement.....	121
Mathematics Attitude Inventory.....	125
Gender differences in MAI scores.....	125
Usability scores and technology related scales.....	128
Discussion.....	128
Students’ attitudes and perceptions about maths and mobile technology.....	128
Mathematics achievement.....	129
Gender differences.....	130
Limitations of the study.....	130
Summary and Next Direction.....	131
Chapter 6 Study 3 – A randomized controlled trial design.....	133
Introduction.....	133

Methodology .....	134
Research Design .....	134
Participants.....	135
The mobile learning activities.....	135
Technology used. ....	135
The learning activities. ....	138
Activities on symmetry. ....	139
Activities on angles. ....	141
Activities on area and perimeter. ....	142
Activities on combined topics. ....	143
Instruments and Measures .....	149
Maths attitude inventory (MAI). ....	149
Maths test (MT). ....	149
End activity evaluation.....	151
Interviews. ....	151
Video recording.....	151
Observation protocol.....	152
Procedure .....	154
Data analysis .....	155
Micro-evaluation. ....	155
Meso-evaluation.....	155
Macro-evaluation. ....	155
Results .....	156
Micro-evaluation.....	156
End activity evaluations by group.....	156
Gender differences in experimental groups' evaluation. ....	160
Differences on end activity evaluations by grade level. ....	162
Meso-evaluation.....	162
Student perception of the tablet activities. ....	162
Perceived advantages/disadvantages of doing mobile-supported activities.....	164
Working in pairs. The .....	165
Challenges encountered. ....	167
Teacher interview.....	168
Video observation of paired activity.....	169
Macro-evaluation .....	173
Mathematics Attitude Inventory (MAI). ....	173
Gender differences (experimental group).....	175
Differences by grade level (experimental group).....	175
Usability scores and technology related scales. ....	176
Mathematics Test. ....	177
Triangulation of student feedbacks on tablet use.....	179
Discussion .....	180
Student Evaluations of Mobile Technology Use .....	180
Gender differences. ....	182
Differences by grade level. ....	182
Student Attitudes to Mathematics.....	183
Student Attitudes to Technology Use .....	184
Student Engagement .....	185
Student Achievement.....	186
Limitations of this Study.....	188

Summary and Next Directions .....	189
Chapter 7 Discussion .....	191
Overall Summary of the Results .....	191
Study 1 .....	191
Study 2 .....	192
Study 3 .....	192
Discussion .....	193
Student Attitudes.....	193
Student perceptions of the mobile learning activities (RQ1).....	193
Student attitudes to technology (RQ2).....	196
Student attitudes to mathematics (RQ3). ....	198
Technology acceptance model. ....	202
Student Engagement (RQ4) .....	204
Breakdowns of mobile learning. ....	205
Collaboration in mobile learning environment. ....	206
Student achievement (RQ5).....	208
Critical success factors.....	211
Appropriate choice of mobile devices and software and user friendliness of design. ....	211
Level of pedagogical integration of technology into the course. ....	211
Level of lecturer modelling and development of technical competence of students.....	212
Technological and pedagogical support (including learner community).....	212
Allowing time for ontological shifts. ....	213
Advantages of Mobile Learning .....	214
Limitations .....	215
Contribution to Knowledge .....	217
Chapter 8 Conclusion .....	219
Recommendations for practice .....	222
Recommendations for researchers .....	223
References .....	224



## LIST OF TABLES

Table 2-1 Critical Success Factors mapped into each other .....	16
Table 2-2 Summary of review studies .....	21
Table 2-3 Exclusion and Inclusion Criteria .....	25
Table 2-4 Characteristics of the Included Studies.....	28
Table 2-5 Summary of Effect Sizes in Elementary Studies.....	41
Table 2-6 Study characteristic and random effect sizes.....	43
Table 2-7 Exclusion and Inclusion Criteria .....	49
Table 2-8 Characteristics of studies included in review .....	52
Table 4-1 M3 Level Evaluation Design .....	67
Table 4-2 Items from end activity questionnaire grouped by scale .....	69
Table 4-3 Survey items grouped by subscale.....	71
Table 4-4 Activities carried out mapped into Sawaya and Putnam (2015).....	85
Table 4-5 Video data in minutes .....	90
Table 4-6 List of issues identified and its category .....	91
Table 4-7 Mean pre-test, mid-test and post-test scores.....	101
Table 4-8 Correlation matrix of usability scores and MAI technology related scales..	101
Table 4-9 Design changes .....	105
Table 5-1 M3 Level evaluation framework .....	109
Table 5-2 Reliability scores of end activity evaluation by subscale .....	110
Table 5-3 Summary of activity ratings grouped by gender.....	116
Table 5-4 Descriptive statistics by gender .....	123
Table 5-5 Descriptive statistics by MT(pre-test) ranking .....	124
Table 5-6 MAI scores of experimental and control group.....	126
Table 5-7 MAI Scores by Gender .....	127
Table 5-8 Correlation matrix of usability scores and MAI technology related scales..	128
Table 6-1 M3 Level evaluation framework .....	135
Table 6-2 Summary of learning activities mapped into SAMR model.....	145
Table 6-3 Observation protocol .....	153
Table 6-4 Descriptive statistics of end activity evaluation. ....	157
Table 6-5 Usability scores of experimental and control group.....	160
Table 6-6 Gender differences in the experimental group's evaluation.....	160
Table 6-7 Descriptive statistics in the experimental group's evaluation by level.....	162
Table 6-8 Breakdown of preferred activities by gender and level.....	164
Table 6-9 Tally of feedback on tablet use by gender and grade level.....	166
Table 6-10 Changes in student scores for MAI and MT.....	169
Table 6-11 MAI scores of experimental and control group.....	174
Table 6-12 Descriptive statistics of MAI subscale scores grouped by gender .....	175
Table 6-13 Descriptive statistics of MAI subscale scores grouped by level.....	176
Table 6-14 Correlation matrix of usability scores and MAI technology related scales	176
Table 6-15 Adjusted vs Unadjusted pre-test scores .....	177
Table 6-16 Item level statistics. ....	178
Table 7-1 Correlation coefficients mapped into the technology acceptance model ....	203
Table 7-2 Checklist of critical success factors across Study 1 – 3.....	211

## LIST OF FIGURES

Figure 2-1. Functional framework of technology use (Patten et al., 2006, p. 296). .....	10
Figure 2-2. SAMR model of technology integration (Puentadura, 2006) .....	11
Figure 2-3. Conversational framework model (Laurillard, 2007). .....	13
Figure 2-4. Task model of mobile learning (Sharples et al, 2007). .....	14
Figure 2-5. Technology Acceptance Model (Davis, Bagozzi, & Warshaw, 1989) .....	15
Figure 2-6. Modified PRISMA flow diagram.....	24
Figure 2-7. Distribution of studies on maths and mobile learning by country .....	27
Figure 2-8. Graph of distribution of studies in terms of learning space. ....	29
Figure 2-9. Distribution of studies categorised by functional use .....	32
Figure 2-10. Distribution of studies categorised by learning strategy used.....	33
Figure 2-11. Forest plot of effect sizes (elementary studies).....	42
Figure 2-12. Comparison of functional pedagogical use between the two reviews.....	51
Figure 3-1. Iterative design process .....	61
Figure 3-2. Framework for the design of mobile learning activities for mathematics....	62
Figure 4-1. Screenshot of Skitch.....	72
Figure 4-2. Screenshot of Mirrord .....	73
Figure 4-3. Screenshot of Measure Map showing area and perimeter.....	74
Figure 4-4. Screenshot of Area and Perimeter application .....	75
Figure 4-5. Screenshot of InstaSurvey.....	76
Figure 4-6. Screenshot of Snapshot Bingo .....	77
Figure 4-7. Screenshots of Simple Measure. ....	78
Figure 4-8. Screenshot of Smart Distance application.....	78
Figure 4-9. Screenshot of Google Sheet used in one of the activities. ....	79
Figure 4-10. An example of student work showing measured length and height.....	82
Figure 4-11. An example of students' work showing supplementary angles. ....	83
Figure 4-12. Average of end activity evaluation grouped by session .....	89
Figure 4-13. Teaching assistant showing line of symmetry.....	95
Figure 4-14. Teacher uses ceiling line as an example of supplementary angles.....	96
Figure 4-15. Students working on an activity. ....	96
Figure 4-16. Graph of pre and post maths test scores with error bars shown.....	102
Figure 5-1. Comparison of lesson structure between Study 1 and Study 2. ....	108
Figure 5-2. An illustration of how Aurasma works. ....	112
Figure 5-3. End activity evaluation.....	115
Figure 5-4. Gains scores of experimental and control group. ....	122
Figure 5-5. Gain scores grouped by gender .....	123
Figure 5-6. Gain scores grouped by MT(pre-test) ranking .....	124
Figure 6-1. Screenshot of Pixel Touch shown with an example of students' work....	136
Figure 6-2. Screenshot of Material Protractor .....	137
Figure 6-3. Screenshot of angle reader application.....	138
Figure 6-4. Student work showing misconception on line of symmetry .....	139
Figure 6-5. Student work showing symmetry on a symmetry camera.....	140
Figure 6-6. Examples of a students' work: (a) experimental group (b) control group .	141
Figure 6-7. An illustration of the mobile learning activity for Session 3. ....	141
Figure 6-8. An activity showing samples of completed work for Session 8.....	144
Figure 6-9a-c. Sample test items on (a) symmetry, (b) angles, (c) area and perimeter	150
Figure 6-10. An example of an annotated picture showing angle .....	151
Figure 6-11. Histogram of usability ratings divided into topics .....	159
Figure 6-12. Histogram of usability ratings split by gender. ....	161

Figure 6-13. Graph of paired activity.....	170
Figure 6-14. Nature of conversation .....	172
Figure 6-15. Scatterplot diagram showing VMT score vs End Activity Evaluation ....	180
Figure 7-1. MAI scores across three studies. ....	199

**LIST OF APPENDICES**

Appendix A.	Clusters of Literature Search .....	241
Appendix B.	Sample Mapping of Studies .....	242
Appendix C.	Copy of ethics approval.....	243
Appendix D.	Copy of consent to undertake research from council.....	245
Appendix E.	Participant information sheets and consent forms.....	246
Appendix F.	End Activity Evaluation .....	261
Appendix G.	Maths Attitude Inventory .....	263
Appendix H.	Critical Incident Analysis.....	265

## **ACKNOWLEDGEMENT**

I would like to thank the research participants of this study, the teachers and students who took part in the intervention - without them this study would not have been possible.

I am very grateful to my supervisors, Prof. Keith Topping and Prof. Ian Barron for their insights, support and encouragement throughout the stages of this PhD.

I am indebted to my husband, Jun, for understanding the concept of a part-time wife, full-time PhD. It's been a long journey.

**DECLARATION**

I hereby declare that the candidate, Ma. Khristin Fabian is the author of the thesis presented herein; that, unless otherwise stated, all references cited have been consulted by the candidate; that the work, of which the thesis is a record, has been done by the candidate, and that it has not been previously accepted for a higher degree.

Signature:

## ABSTRACT

The ubiquity of mobile devices together with their potential to bridge classroom learning to real-world settings has added a new perspective to contextualising mathematics learning, but this needs further exploration. The aim of this thesis is to examine the effects of using mobile technologies on students' attitudes, engagement and achievement in mathematics. The study starts with a systematic review of maths and mobile learning studies followed by three iterations of data collection. The three studies were mixed-methods studies guided by the micro, meso, macro (M3) Evaluation Framework. The studies included eight mobile learning sessions spread over three months covering topics on geometry and information handling. These sessions were conducted as collaborative learning activities in indoor and outdoor settings. Participants were Primary 6 and 7 students from three different schools in Scotland. In Study 1 (a single-group design,  $n=24$ ), students had positive evaluations of mobile learning but some technical problems experienced lessened their initially positive views. There was a small effect in student self-confidence ( $ES=.20$ ) and a significant positive difference between pre and post-test achievement scores. Breakdowns identified via the critical incident analysis in Study 1 informed the activity design of Study 2. In Study 2 (a quasi-experimental design,  $n=52$ ), students had more positive perceptions about the use of mobile technology. The experimental group had higher gain scores on the maths test than the control group. In Study 3, a randomised controlled trial over six weeks ( $n=74$ ), students also had positive evaluations of the mobile learning activities but this varied by gender. Analysis of the maths test scores with pre-test as covariate showed both groups had significantly improved their scores, but no significant treatment effect was found. For items relating to common student misconceptions on angles, students in the experimental group had significantly higher gains than the control group. The overall results from the three studies provide some evidence that students can have positive perceptions about the use of mobile technologies and that these can be effective in supporting students' engagement and performance in mathematics, especially when learning takes place outside the classroom. It also showed that the success of a mobile learning intervention is dependent on various factors, such as student and teacher characteristics, stability of the technology and content compatibility, among other factors. There were several limitations including sample size, length of intervention, and programme fidelity. Implications for practice and future researchers are discussed.

## CHAPTER 1 INTRODUCTION

### Scope of the Research

Over the years, several programs in mathematics education have been introduced, ranging from programs that emphasise a constructivist view, and on the opposite end of the scale, programs that support direct instruction (Slavin, Lake and Groff, 2009). Kirschner, Sweller and Clark (2006) argued that “novice learners should be provided with direct instructional guidance on the concepts and procedures required by a particular discipline and should not be left to discover those procedures by themselves” (p. 75). The constructivist view on the other hand takes a more student-centred approach to learning. Among its basic tenets includes the belief that knowledge is actively created and not passively received from the environment and that ideas are constructed or made meaningful by reflection (Clements and Battista, 1990). Rowe (2006) has provided a good middle ground for the constructivist versus direct instruction debate. He argued that

*“it is important to note that the relative utility of direct instruction and constructivist approaches to teaching and learning are neither mutually exclusive nor independent. Both approaches have merit in their own right, provided that students have the basic knowledge and skills (best provided initially by direct instruction) before engagement in ‘rich’ constructivist learning activities. The problem arises when constructivist learning activities precede explicit teaching, or replace it, with the assumption that students have adequate knowledge and skills to efficiently and effectively engage with constructivist learning activities designed to generate new learning” (p. 14).*

Regardless of the learning paradigm adopted, mathematics programs in schools converge in their goals to improve student learning outcomes.

There are several issues surrounding mathematics education, among which are student attitudes, student engagement and achievement. A recent Scottish Government report on Making Maths Count (Scottish Government, 2016) started with the admission that “Scotland has a maths problem. Too many of us are happy to label ourselves as *no good with numbers*” (p.3). Negative attitudes to mathematics and students’ own perception of their ability to do mathematics are linked to student perceptions of the learning environment (Fast et al., 2010), motivation (Hannula et al., 2016) and



engagement (Linnenbrink & Pintrich, 2003) which consequently affects maths performance. It is thus important to employ strategies that encourage students to engage fully and positively in learning mathematics.

Technology enhanced learning is one of the strategies employed to engage students with mathematics. For example, Scotland's Curriculum for Excellence (Education Scotland, nd.) encourages the use of technology to promote enjoyment of mathematics. However, technology use must not just be for technology's sake. It must be guided by a rationale to promote transformative learning in the classroom (Puentadura, 2006). Carpenter and Lehrer (1999) outlined mathematical activities that promoted understanding: constructing relationships, extending and applying mathematical knowledge, reflecting about experiences, articulating what one knows, and making mathematical knowledge one's own. On the other hand, potential benefits of using mobile technologies for learning include: facilitating learning across contexts, facilitating contextual learning, and providing personalisation in both personal and collaborative environments (Cochrane, 2010b). These potentials make mobile technology seem an ideal tool for learning mathematics.

Hirsh-Pasek et al. (2015) suggests that students learn best when they are engaged in meaningful and socially interactive learning experiences. Previous studies on mobile learning for maths have shown that it facilitates engagement (Project Tomorrow, 2010), contextualises mathematics learning (Tangney et al., 2010), supports collaboration (Zurita & Nausbaum, 2004) and facilitates new ways to visualise abstract maths concepts in the real world (Spikol and Eliason, 2010). These findings are promising, but studies on maths and mobile learning are few.

Pollara & Broussard (2011) noted that the majority of studies on mobile learning reported positive student perceptions of mobile use in the classroom. Mobile learning studies on mathematics yielded the same results. Students found the use of mobile technologies engaging and useful (Kong, 2012; Lai, Lai, Shen, Tsai, & Chou, 2012). However, like the studies noted above, many of the current studies on mobile learning focus on very short duration implementations, the majority less than a month long (Sung, Chang, & Liu, 2015), therefore, how students perceive the use of mobile devices without regard to novelty value is unknown.

Literature on the effect of technology use on attitudes towards mathematics is limited, with few quantitative studies (Li & Ma, 2010). This is also the case for maths and mobile learning studies. There is evidence showing that students have improved

their attitudes to maths as a consequence of a mobile learning intervention (Main and O'Rourke, 2011), but there are also studies that show otherwise (Miller and Robertson, 2011). The limited and differentiated results of effects in attitudes to mathematics studies is a gap in mobile learning literature and one that study this attempted to address.

Furthermore, the research methodology adopted by mobile learning studies tends to focus on interviews, surveys or observation. Only a few studies have capitalised on comparative studies (Sharples, 2013). In studies that used outdoor settings, these narratives and observations provided evidence of high student engagement, but evidence of student achievement are not explored, or in cases where it was explored, then the narratives were not present (Kurti, Spikol, Milrad, 2008; Huang, Wu, Chen, Yang & Huang, 2012). In addressing this gap, the current study employed an integrated framework that allowed for different levels of evaluation, focusing on various aspects of mobile technology use.

### **Overview of the Current Study**

The current research investigated the effects of using mobile technologies on students' attitude towards mathematics, attitudes towards technology, student engagement as well as achievement. Three studies were conducted as part of this research, with the outcome of each study informing the changes for the next. The iterative design approach blended with a mixed methods study allowed exploration of mobile technology use for maths in different settings.

The research was carried out in three Scottish primary schools from two councils in Scotland. The participants were Primary 6 and 7 students (aged between 9-11) and their respective teachers. The classrooms were self-contained and consisted of students with mixed ability.

The five specific research questions this study attempted to address are as follows:

- RQ1. What are the students' views on the use of mobile technology for learning mathematics?
- RQ2. Is there a change in attitudes towards technology when mobile technology is used for learning mathematics?
- RQ3. Is there a change in attitude towards mathematics when mobile technology is used for learning maths?
- RQ4. How has the use of mobile technologies affected student engagement?

RQ5. Is there an improvement in mathematics achievement when using mobile-supported maths learning activities?

### **Outline of Chapter Content**

The introductory chapter outlines the scope of the research and the objectives of the current study. Chapter 2 examines the evidence from the literature and provides theoretical and empirical background on mobile learning and mathematics. The section also covers the two systematic reviews conducted, one before the current study was carried out (covering studies between 2003-2012) and an updating of the review (studies between 2013-2016) that followed shortly after data collection. Chapter 3 describes the general method for Study 1 to 3 and the ethical considerations. Chapters 4-6 give detail on Studies 1 - 3 respectively. Within these chapters are discussions of the methodology, the results, a short discussion of the findings, limitations and suggested changes for the next iteration. The main overall discussion is in Chapter 7 and answers the research questions raised in Chapter 1. It also contains the overall limitations of the current study and summary of contributions to knowledge. The conclusion, implications and recommendations for practice and research are in Chapter 8.

## **CHAPTER 2 REVIEW OF LITERATURE**

This section is in three parts. It starts off with a background on theories of maths and mobile learning. Part two is an empirical framework on technology use in mathematics education. The third section covers a systematic review of maths and mobile learning studies.

### **Theoretical Framework**

#### **Theories of Technology Supported Mathematics Learning**

The use of technologies in doing and learning mathematics has evolved. Prior to the proliferation of digital technologies, devices used in the mathematics classroom for teaching and learning can be categorised into: tools for information storage (e.g. books), tools for information display (e.g. chalkboard), tools for demonstration (i.e. physical manipulatives like geoboards) and tools for calculation (e.g. abacus) but this categorisation is no longer relevant. Digital technologies as modern tools have evolved into multifunctional devices (Roberts, Leung, & Lins, 2012). For example, a mobile device can provide all of those four functions. Another tool-centric categorisation is Drijvers's (2015) didactical functions of technology in maths education: for doing mathematics, for practicing maths skills and developing conceptual understanding. He notes that these functionalities are not mutually exclusive but highlights that it is the use of technologies for developing conceptual understanding that is the most challenging one to exploit.

While the history of using tools for mathematics is long, theories related to maths and technology use isn't. Drijvers et al. (2009) noted that theorising this subject area was only just developing in the 1980s, and that these theories were not theories per se but more descriptive categories (for example, Taylor's (1980) Tool, Tutor, Tutee metaphor). By the mid-1990s, classroom use of technology had matured and flourished and theoretical discussions had begun to touch on issues related to visualisation, multiple representation and situated learning (Lagrange, Artigue, Laborde, & Trouche, 2003), with most research adopting constructivism as a learning paradigm (Li & Ma, 2010). Since then, constructivism has been the "leading if not the dominant theory or philosophy of learning in the mathematics education research community" (Ernest, 2010, p. 39).

Constructivism is a learning theory that sees knowledge as actively constructed by learners. Its roots in mathematics education can be traced from elements of problem

solving, misconceptions literature and cognitive development (Confrey & Kazak, 2006). There are four critical elements of constructivist learning activities: eliciting prior knowledge, creating cognitive dissonance, application of knowledge with feedback and reflection on learning (Baviskar, Hartle, & Whitney, 2009). These elements are also the sequential steps that learners go through in the process of creating new knowledge.

Knuth & Cunningham (1993) outlined designed principles for constructivist learning:

1. Provide experience with knowledge construction process
2. Provide experience for multiple perspectives
3. Embed learning in realistic and relevant context
4. Encourage ownership and voice
5. Embed learning in a social experience
6. Encourage the use of multiple modes of representation
7. Encourage self-awareness of the knowledge construction process

These design principles lead to one form of constructivism typically discussed in maths learning literature---social constructivism (Eynde, Corte, & Verschaffel, 2006; Simon, 1995). This paradigm views knowledge building as a social activity as the learner interacts with others and the environment. In this view, collaborative discussions and tools facilitate knowledge building. Despite being typically used as a paradigm in mathematics intervention research, there are also criticisms of constructivist learning theories. One is that it fails to link to practice in terms of providing a guideline for instructional design (Simon, 1995), another is that, constructivism being a borrowed theory, “tended to dismiss or deny the integrity of fundamental aspects of mathematical knowledge” (Sriraman & English, 2010, p.14). These criticisms paved way for “homegrown” theories of mathematics education that served as a link of constructivist theories into practice.

Realistic Mathematics Education (RME) is one of the bridging theories conceived specifically for mathematics education. Originally developed in the Netherlands, this model has been adapted in the US in the form of Mathematics in Context (MiC) and in the UK in Making Sense of Maths materials (Dickinson & Hough, 2012). It has six teaching principles

- Activity principle, where students are treated as active participants;
- Reality principle, where activities are connected to “real-life;”

- Level principle, where students level of understanding goes through various levels beginning from an informal understanding of content via existing schemas to levels that can connect how concepts and strategies are related;
- Interactivity principle, where learning is seen as a social activity;
- Guidance principle, where teachers have an active role in terms of guiding students towards conceptual understanding (Van den Heuvel-Panhuizen & Drijvers, 2014).

From these guiding principles, it can be observed that RME complements the constructivist view of learning by doing.

Moving to a domain-specific theory, the Van Hiele model (Van Hiele, 1984) is one of the theories of cognitive development that has influenced constructivist movement in mathematics (Confrey & Kazak, 2006). Mason (1997) describes the five levels of geometric thinking which are as follows:

- Visualisation (Level 1). Ability to identify geometric figures according to their appearance.
- Analysis (Level 2). Ability to analyse geometric figures in terms of their components and properties.
- Abstraction or sometimes called informal deduction (Level 3). Ability to connect previously discovered properties by giving informal arguments.
- Deduction (Level 4). Ability to construct proofs and establish interrelationship between theorems.
- Rigor (Level 5). At this level, the student understands the formal aspects of deduction.

The model represents a hierarchical model and that learners cannot achieve one level without mastery of the previous level. Progression from one level to the next is a result of the nature of educational experiences provided to the students. Crowley (1987) adds the importance of context in these activities and matching the level of instruction to the students. A summary of previous studies given by Mason (1997) found that for students between kindergarten and middle school, their level would typically be between 1 and 2 and recent studies reaffirm this (Crompton, 2015; Rehm, Stan, Wøldike, & Vasilariou, 2015). One of the main criticisms is that it was developed in the 1950s and geometry teaching models have progressed since. Nevertheless, the model continues to be useful

and has been adopted by several mobile learning studies (Crompton, 2015; Zaranis, Kalogiannakis, & Papadakis, 2013).

Thirty years since the wide adoption of computers in the classroom, theories of technology supported learning in mathematics have flourished, but the focus of having a grand theory for mathematics education has shifted to that of having multiple theories to understand mathematics education. Drijvers et al. (2009) argue that “no single theoretical framework can explain all phenomena in the complex setting of learning mathematics in a technology-rich environment (p.121)” and this is the stance that this dissertation takes on adopting a mathematics based theoretical framework.

### **Theories of Mobile Learning**

Before discussing theory, it is important to give a definition of how this study interprets mobile learning. Although the history of mobile learning as a field is relatively short compared to other forms of technology enhanced learning, its definition has evolved over the past two decades. Early definitions of mobile learning present itself as an offshoot of elearning in a technocentric view, for example, Quinn (2000) defined it as “the intersection of mobile computing and e-learning,” while more recent definitions highlighted the mobility of the learner. Crompton (2013) defined mobile learning as “learning across context, through social and content interaction, using personal electronic devices (p.4)” More recent mobile learning studies particularly those in school based settings tend to agree with the former definition (Pope & Mangram, 2015; Riconscente, 2013). Systematic reviews (Crompton & Burke, 2015; Sung et al., 2015) also tend to focus on the type of device used rather than the context of the learning activity. Sharples (2013) argued that a definition of mobile learning should capture the dual perspective of learner mobility and learning with portable technologies and refers to the study of O’Malley et al. (2005) as one that captures this. O’Malley and colleagues defined mobile learning as “any sort of learning that happens when the learner is not at a fixed, predetermined location, or learning that happens when the learner takes advantage of the learning opportunities offered by mobile technologies (p.7).” While Crompton’s definition is the more recent definition of mobile learning, the definition puts emphasis on the mobility of the learner and is less relevant to the design of the current study. O’Malley et al.’s definition, on the other hand, is more inclusive in their definition by also considering the use of mobile devices in non-mobile settings.

Several studies have classified ways by which mobile technologies can be used in educational settings. Naismith, Lonsdale, Vavoula, & Sharples (2004) took an activity-centred perspective to classify mobile technology use: behaviourist, constructivist, situated, collaborative, informal and lifelong, and learning and teaching support. The first four items have been discussed at length in e-learning literature (for example, Mayes & De Freitas, 2004) and also in the previous section. Informal and lifelong learning refers to mobile learning activities that support learning outside the formal curriculum. Examples of this include the plethora of language learning applications on mobile phones or the use of phone sensors to gather data from the environment. Learning and teaching support are activities with mobile devices that assist in the coordination of learners and resources for learning activities. Studies of this nature are not common place these days as this has somehow been embedded in practice (for example, sending out school wide announcements via messaging systems).

Patten, Sanchez, & Tangney (2006) built on Naismith and colleagues' theory-based categories by looking at mobile technology use in terms of functionality and pedagogy. These categories are: administrative, referential, interactive, microworld, collaborative, location aware and data collection. Figure 2-1 is a mind map of the different categories and provides examples of use. The items on the right-hand side of the figure are functions that replicate the functionalities of traditional desktop computers while the ones on the left (collaborative, location aware, data collection) are functions that take advantage of the unique feature of mobile devices. For example, in Boticki, Looi and Wong 's (2010) study, each student is assigned a mobile device. The mobile device allocates each student with a fraction. The task was for students to form a group with other students so that the sum of their fractions was one. The condition of the game was that every student should belong to a group. If one student doesn't find a group, then even if the rest of the class has managed to form a group, the groupings should reshuffle to meet the condition of the game. The class activity completed only when each student belonged to a group. In this example, the game mechanics is being handled by the mobile device but there is also collaboration happening at social level. These functional pedagogical categories are discussed later in this chapter in light of maths and mobile learning literature.



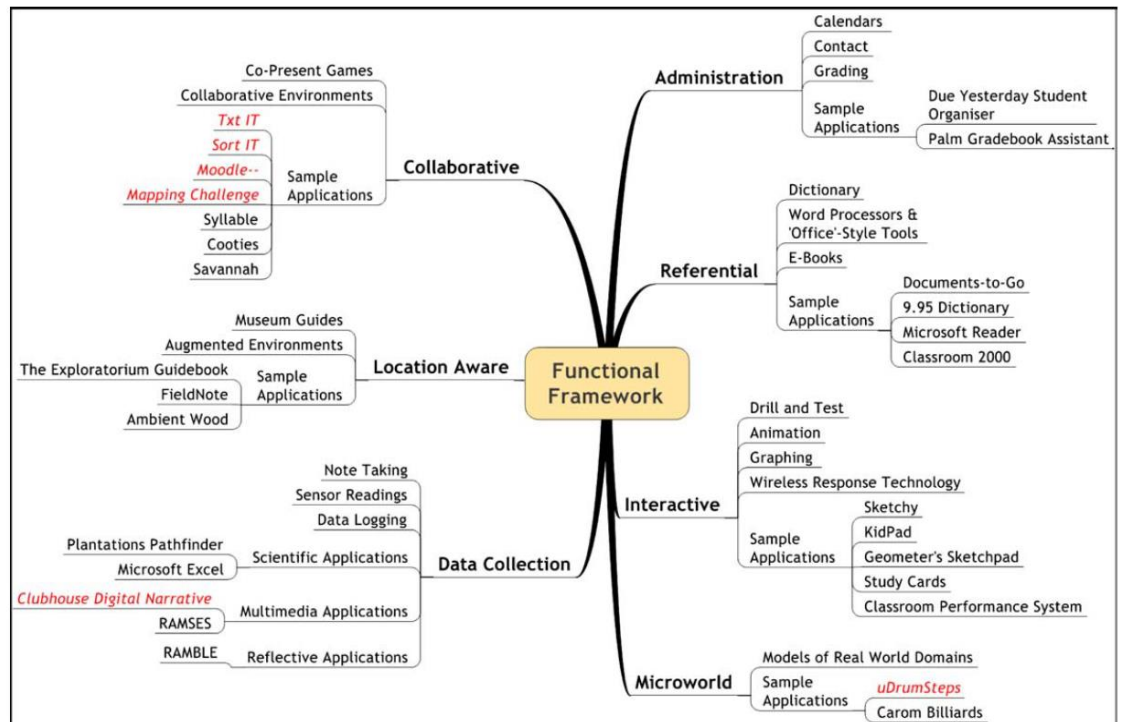


Figure 2-1. Functional framework of technology use (Patten et al., 2006, p. 296).

The SAMR Model (Puentadura, 2006) is a framework that categorises the level of technology adoption into substitution, augmentation, modification, and redefinition. Naismith et al. and Patten et al.'s categorisations provided frameworks for categorising the activities by pedagogical design. This model, on the other hand, categorises the impact of introducing the technology into an activity. A diagram of this model is shown in Figure 2-2. The first two levels show how learning technologies can be used to enhance learning activities, while the latter two show how technologies can transform the learning tasks. This model, while not specifically created for mobile learning, has been used in several mobile learning studies (Burden, Hopkins, Male, Martin, & Trala, 2012; Fabian & MacLean, 2014), and has been a useful reflection tool to gauge how technologies add value to non-technology based learning activities.

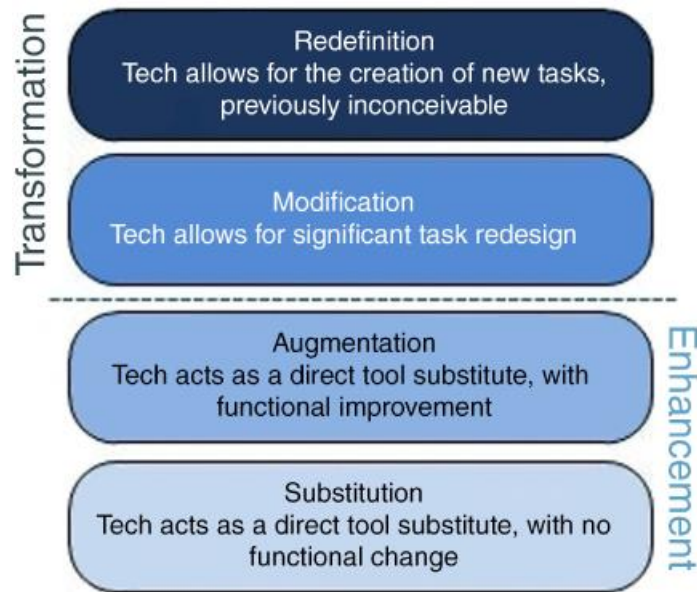


Figure 2-2. SAMR model of technology integration (Puentadura, 2006)

There are other notable mobile learning frameworks that have emerged in the past five years. Park's (2011) adaptation of Moore's (1997) transactional distance theory into mobile learning categorised four types of activities that can be carried out on mobile devices: high transactional distance, individualised activity, high transactional distance socialised activity, low transactional distance individualised activity and low transactional distance socialised activity, where transactional distance refers to the immediacy of communication between participants. Kearney, Schuck, Burden, & Aubusson's (2012) framework highlighted the socio-cultural features of mobile learning and through this framework, identified three key features of mobile learning: authenticity, collaboration and personalisation. There are also mobile frameworks targeted for specific groups, for example, Ng & Nicholas's (2013) model for sustainable mobile learning in school settings, Nordin, Embi, & Yunus's (2010) mobile learning framework for lifelong learning. These frameworks are mentioned to show the growing literature of mobile learning and to emphasise that there are various ways to characterise a mobile learning activity.

Mobile learning, being a relatively new field, is short on theory in the same way that elearning theories had been sparse during the first decade of its introduction into schools. Mayes & De Freitas, (2004) noted that “there are really no models of e-learning per se – only e-enhancements of models of learning (p. 4)” and this is at present the same for mobile learning theories. Some of the theories underpinning mobile learning studies include: behaviourism, cognitivism, constructivism, situated learning,

collaborative learning, socio-cultural theory and many others (Keskin & Metcalf, 2011). These learning theories are not exclusive to mobile learning but have been discussed in terms of how these theories were applied or adapted considering the mobility of the devices and mobility of the learner.

Constructivist learning has already been mentioned in the maths section of this chapter. Its application to mobile learning literature is just as prominent as it is in maths learning literature. Naismith et al. (2004), in their earlier framework of mobile learning, have constructivism as one of the categories to describe a mobile learning activity. Rather than adapt the more general form of constructivism, most mobile learning literature refers to social constructivism. For example, Cochrane (2014) in their review of mobile learning literature underlined social constructivism as a fundamental theory for research projects. Mobile technologies support constructivist learning through active learning activities (Wijers, Jonker, & Drijvers, 2010), immersion in authentic environments (Sommerauer & Müller, 2014), and learner-generated context (Bray, Oldham, & Tangney, 2013). Moreover, mobile devices are “inherently social collaboration and communication devices that provide powerful tools for enabling social constructivist pedagogy” (Cochrane, 2014, p. 72).

One of the highlights of mobile learning research is the context and setting of the learning environment. For example, Frohberg, Göth, & Schwabe's (2009) review of state-of-the-art mobile learning studies included mobile learning activities in both formal and informal learning environments like museums, rivers, forests, towns, among many others. These rich contexts facilitated several studies designed within the situated learning framework (Kurti et al., 2008; Rehm et al., 2015; Sommerauer & Müller, 2014). Situated learning theories emphasise that knowledge and cognition cannot be separated from context and calls for authentic learning environments (Lave & Wenger, 1991). This has a lot of similarities with RME model discussed previously. In computer based learning environments, examples of applications of this framework are in microworlds, virtual reality, and simulations (Herrington & Oliver, 1995). Of course, microworlds are not real world either, by the process of abstraction and simulation the authenticity of the environment is compromised. In mobile learning environments, these representations move to the real world. As discussed previously, mobile devices can capture data from the environment with its built-in sensors, camera and communication tools and these features help facilitate learning activities designed with the situated learning framework by allowing learning to take place in authentic context.

For example, in Tangney et al.'s (2010) study of mobile learning activities based on the Realistic Mathematics Education principle, one of the activities used the mobile device to measure the height of an object, and in this instance the technology use was situated within the problem that the students were trying to work out and was therefore authentic.

Aside from the more widely acknowledged theories like the two listed above, there are two other theoretical frameworks for evaluating mobile learning: Laurillard's (2007) conversational framework and Sharples, Taylor, & Vavoula's (2007) Task Model. Laurillard (2007) conversational framework, though not specifically designed for evaluating mobile technology use was adapted to provide a framework of analysing the pedagogical process of mobile learning activities. This framework draws from Pask's (1975) conversation theory and shows the different roles technology plays in facilitating discourse between teacher and learners (refer to the numbered items in Figure 2-3.)

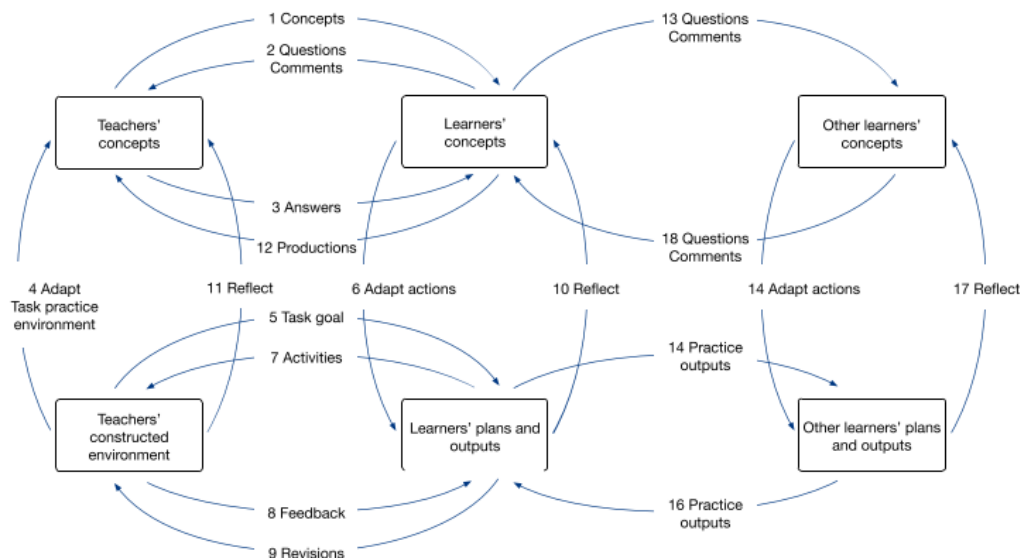
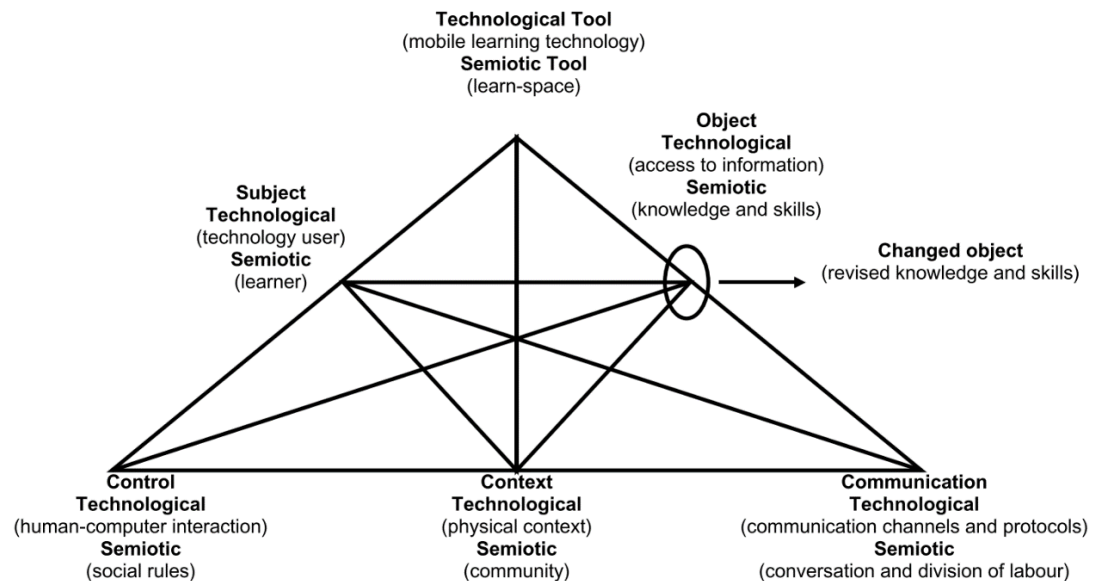


Figure 2-3. Conversational framework model (Laurillard, 2007).

Sharples et al.'s (2007) Task Model provides a framework for analysing the role mobile technologies play in mediating learning activities. This model, which has been noted extensively in mobile learning literature (for example, Eliasson, Nouri, Ramberg, & Pargman, 2010; Frohberg, Göth, & Schwabe, 2009), draws from Engestrom's (1999) activity theory. Figure 2-4 provides a diagram of this model. The upper part of the triangle are the typical elements of a learning activity: subject (the learner), tool, and object (learning objective) while the three elements (control, context, and

communication) at the bottom refer to factors that influence the interaction of the first three. With the many connections branching off from a single element, this shows how one factor is affected by another, where a change in one setting will trigger an effect to the other elements. However, a criticism of this model is its difficulty to be operationalised in practice (Cochrane, 2014) and as such it will not be adopted further in this study. Instead, this dissertation adopts the more generic constructivist learning theory as a framework to inform the design of the mobile learning activity.



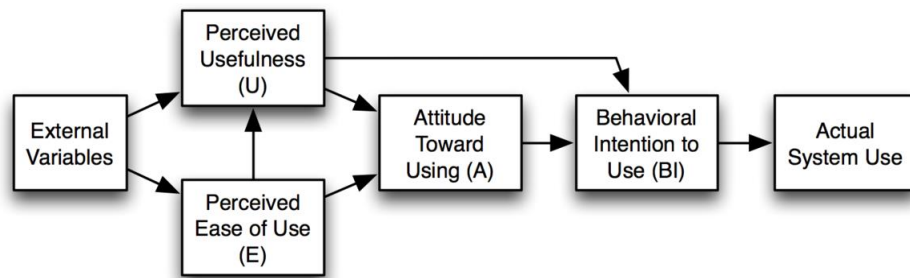
*Figure 2-4.* Task model of mobile learning (Sharples et al, 2007).

### **Technology Acceptance Model**

Early mobile learning studies tend to focus on user acceptance. Hwang & Tsai (2011) in their review of mobile learning studies between 2001 to 2010 found that majority of the studies focused on student perceptions of mobile use. Technology acceptance models built on these studies in their effort to understand how and why users come to use technology.

Davis's (1989) Technology Acceptance Model (TAM) focuses on two constructs that explain and predict technology use: perceived usefulness and perceived ease of use. Davis's model describes that users tend to use technology they consider useful (perceived usefulness), but this belief must be coupled with the perception that the benefits will outweigh the effort of using the technology (perceived ease of use). These two constructs provide a direct link to usability evaluation (Morris & Dillon, 1997). Davis believes these perceptions about usability affect the users' attitudes towards

technology and consequently their intention to use it. An illustration of the technology acceptance model is shown in Figure 2-5.



*Figure 2-5. Technology Acceptance Model (Davis, Bagozzi, & Warshaw, 1989)*

A modification of Davis's TAM is Venkatesh, Morris, Davis, & Davis's (2003) Unified Theory of Acceptance and Use of Technology (UTAUT). UTAUT adds two additional factors that affect behavioural intention to use: social influence and facilitating condition. Social influence refers to the degree to which a user cares about how others will perceive them. Facilitating conditions refer to the user's belief of support available, either in terms of technical infrastructure or organisational support, to enable system use. The four factors are moderated by gender, age, experience and voluntariness of use. For example, perceived usefulness is affected by the user's gender and age while facilitating conditions are affected by the user's age and experience. Unlike TAM, UTAUT does not include the variable attitude but rather forms a direct link between perceived usefulness/perceived ease of use to behavioural intention to use. Both TAM and UTAUT have been used in several mobile learning studies (MacCallum & Jeffrey, 2013; Tavernier, 2016; Wang, Wu, & Wang, 2009). This study, however, does not have the construct behavioural intention as this was an evaluation of actual use. Consequently, this study adopted Davis' (1989) TAM but also acknowledged UTAUT's moderating factors as elements that affect attitudes towards use.

### **Critical Success Factors**

Critical success factors (CSF) refer to elements necessary for a project to succeed. In mobile learning literature, a few CSFs have been noted. An early version of CSF in mobile learning is the work of Naismith & Corlett (2006) based on pilot projects pre-2005. They note that availability of technology, ownership, connectivity, integration and institutional support are factors that make mobile learning implementations

succeed. Cochrane (2010a) examined 15 mobile learning projects from 2006-2009 and identified the following success factors:

- level of pedagogical integration
- level of lecturer modelling of pedagogical use of the tools
- appropriate choice of mobile devices and software
- creating a supportive learning community
- technological and pedagogical support
- allowing time for developing an ontological shift for the lecturers and students.

A criticism of this success factor is its age. Mobile learning studies have come a long way since 2009 and while the six factors still appear to be relevant, new literature may point to additional factors. A more recent CSF was from a meta-analysis of 19 mobile learning studies published between 2007 to 2015 (Alrasheedi & Capretz, 2015). The study identified six CSFs: user friendliness of design, technical competence of students, learner community development, learner's perceptions, content, and ownership. These success factors can be compared and validated against each other as shown in Table 2-1.

Table 2-1

*Critical Success Factors mapped into each other*

<b>Cochrane (2010a)</b>	<b>Naismith &amp; Corlett (2006)</b>	<b>Alrasheedi &amp; Capretz, (2015)</b>
Allowing time for developing an ontological shift, both for the lecturers and the students.	Ownership	Ownership Development of technical competence of students
Creating a supportive learning community	Institutional Support	Learner community
Technological and pedagogical support	Availability of technology Institutional Support	Development of technical competence of students
Appropriate choice of mobile devices and web 2.0 social software.	Integration	Content User friendliness of design
Level of pedagogical integration of the technology into the course criteria and assessment.	Integration	Content

Although Alrasheedi and Carpetz's CSF, is the more recent one, some of the success criteria are somewhat ambiguous. So, Cochrane's CSF is adapted in this study,

but with some of the factors from Alrasheedi and Carpetz's merged into the criteria heading. This leads to the following reworded success factors:

- *Appropriate choice of mobile devices and software and user friendliness of design.* Usability is a recurring feature in teacher guides for selecting mobile applications for the classroom (Mahon, 2014). In a large scale review of maths educational applications available for mobile devices (Larkin and Jorgensen, 2016), the criteria also included elements of usability (i.e. age appropriateness, clear instructions, technical features). Kukulska-Hulme (2007) discussed that technical difficulties affect the users' collective experience and technical issues "will be tolerated only under certain very limited conditions" (Wagner, 2005, p.9).
- *Level of pedagogical integration of technology into the course.* This criterion relates to the design of learning activities for mobile learning. This includes elements like authentic contexts and active learning activities (Cochrane, 2010a).
- *Level of lecturer modelling and development of technical competence of students.* Cochrane (2010a) defines lecturer modeling as something that relates to creating a Zone of Proximal Development (ZPD), the difference between what a learner can do with help from adults/capable peers and what a learner can do on their own. This process involves provision for access to expert performances, worked examples and the modelling of processes (Herrington, Reeves, & Oliver, 2009).
- *Technological and pedagogical support (including learner community).* The previous success partially covered initial training in the form of teacher modeling, but while an initial technology training is useful in mobile learning adoption, ongoing technological support and a peer buddy system are just as valuable (Nerantzi, Wilson, Munro, Lace-Costigan, & Currie, 2013).
- *Allowing time for ontological shifts.* Cochrane (2010a) explains that ontological shift, the reconceptualization of teaching and learning, requires time from both the lecturer and the student for them to become comfortable with using new technologies for enhancing their course.

These success factors will later be used to analyse how the studies have met these criteria. The next section covers the empirical framework and the systematic review of maths and mobile learning studies.



## **Empirical Framework**

### **Student Attitudes**

Student attitudes to mathematics is one of the popular topics in mathematics education research (Di Martino & Zan, 2015). Attitudes has been recurrently defined in terms of positive and negative feelings associated with maths (Hannula et al., 2016) and this definition aligns with Aiken's (1970) definition of “a learned predisposition or tendency on the part of an individual to respond positively or negatively to some object, situation, concept, or another person” (p. 555). Several studies suggest that attitudes towards mathematics is a multi-dimensional construct (Di Martino & Zan, 2010; Tapia & Marsh, 2004) but these constructs are dependent on the instrument being used (Hannula et al., 2016). Tapia & Marsh’s Attitudes Towards Mathematics Inventory Scale (ATMI), whose constructs were derived from a review of previous research, include: confidence, value of mathematics, enjoyment and motivation. Di Martino & Zan’s three-dimensional model for attitude (TMA) was created from a grounded theory approach and includes an emotional disposition towards mathematics, vision of mathematics (perception of maths as a subject) and perceived competence in mathematics. Di Martino & Zan’s model is similar to that of Tapia & Marsh excluding the motivation construct. Given the similarity of the two models and the more established use of Tapia & Marsh’s instrument in mathematics education research, this dissertation adopts Tapia and Marsh construct for attitudes.

Evidence on the effect of technology use on students attitudes towards mathematics is limited (Li & Ma, 2010) and available literature points to inconclusive results, depending on the technology used, teaching strategy involved and length of intervention. For example, in technology supported game-based learning, there are studies that reported a positive change in students attitude (Afari, Aldridge, Fraser, & Khine, 2013; Chen, Liao, Cheng, Yeh, & Chan, 2012) while there are studies that found no significant change in attitudes to mathematics (Kebritchi, Hirumi, & Bai, 2010). Afari et al. (2013), in their six-week game based intervention, found that students who used mathematics games had significantly more positive attitudes to mathematics after the intervention but the effect size was small (ES was between .12 - .18). The study also found that students’ enjoyment of mathematics was greater in classrooms with more teacher support, cooperation and personal relevance (value of mathematics). Kebritchi et al. (2010), in their 18-week game-based learning intervention, found no significant

improvement in students' motivation to study maths but found significant differences in motivation scores depending on where it was played. Students who played in the classroom and computer laboratory had higher motivation scores as compared to those who played games only in the computer laboratory or those who didn't play games. Still, such change cannot be attributed to location alone as the amount of game exposure also plays into this. Student interviews, on the other hand, showed positive student perceptions about the game based learning environment. This finding highlights that positive student perception about the intervention does not necessarily link to positive gains in student outlook towards math. On the other hand, attitudes are formed over time and so are attitude changes. While there are short term studies that produced attitude changes (Afari et al., 2013), this has not always been the case and neither should it be expected for short term interventions. The positive changes in attitudes in short term interventions are also possibly explained by novelty effect. In fact, in Hilton's (2016) two year longitudinal study of using iPads in the classroom, attitude change was only observed at the end of the second year.

Studies that employ learning environments that include other forms of interactivity (e.g. virtual manipulatives or videos) also had varying results in terms of student attitudes. Olsen (2016) used a web-based interactive maths lesson for 10 weeks and found that the change in students' attitudes before and after the web-based learning activities was not statistically significant. However, student perception about the use of this technology was tending to a negative perception with only 9% of the sample having positive attitudes towards it. Furthermore, no link was found between technology use and students' attitudes to math. In contrast, Yang & Tsai (2010), in their four weeks intervention, found a significant improvement in the experimental group's attitude to maths as opposed to those who were taught without the computer visual aids. The examples given in this section showed the varying results of studies relating to student attitudes towards maths in technology enhanced learning environment. It has also shown that student positive attitudes towards technology does not always link to better attitudes towards math.

Gender is said to be one of the factors that plays a role in attitude towards mathematics. An early meta-analysis of students' attitudes and gender effect found significant differences in boys and girls general attitude towards maths and self-confidence, and that this difference increased with age but the magnitude of this difference was only small (Hyde, Fennema, Ryan, Frost, & Hopp, 1990). A meta-

analysis of the Trends in International Mathematics and Science Study (TIMSS) by Else-Quest, Hyde, & Linn (2010) found that boys tend to report higher self-confidence in maths and value of maths than girls but the magnitude of this difference is small ( $d=.15$ ). Another large scale study from the Organisation for Economic Cooperation and Development (OECD) (OECD, 2015), found that in their worldwide study, Programme for International Assessment (PISA) 2012 of 15-year olds, girls have lower maths self-concept or belief in their own maths abilities in comparison to boys. Girls were also found to have higher levels of maths anxiety than boys in most of the countries included in the study. Girls are less confident with mathematics than boys, particularly in applied mathematics scenarios that contain gender stereotypes. For tasks that are abstract, gender differences in confidence were not observed. This research also highlights the role of context in how students perceive their confidence in learning math.

As discussed earlier, change in attitudes to mathematics as a by-product of computer use is limited and as such, studies on gender difference in attitudes to maths and computers is even more limited; sometimes with contrasting results. Miller & Robertson (2011) found that gender was not a factor that affected students change in mathematics self-concept after a game-based intervention for nine weeks. On the other hand, Sáinz & Eccles (2012) found that male gender differences become more pronounced after enrolling in ICT-related studies. A literature search on “attitudes AND math AND technology AND gender difference” led to studies on gender difference in perception of technology use in mathematics rather than gender difference in attitudes. In this regard, findings suggest that male students tend to have higher perceptions about the value of computer use than female students (Barkatsas, Kasimatis, & Gialamas, 2009; Reed, Drijvers, & Kirschner, 2010).

### **Achievement**

The use of technology in mathematics education has been discussed by researchers over the past thirty years. In the US, the National Council of Teachers of Mathematics (2000) considered technology as “essential in teaching and learning mathematics” (p. 3). Scotland’s Curriculum for Excellence (Education Scotland, n.d., p. 40) noted that “use of technology in appropriate and effective ways” allows for learning experiences that promote enjoyment of mathematics. Endorsements from these organisations highlight that technology has a positive role to play in mathematics

education. The literature has a lot of primary studies in terms of the effects of technology in mathematics achievement/performance, varying with the type of technology use and pedagogy (Slavin et al., 2009). However, primary studies tend to show differing results and so, systematic reviews are considered instead to provide an overall background of the effect of technology use on student achievement. Findings of the systematic reviews are summarized in Table 2-2 below. Overall, there is a small to moderate effect of technology on maths achievement. A recent review commissioned by the Scottish Government (ICF Consulting Services Ltd, 2015) confirms this. This study also stressed the roles of teachers in harnessing technology potential. Yet, while there is considerable evidence that technology has a positive effect on student achievement, the review studies also noted how different approaches to technology use tend to yield different results. It is the goal of this research to focus evaluation of the use of mobile technologies.

Table 2-2  
*Summary of review studies*

Study	Scope	Findings
Li & Ma (2010)	46 studies 1990 - 2006	<ul style="list-style-type: none"> <li>• There was a small effect of technology (<math>d=.28</math>) on mathematics achievement.</li> <li>• Elementary studies showed larger effects than high school studies.</li> <li>• Constructivist approach to teaching had stronger effects of technology as opposed to traditional teaching.</li> </ul>
Tomic & Divjak, (2011)	27 studies 1995-2010	<ul style="list-style-type: none"> <li>• Studies that employ game-based learning strategies mostly have positive results in terms of student achievement (21 out of the 27 sample)</li> </ul>
Cheung & Slavin, (2013)	74 studies 1980-2010	<ul style="list-style-type: none"> <li>• An overall weighted effect size of .16 was computed for the 74 studies.</li> <li>• The effect size for elementary studies was higher than high school studies.</li> <li>• Programs that were used between 30-75 minutes per week had higher effect sizes than those used that used outside that range.</li> <li>• Effect varied with the nature of technology use.</li> </ul>
Chan & Leung, (2014)	9 studies 2001 - 2013	<ul style="list-style-type: none"> <li>• The use of technology for geometry (dynamic geometry systems) was more effective than traditional approaches with an effect of 1.02.</li> </ul>
Chauhan (2016)	41 studies 2000 – 2016	<ul style="list-style-type: none"> <li>• An effect size of .47 was computed for the 41 studies included in the review.</li> <li>• Other findings, such as effect of length of study, grade level, etc. were presented but this includes findings from other subject domains so this is not reported here.</li> </ul>

### **Systematic Review of Maths and Mobile Learning Studies**

Petticrew & Roberts (2008, p.9) defined systematic reviews as "literature reviews that adhere closely to a set of scientific methods that explicitly aim to limit systematic error (bias), mainly by attempting to identify, appraise and synthesize all relevant studies (of whatever design) to answer a particular question (or set of questions)." There are two systematic reviews conducted as part of the literature review, one covered a 10-year period carried out to inform the initial design of the research study, the other covered a shorter time frame (2013-2016) carried out to help identify how the results of the research study align with more up-to-date research. The research questions for the two systematic reviews were "How have mobile technologies been used for mathematics?" and "To what effect were mobile technologies useful for learning mathematics?" The screening processes for the two reviews were slightly different and so, the results are presented separately. The 2003-2012 review was published by Fabian, Topping and Barron (2015). The systematic review was part of the PhD work and the paper was written during the course of the PhD. As such, it contains a lot of similarity with the version below.

#### **Maths and Mobile Learning (2003-2012)**

At the start of this PhD journey, systematic reviews of mobile learning were not abundant and hard evidence on the use of mobile technologies for mathematics was patchy and limited. For instance, in Hwang & Tsai's (2011) review of mobile learning studies from 2001-2010, only six maths studies were identified while a further review of studies between 2008-2012 had only seven (Hwang & Wu, 2014). Both reviews only searched in high impact journals and did not consider conference papers. Wu et al.'s (2012) wider search of mobile learning literature from 2003 – 2010 in indexing databases identified only three. These three reviews were about mobile learning in general, and so, the implications of using mobile technologies in mathematics were not identified. At the time this review was conducted, there was no published maths and mobile learning systematic review that existed so it was the purpose of this review to bring together the research findings that exist.

Specifically, the review aims were as follows:

1. To create a descriptive map of research on mobile technology use and mathematics
2. To evaluate student attitudes towards mobile technology

3. To synthesise forms of engagement in using mobile technologies
4. To evaluate the effectiveness of mobile-supported activities in terms of student achievement

It is important to note that this review focused only on a subset of mobile devices, specifically mobile phones, handheld gaming consoles, pocket digital assistants (PDA) and tablets, as these are the mobile technologies more commonly associated with mobile learning.

**Systematic review methodology.** The systematic review was conducted following the approach recommended by the (Evidence for Policy and Practice Information and Co-ordinating Centre (2007)). The following section outlines the procedures undertaken:

***Searching and screening for studies.*** This review included a search of math-related mobile learning projects and research published between 2003-2012. The search process is illustrated in Figure 2-6. In Cluster 1, indexing databases (Directory of Open Access Journals, Education, Information Technology Library, EBSCO, Proquest, Scopus and Web of Knowledge) were used to search for relevant studies. The keywords used were mobile, learning, mathematics and its associated terms (for a full list of keywords used, refer to Appendix A). All matches retrieved were recorded as bibliographic entries. Duplicates across and within indexing databases were removed.

The abstracts were then screened and coded using the Exclusion Criteria (see Table 2-3). An external reviewer coded a sample of the abstracts independently. The inter-rater agreement was 92%. The disagreements were mostly about what constituted mobile technologies and were resolved by clarifying the definition of mobile technologies. Abstracts of studies with insufficient information were included to be processed in the next stage. Full-text versions of all remaining studies were retrieved. The studies were then filtered using the Inclusion Criteria.

Cluster 2 involved manual searching and looked for publications in specialised journals and conferences on mathematics education as well as mobile learning. Networks of organisations with an interest in mobile learning were also checked for possible studies. Studies from Cluster 3 were identified through the math-related references cited from studies in Cluster 1 and 2. Full texts of these citations were spot checked and processed using the inclusion criteria.

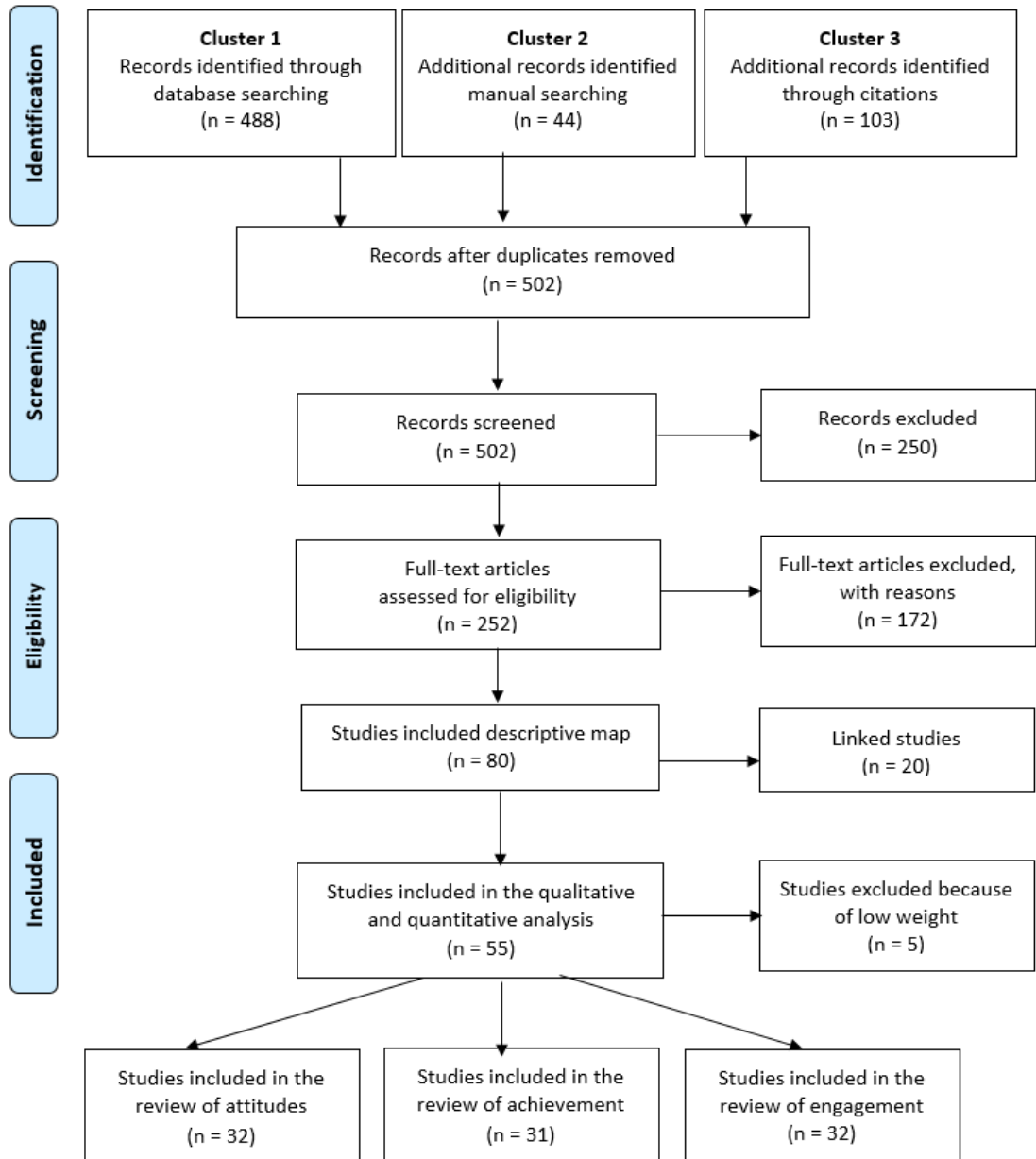


Figure 2-6. Modified PRISMA flow diagram

Table 2-3  
*Exclusion and Inclusion Criteria*

Exclusion criteria	Inclusion criteria
1. Non-empirical studies	1. Papers in various forms: a case study, an experimental/quasi-experimental design, a design-based research and a report of a research study
2. Non- K-12 (Kindergarten- Grade 12) participants	2. Studies conducted on K-12 (kindergarten through Grade12)
3. Studies that used other mobile devices (e.g. laptops, calculators, GPS)	3. Mobile devices used were any of the following: PDA, mobile phone, tablet, iPod® touch, handheld gaming devices
4. Mobile learning studies on a different subject	4. Student participants used a mobile device as part of a maths learning activity in a formal or informal learning environment
5. Non-English	5. Outcomes report how the mobile device affected mathematics learning, either in terms of student perceptions, student engagement, attitude towards mathematics or student achievement

***Describing and mapping of studies.*** The methodology and key characteristics of each of the included studies (such as country of publication, nature of activity with the mobile device and participant characteristics) were mapped into a table as shown in Appendix B. This process created a descriptive map of studies that used mobile technologies in mathematics and helped address the first objective of this systematic review.

***Quality and relevance appraisal.*** The studies were appraised for quality and relevance by adopting Davies et al.'s (2013) rubric. The rubric judges the quality of the article at three levels: methodological quality, methodological relevance and topic relevance in a scale of 1 – 4 with 1 being inadequate and 4 being excellent. For example, research with a design that justifies all decision taken gets a rubric score of 4



for excellent methodological quality whereas a research design that contains flaws would have a rubric score of 1 for being inadequate. The score for each section in the rubric is added and the total score is translated into weights using the following conversion: 3 – 5: low; 6 to 10: medium; 11 - 12: high. Using the rubric, five studies (Kong, 2008; Mahamad, Izzriq, Foad & Taib, 2008; McCabe & Tedesco, 2011; Song, Kim, & Karimi, 2012; Wu & Zhang, 2010) were excluded as they did not fully match the research objectives. Of the 55 studies remaining, eight studies were categorized as highly relevant (Main & O'Rourke, 2011; Miller & Robertson, 2010, 2011; Roberts & Butcher, 2009; Roberts & Vänskä, 2011; Rosas, Nussbaum, Cumsille, Marianov, & Lo, 2003; Zurita & Nussbaum, 2004; Zurita, Nussbaum, & Shaples, 2003), while the rest of the studies were categorized as either good or satisfactory and were given medium weights.

*Synthesising study findings and data analysis.* The remaining studies were mapped into three learning outcomes (attitudes, engagement and achievement) to address objectives 2-4 respectively. Data were extracted from the study findings and are coded according to the three learning outcomes. In the attitudes and engagement sections, thematic analysis has been used to bring together the results of the individual studies. This involved coding data and developing themes common in the studies obtained from either the findings of the study or their primary data. For studies that discussed the effect on student achievement, these were sectioned into elementary, middle school and high school levels. These studies were then synthesised by meta-analysis and vote-counting.

Before presenting the findings, it is important to note some of the limitations of this review. One limitation is the lenient inclusion criteria in terms of sample size, duration of the intervention and quality of the study. As no systematic review on maths and mobile learning had been identified at the time of writing, it was felt that it would be better to include studies ranging from usability pilot tests to classroom implementations.

**Results.** The results are organised into four sections corresponding to the four objectives of this review: (1) descriptive map of research on mobile technology use for learning mathematics; (2) student attitudes and perception; (3) student engagement; (4) achievement.

*Descriptive map of research on mobile technology uses for learning maths.* There were 80 studies found between 2003-2012 that matched the inclusion criteria.

Published research consistently increased over the years, especially during the latter half of the decade, mostly through educational technology conferences and journals. On closer inspection, it appeared that some papers were referring to the same project. These papers are referred to as linked studies, reducing the total number of studies being considered to 60.

The United States topped the list of countries ( $n = 17$ ) that published maths and mobile learning studies, followed by Taiwan ( $n = 7$ ), then Sweden (see Figure 2-7). While it is unsurprising that the USA tops the list, it is interesting to see how mobile learning research is not confined to developed countries but also attracted publication from developing countries. The lower number of included studies in the United Kingdom was unanticipated in comparison to the overall number of publications of mobile learning studies in the UK. A number of pilot studies in the UK were school-wide implementations of tablets and PDAs, for example, the iPad® Report in Scotland (Burden et al., 2012) and so, data on mathematics were lost in the generalised report findings.

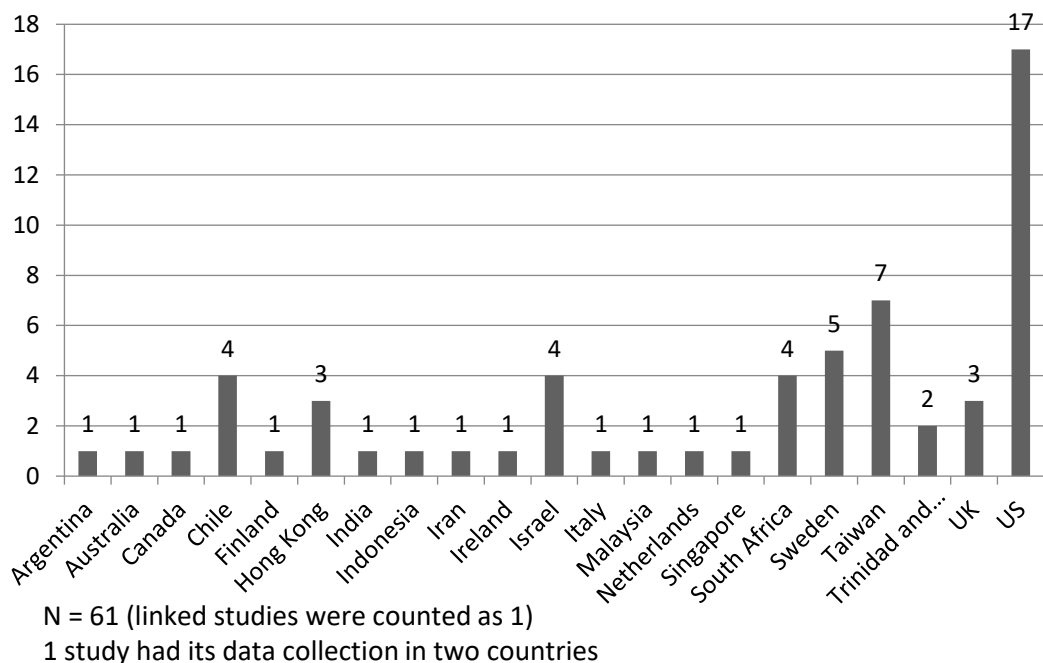


Figure 2-7. Distribution of studies on maths and mobile learning by country

The most frequently used mobile devices were mobile phones (25 studies), followed by PDAs (15 studies). More recently, the preferred mobile devices were tablets. There was a spike in tablets use, from one study in 2009-2010 to 10 studies in 2011-2012. This spike is partly explained by the arrival of relatively low-cost iPads® and Android tablets. Earlier maths and mobile learning studies (2003–2006) were

confined to creating or re-purposing bespoke applications for mobile devices. It was only in studies published in 2009 onwards where exploitation of off-the-shelf applications began.

The design of the interventions used in the studies was greatly variable in terms of sample size and duration of the intervention (see Table 2-4). Most of the studies presented results as a combination of the three outcome measures and so some studies were counted more than once. For example, Main & O'Rourke (2011) investigated both attitudes and achievement; hence this study was counted once under attitudes and again under achievement. There were 32 studies that discussed student attitudes, 31 studies on achievement and 32 studies on student engagement.

Table 2-4  
*Characteristics of the Included Studies*

Characteristic	Number of Studies
Level	
Elementary	30
Middle School	19
High School	11
Duration of the study	
Less than 1 week	11
Less than 4 weeks	13
Less than 10 weeks (or an academic term)	17
More than 10 weeks but less than year	8
One or more academic year	4
No data provided	7
Sample Size	
Less than 10	7
Less than 50	29
Less than 100	12
Less than 500	7
Less than 1000	3
More than 1000	1
Not specified	1
Learning Outcome Investigated	
Attitudes	32
Elementary	13
Middle School	10
High School	9
Achievement	31
Elementary	19
Middle School	6
High School	6
Engagement	32
Elementary	18
Middle School	9
High School	5

\* Note that studies that are weighted low are not included in the count for learning outcomes

*Charting the learning space.* A feature of mobile device often underlined in mobile learning studies is its capacity to support learners in a variety of learning activities as they move in and out of learning spaces. Figure 2-8 below charts the learning spaces where mobile devices were used for learning mathematics. Each quadrant represents a space where mobile technology use is taking place. A complete circle of the charting space means that the mobile device was used during class hours both indoors and outdoors and beyond regular class hours (whether indoors or outdoors). For example, if an arc is only drawn on the first quadrant, then it means that mobile technology use only occurred indoors and during class hours (although this does beg the question of whether time beyond class hours was supervised or unsupervised). Note that class does not necessarily mean the regular maths class that the students attend. It could also be the class that the researchers have set up as part of the study. The main element here is that there was a person in-charge over the group during that “class time”. Also, outside class hours and outdoors was an assumed arrangement particularly if the users were provided with mobile devices to use at home.

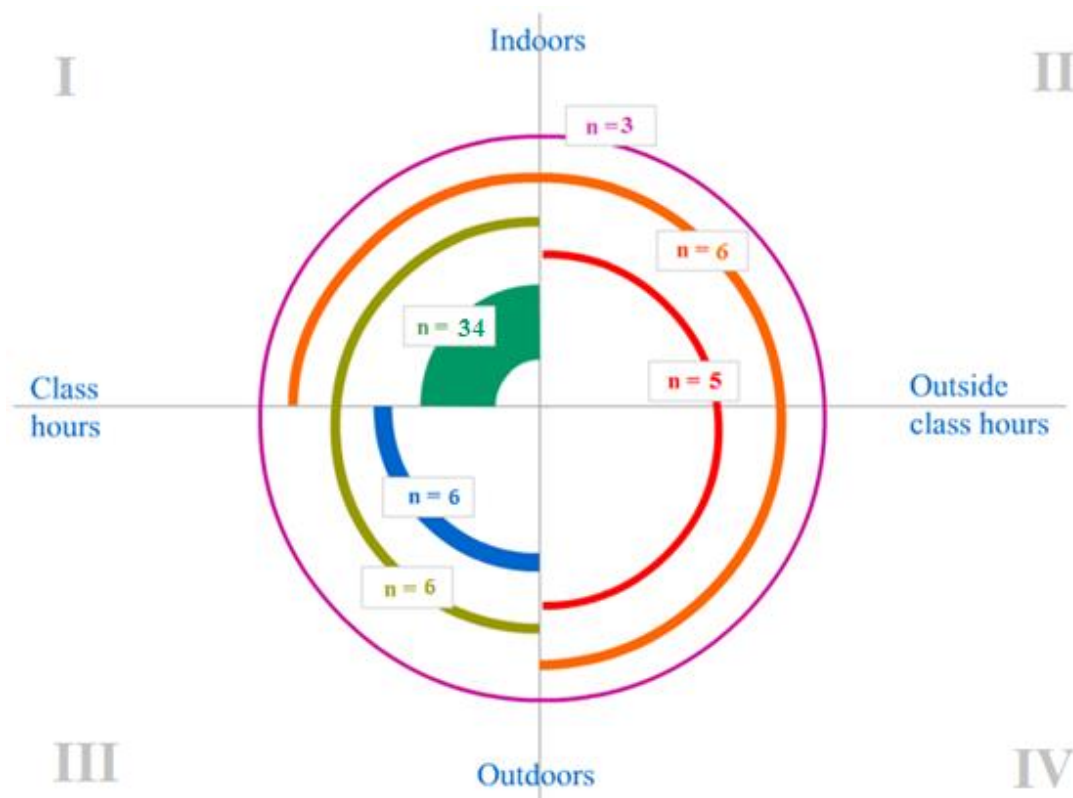


Figure 2-8. Graph of distribution of studies in terms of learning space.

(Note: The numbers on the arc represents the number of studies that were conducted in those learning spaces.)

What the figure above shows is that while most of the studies have underlined mobility as a feature of mobile learning, 57% (n = 34) of the studies have kept to using mobile devices in class indoors during class hours. That is not to say that the users were at a fixed location (*i.e.* on their seats) the whole time during the activity, as there were some forms of mobility in the classroom that mobile devices allowed in contrast to desktop computers.

About 25% (n = 15; Quadrant 3) of the studies employed the use of mobile devices during a guided maths activity outdoors, with 9 out of the 15 studies transitioning to or from a different learning space or quadrant. Some studies (23%, n = 14) allowed the use of mobile devices outside class hours either by providing the students with the hardware or providing them with the software they needed to be able to do some activities on their own mobile devices.

*Functional pedagogical use.* Patten et al. (2006) created a framework to categorise the educational uses of mobile devices. These were administration, referential, interactive, microworld, data collection, location-aware, and collaborative. What follows is a discussion of how the studies fell into these different categories.

- *Administration.* As Patten et al. (2006) have explained, uses of this nature have no or little pedagogy involved. In the two studies that used this function (Eliasson et al., 2010; Spikol & Eliasson, 2010), both used the mobile device to push information to students as they worked in the field. However, while there was no pedagogy involved, the studies showed how mobile devices can help organise outdoor learning environments.
- *Referential.* Referential uses of mobile devices usually involved both textual information and videos. In most examples, the contents were bite-size information and accessed on demand. For example, in Engel & Green (2011) students used their mobile phones to look up information on the internet as and when the need arose in class. The use of tablets to access enhanced textbooks (Jaciw, Toby, & Ma, 2012) is another example.
- *Interactive.* Scenarios of interactive use are mainly about eliciting interactions and giving feedback in game-like activities, maths manipulative and drill and practice exercises. This type of application is either available commercial-off-the-shelf (COTS) or made bespoke for the study. Examples of maths manipulative are not abundant and most studies used bespoke applications for their own study. There is

however, a wide adoption of drill and practice activities usually packaged in a game-like environment (Main and O'Rourke, 2010; Miller and Robertson, 2011).

- *Microworld.* Papert (1980) defined microworld as a "subset of reality or constructed reality whose structure matches that of a given cognitive mechanism so as to provide an environment where the latter can operate effectively (p. 204). Patten et al. (2006) acknowledge that there is a lack of microworld for handheld devices. In fact, of the 60 studies, none featured a microworld.
- *Data Collection.* Mobile devices have built-in functionalities that help capture information from the environment. Most of the studies used the phone camera for gathering data, both as still pictures and videos. A typical approach was using the camera to create video blogs (Engel and Green 2011). In some studies, the cameras were paired with the phone's sensors to measure the height of an infrastructure or the distance between two objects (Tangney et al., 2010). Other data collection activities were using Quick Response (QR) code readers to capture tagged information from the environment (Huang et al., 2012) or having students take pictures of objects that would represent a mathematics function (Baya'a & Daher, 2009; 2010). An advantage of the mobile device is that it provides students with an opportunity to use the outdoor environment as a medium to help visualise maths concepts. Also, it allows a streamlined process of content creation and sharing as facilitated by the networking capabilities of mobile devices.
- *Location-aware.* Mobile devices are typically equipped with built-in sensors like GPS and near field communication (NFC) receivers to allow communication between the environment, the mobile device, and the user. Examples of location-aware activities were the use of the phone's built-in GPS to measure distance between two locations (Spikol & Eliasson, 2010); the use of the GPS to geo-tag information, a process of associating information with a specific place (Shih, Kuo, & Liu, 2012); or the use of the GPS to identify the user location to create a gaming environment (Wijers et al., 2010). In these examples of location-aware activities, the outdoor learning environment provided the opportunity to create connections between maths and the real-world.
- *Collaborative Communication.* Collaborative activities in mobile devices are anchored to the mobile devices' communication features like short messaging system (SMS), voice communications, Bluetooth connectivity and wireless

network connectivity. The use of the mobile devices' communication tools for knowledge-sharing was a common feature in the studies. The devices facilitated communication among students and between students and teachers both inside and outside the classroom environment.

Figure 2-9 shows the distribution of studies by these categorical functions. Most of the studies used the mobile devices as a combination of several functions, with some studies having at most four differing tasks, although the most frequent combination was that of interactive and collaborative.

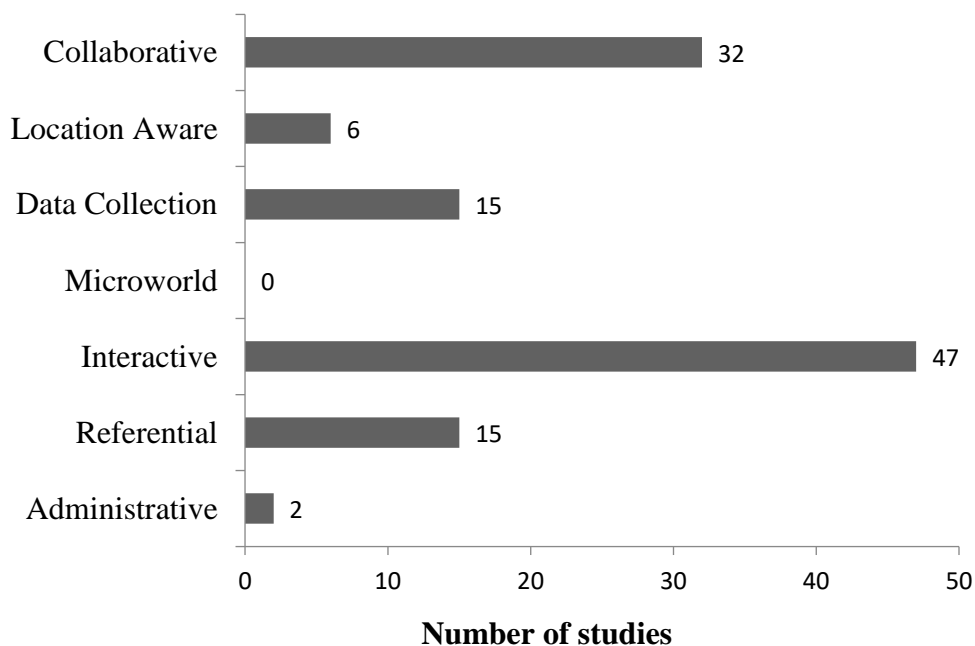


Figure 2-9. Distribution of studies categorised by functional use

*Learning strategies used.* The studies used various learning strategies to engage students in the mobile-supported learning activities. This covered both pedagogy and the interaction types that were utilised in the mobile learning activities reviewed. These were: direct or explicit instruction, drill and practice, formative assessment, game-based learning, visualisation of maths concepts, video creation or podcasting, collaborative learning, peer learning and inquiry or problem-based learning. Figure 2-10 shows the different learning strategies used in the studies.

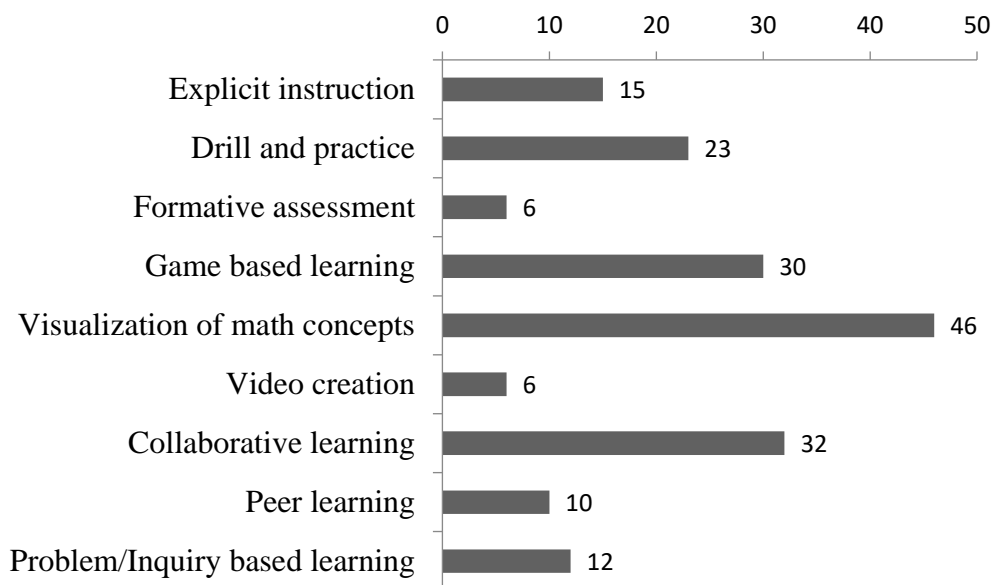


Figure 2-10. Distribution of studies categorised by learning strategy used

- Direct/Explicit instruction.* Explicit instruction involves a “teacher-centred classroom where the teacher delivers content to students in a piece by piece process” (Moran & Malott, 2004, p. 96). In a computer-supported environment, the technology takes the role of the teacher in providing direct instruction. Studies that fall under this category were those that used various forms of media to clarify and explain maths concepts. Other times, technology reverts to being the medium rather than the source as is the case in most SMS-based services (Amiratashani, 2010; Roberts & Butcher, 2009).
- Drill and Practice.* Drill and practice are characterised by the “systematic repetition of concepts, examples, and practice problems” (Lim, Tang, & Kor, 2012, p. 1040). Drill and practice on a mobile device are not entirely different to drill and practice on computers as both media are able to provide students with immediate feedback following an exercise. What makes mobile-based drill and practice different is the device’s form factor, allowing learners to make use of their idle time (like on bus rides, as was shown by van’t Hooft, Swan & Bennett, 2009) to practice maths. At the same time, in countries where computers are not as commonplace as mobile devices, the ability to deliver these practice exercises on a mobile device allowed students to work on maths exercises which would not have been available to them otherwise (Roberts & Butcher, 2009; Roberts & Vänskä, 2011)



- *Formative assessment.* Formative assessment is the “monitoring of progress during instruction that includes useful feedback, opportunities for improvement, and information helpful for tailoring future instruction” (Green, 2011, p. 661). One way of implementing formative assessment activities with mobile devices is by using the mobile device as a classroom response system, taking advantages of the networked feature of mobile devices allowing teachers to be synchronously connected to a student as they work on tasks. This gives teachers the chance to target specific skills and explain further depending on students’ progress (Engel & Green, 2011; Lan, Sung, Tan, Lin, & Chang, 2010; Liu, 2007). Alternatively, data logs on mobile devices can be sent to servers so that teachers will be able to monitor student progress (Kalloo & Mohan, 2011a, 2011b).
- *Game-based learning.* Game-based learning is learning facilitated by the use of games. Quite often, drill and practice takes the form of a game environment, but there are also other instances of mobile games that take advantage of the mobile devices’ form factor and connectivity. Examples of these are the co-located games discussed earlier. Another example is Wijers et al. (2010) study, where students play a game of creating quadrilaterals on an actual field with their movements, but their movements are tracked by the mobile device’s GPS. Of the 30 studies that used this approach, 19 were from the elementary level, 7 from middle school and 4 from high school. This shows that game-based learning approach was a design adapted regardless of the age group of the participants of the studies.
- *Visualisation of maths concepts.* Graphic representation of maths concepts is a typical approach to learning maths. Of the 60 studies included in this review, excluding the two studies excluded because of the nature of the activity (Mahamad et al., 2008; Wu & Zhang, 2010), only 12 studies did not make use of this approach. For example, Amiratashani (2010) made use of SMS to deliver formative assessment and hence could only display texts, while the Braintraining DS studies (Main and O’Rourke, 2011; Miller and Robertson, 2010, 2011) were drill and practice exercises and more about the quick recall of basic maths facts rather than maths concepts. Aside from the typical medium like videos and animation, mobile learning studies facilitated learning in real-world context, thereby, enabling visualisation of abstract maths concepts in its concrete, environmentally-situated form (Eliasson et al., 2010; Spikol and Eliasson, 2010).

- *Video creation or video podcasting.* The use of video creation allows learners to verbalise their understanding of a maths topic. However, the use of video creation for sharing (or video podcasting) makes video production more than a think-aloud process captured on video. This is because, with video podcasts, users are creating videos with the intent of having the viewer understand the topic rather than the user merely verbalising what he/she thinks. Six studies that employed the use of video creation all used mobile phones (Engel & Green, 2011; Franklin & Peng, 2008; Kim, 2011; Ligorio, 2008; Project Tomorrow, 2010, 2011). Mobile phones are equipped with video capture and networking capabilities allowing students to share their created videos on a shared portal.
- *Collaborative learning.* Collaborative learning occurs when “dyads or small groups have been engineered to share responsibility, authority, and learning outcomes” (Udvari-Solner, 2012, p. 631). To clarify, collaborative learning here is not synonymous to Patten et al.’s functional framework of collaborative use. There are instances of collaborative learning activities without a counterpart collaborative use (see Tangney et al., 2010). In these examples, collaborative learning was something happening outside the mobile environment. Examples of mobile supported collaborative learning activities are the shared decision-making activities in co-located games (Boticki et al.; Roschelle, Rafanan, Bhanot, & Estrella, 2010; Zurita and Nussbaum, 2007), the collaborative work of taking measurements in outdoor learning environments (Eliasson et al., 2010; Tangney et al., 2010) and game-based collaborative activities that required strategising and discussion (Goldman, Pea, & Maldonado, 2004; Wijers et al., 2010).
- *Peer-learning.* Topping (2005) defined peer learning as “the acquisition of knowledge and skill through active helping and supporting among status equals and matched companions” (p.631). Examples of peer learning in the studies included in this review are the creation of maths videos to be shared with other students as a reference material (Franklin & Peng, 2008; Project Tomorrow, 2010, 2011). Peer learning also happened in terms of students supporting each other during an activity, either in terms of technical support or the lesson content.
- *Inquiry/Problem-based learning.* Problem-based learning (PBL) occurs in learning environments with real-world settings that require students to solve problems (Jonassen & Hung, 2012). Inquiry learning, on the other is “a learning

process that requires learners to get involved in the learning process so that they can search for knowledge by questioning and investigating the matters” (Caliskan, 2012, p. 1571). A total of 12 studies were categorised under this theme, but most of them were PBL by design and only two were inquiry based (Baya'a & Daher, 2010; Song et al., 2012). A similarity in the design of these studies was the outdoor location of the learning environment (excluding Song et al.) The outdoor learning environment provided opportunities to create a connection between maths and the real world, as is the objective of PBL learning environment.

Collaborative learning activities, visualisation and game-based learning top the list of instructional strategies used in mobile learning activities (see Figure 2-5). Comparing these with the most frequent functional use of mobile devices earlier (see Figure 2-4), an alignment of the use of mobile devices in maths learning activities can be seen. Interactive uses of mobile devices are frequently in the form of drill and practice and game-based learning and most often associated with collaborative learning activities, either via the mobile environment or the social environment.

***Student attitudes and perceptions.*** The studies included in this section either focused on (a) student attitudes and perceptions towards mobile technologies or (b) student attitudes and perception towards math. The first group mostly covered the degree of acceptance of mobile technology for learning mathematics and the underlying reasons for accepting it while the second group focused on the change in student attitudes and perceptions towards mathematics as a result of the mobile-based activity. It was often difficult to identify if the study was referring to the mobile device per se or the mobile-supported activity. Thus, when the students evaluated the usefulness of mobile technologies for learning math, it was assumed that they were also evaluating the activity and not the mobile device on its own.

***Student attitudes and perceptions towards mobile technologies.*** There was a positive response towards mobile technologies for learning mathematics (except for Liu, 2007). Most of the studies reported that students liked the mobile-based activity to learn math, regardless of the age group. Studies in elementary schools were most likely to report that students found the activity enjoyable and the use of the mobile device easy. The middle school and the high school groups focused more on the value of the help the mobile-based activity brought rather than the activities being fun.

Novelty is a characteristic of all the studies and one that potentially affects student perceptions. Baya'a and Daher (2009, 2010) cited novelty as one of the reasons students

volunteered to engage in the mobile-based activity. Several more studies reported that the technology made learning mathematics more enjoyable (Lai et al., 2012). However, this can depend on context. In Roberts and Vänskä's (2011) study, students from affluent schools found the mobile-based tutorials "boring and not appealing enough, while those in poorer contexts had no such complaints" (p. 256).

Game-based learning and cooperative learning activities were another common factor that engages students. Ten studies implemented a game-based learning approach and all ten had positive responses. Participants of studies that employed collaborative learning activities enjoyed the collaborative aspect of the activity as well as the help they obtained in a networked environment.

The outdoor learning environment was yet another source of student satisfaction (Baya'a and Daher 2009; 2010; Spikol and Eliasson 2010). Not only did it facilitate the visualisation of maths concepts, but students also found this way of learning maths interesting, easier to understand and a good way to experience maths - changing their ideas about maths in a positive way.

*Change in student attitudes and perceptions towards mathematics.* Do mobile activities improve attitude towards math? Contrary evidence was found with two studies favouring mobile technology (Main & O'Rourke, 2011; Wu, Hsiao, Chang, & Sung, 2006) and three studies that did not (Jaciw et al. 2012; Miller and Robertson 2010, 2011). Wu et al. (2006) found that students who used the mobile device improved their attitudes towards mathematics after the intervention, while Jaciw et al. (2012) found otherwise. Main and O'Rourke (2011) found that the intervention group improved their self-concept for mathematics, but there was no significant improvement in the control group. On the other hand, Miller and Robertson (2010) found no improvement in the experimental group's maths self-concept scores, although there was a significant fall in maths self-concept in the control group. Miller and Robertson (2011) replicated the 2010 study and used a random assignment with a bigger sample size but found no significant change in maths self-concept and academic self-concept. However, there was an increase in student attitude towards school (although the effect size was very small). It is important to note that the studies varied in length of the intervention (from one day to one year) and in terms of the activity (from interactive use to problem based learning outdoor activities). The point here is not evidence weighting but how different designs elicit different results.

***Student engagement.*** Among the benefits frequently associated with mobile learning is that it promotes student collaboration and that it allows learning to be situated in authentic learning environments. The next paragraphs will be looking at student engagement and focus on group dynamics, collaboration and student engagement with the mobile activity.

***Group dynamics and collaboration.*** Kim, Buckner, Kim, Makany, Taleja and Parikh (2012) found that when a mobile device is shared between members of the group, the initial reaction was a competition between group members for control over the device. This competition was resolved by the person holding the device acting as the group leader. However, some frustration among group members was observed as they waited for the leader to try out the different answers. This frustration contributed to the loss of interest and active involvement of some members of the group.

Goldman et al. (2004) gave each student their own PDA, but still found similar competition within group members at the start. A conflict broke out among students who were vying for control of their group's communication with the server. To foster collaboration rather than competition, a redesign of the social component of the activity was implemented with students within groups having rotating roles. This process resolved the competition but also made some students tune out when they were working in less critical roles.

Kim et al. (2012) tried various group configurations (individually, in groups of three or in groups of seven) in which a handheld gaming console could be shared. They found that students working individually solved fewer problems than those working in groups. However, a smaller group was preferable to a larger group - those in groups of three advanced more efficiently and quickly than those in groups of seven. On the other hand, Zurita and Nussbaum (2004) found in their co-located game that there was no significant difference between a group of three and a group of five. They concluded that "handhelds are tools that facilitate coordination of a greater number of members" (p. 308). Boticki et al. (2010) who implemented an activity with the same mechanics as Zurita and Nussbaum's found that in a co-located game with a much bigger group of students ( $N=40$ ), strategies moved from decisions based on maths to random strategies and the waiting time became long.

Boticki pointed out "that the understanding of shared goals was perhaps the most difficult for the primary school children to grasp" (p. 198). Goldman's solution was to do a "great deal of social engineering" (p. 5), whereby social engagement rules had to

be established to provide all students the opportunity - not just those who were able to adjust the quickest in using the technology.

Despite the difficulties in terms of student collaboration, there were positive results observed when using mobile devices for collaborative activities. Zurita et al. (2003) suggested the following benefits: 1) provides a communication channel between the technological network and the social network; 2) mediates social interaction and 3) allows the participants to be mobile. These benefits have been observed in studies that opted for co-located game design. Roschelle et al. (2010) found that students who were using the mobile-based activity were communicating more than those who were using a desktop-based application. Similarly, Vahey, Tatar, & Roschelle (2004) observed students communicated more in a game specifically designed to be collaborative, in comparison to a game with multi-player features but which could be played as a single player game.

Due to the novelty of the activity and the technology, some students acted as mediators and experts, providing help to the rest of the class. Baya'a and Daher (2010) also observed that there was a lot of peer support available in terms of technical support. The studies reported that these interactions were evident during the first few instances of using the technology, but eventually died down as students became more familiar with the activity/device.

*Engagement with the mobile-supported activity.* One of the gauges used to measure student interest in the activity was the time students choose to spend on it. Both Main and O'Rourke (2011) and Lee et al. (2004) reported positive results in terms of time spent by students on mobile-based activities. Main & O'Rourke found that with the 20 minutes daily use, students on average spent 65% of the session on task, 25% on sharing and helping other students and 10% on non-class activity while the control group appeared to have spent more time on non-specific activities and less time completing the mental mathematics activities. Lee et al. found that each student answered as many as 1296 questions in the 19 days of the pilot study, which was 285% more than they could have finished using paper versions of exercises.

In the outdoor environment of the Eliasson et al. (2010) study, students only used the mobile device to get the information that they needed and then shifted their focus to the learning environment. Sollervall, Otero, Milrad, Johansson, & Vogel (2012) on the other hand reported that efficiency had much to do with the guided prompts the students were receiving on the mobile device as they progressed with the activity. They added

that “the prompts appear to have provided a structure that was easy for the students to follow, without hampering their discussions and own initiatives directed at solving the tasks” (p. 39).

In Baya'a and Daher's (2009, 2010) studies, the mobile phone was used for data collection as well for communication while working outdoors. The phones were perceived to have facilitated a seamless and dynamic learning environment. These studies claimed that the system provided the students with a different perception of mathematics as a real-life modelling tool.

Overall, regardless of the design of the activity, there was an observed improvement in student engagement and participation. In quasi-experimental studies, students in the experimental group were observed to be more highly involved than the control group (Lan et al., 2010; Main & O'Rourke, 2011). This involvement was in the form of assisting classmates and sharing information, increasing the amount of time spent engaging in the activity.

***Student achievement.*** Student achievement refers to student scores on various tests of maths ability. These studies used either a standardised test, a test specifically aligned to the intervention, or a test incorporated in the game. There were 19 studies (2933 pooled participants) at the elementary level, six in middle school (411 pooled participants) and six in high school ( $\approx 1987$  pooled participants). The total pooled number of participants was  $\approx 5331$ .

*Elementary studies: A meta-analysis.* The elementary studies were the only ones where there was enough data given to permit the calculation of effect sizes (ES), a measure for quantifying the difference between two groups across studies. Several formulas were used when computing for the effect size, depending on which data is available but for most, the formula below has been used:

$$ES = \frac{\mu_{Experimental} - \mu_{Control}}{Pooled\ SD}$$

An exemption to this was Carr's (2012) study. Carr's study had unequal group to begin with unlike the other studies in this meta-analysis. To give weight to the unequal groups, Morris's (2008) formula for effect size was used which is

$$ES = \frac{(\mu_{Experimental,PostTest} - \mu_{Experimental,PreTest}) - (\mu_{Control,PostTest} - \mu_{Control,PreTest})}{Pooled\ SD}$$

The ESs in Table 2-5 are Hedge's *g*, a correction of Cohen's *d* for smaller samples. In studies with two or more tests, the ES for each of these tests is computed

then averaged so only one ES is reported (e.g. Kiger, Herro, & Prunty, 2012). Using Cohen's (1988) interpretation of effect sizes, there were a substantial number of studies with moderate to large effect sizes.

Single-group pre-post-test (SGPP) designs appeared to have higher ESs, with four studies having a large ES and another a moderate ES. In fact, Kong and Li (2007) (2007) and Liao, Zhen, Cheng, Chen, & Chan (2011) studies have the first and second highest ES of all studies. To avoid bias resulting from the type of research design, the ESs of SGPP designs are not included in the computation of the overall ES (as recommended by Lipsey & Wilson (1993)). This left 14 studies to be included in the meta-analysis.

Table 2-5  
*Summary of Effect Sizes in Elementary Studies*

<b>Author/s (Year)</b>	<b>Control Group</b>	<b>Pre/Post Test</b>	<b>Sample Size</b>	<b>Duration</b>	<b>Effect size Hedge's <i>g</i></b>
Carr (2012)	Yes	Yes	104	10 weeks	.01
Huang et al. (2012)	Yes	Post-test only	60	3 weeks	1.14
Ketamo (2003)	Yes	Yes	47	Not specified	1.20
Kiger et al. (2012)	Yes	Yes	87	9 weeks	.67
Kong (2012)	Yes	Yes	43		.84
Kong & Li (2007)	No	Yes	36	3 sessions	1.45
Lan et al. (2010)	Yes	Yes	28	4 weeks	.18
Liao et al. (2011)	No	Yes	9	9 weeks	1.37
Main & O'Rourke (2011)	Yes	Yes	59	10 weeks	.45
Miller & Robertson (2010)	Yes	Yes	71	10 weeks	.56
Miller & Robertson (2011)	Yes	Yes	634	10 weeks	.07
Rosas et al. (2003)	Yes	Yes	1274	12 weeks	Not possible to compute
Roschelle et al. (2010)	Yes	Yes	155	2.5 weeks	.20
Shin et al. (2006)	Yes	Yes	50	18 weeks	.31
Shih et al. (2012)	Yes	Yes	118	10 sessions	.39
van'tHooft et al. (2009)	No	Yes	18	6 weeks	.95
Zurita et al. (2003)	Yes	Yes	48	4 weeks	.81
Zurita & Nussbaum (2004)	Yes	Yes	27	4 weeks	.51
Zurita & Nussbaum (2007)	No	Yes	24	4 weeks	.65

*Note:* Kong et al. (2007), Liao et al. (2011), van'Hooft et al. (2009) and Zurita and Nussbaum (2007) are all SGPP and so are not included in the meta-analysis.



An overall ES of .30 using a fixed effect model resulted. However, a fixed effect model assumes that the ESs differ only because of the sampling error and that all studies share a common mean (Borenstein, Hedges, Higgins, & Rothstein, 2009) which is not the case here. In this instance, the 14 studies being combined used different scales and methods and so a random-effects model was more appropriate. Furthermore, heterogeneity yielded a  $\tau^2 = .09$ , a  $Q (df=13)$  of 38.45, and an  $I^2$  of 66%, with statistical significance less than 0.01. Using the random effects model instead, this yielded a mean ES of .48, ranging from .27 to .68, with an SE of .10, which is a moderate effect size. Most of the studies reported a significant difference in mean test scores between the control group and the experimental group, except for three studies where the ES did not achieve significance (Carr, 2012; Lan et al., 2010; Miller and Robertson 2011). A forest plot of the studies is shown in Figure 2-11.

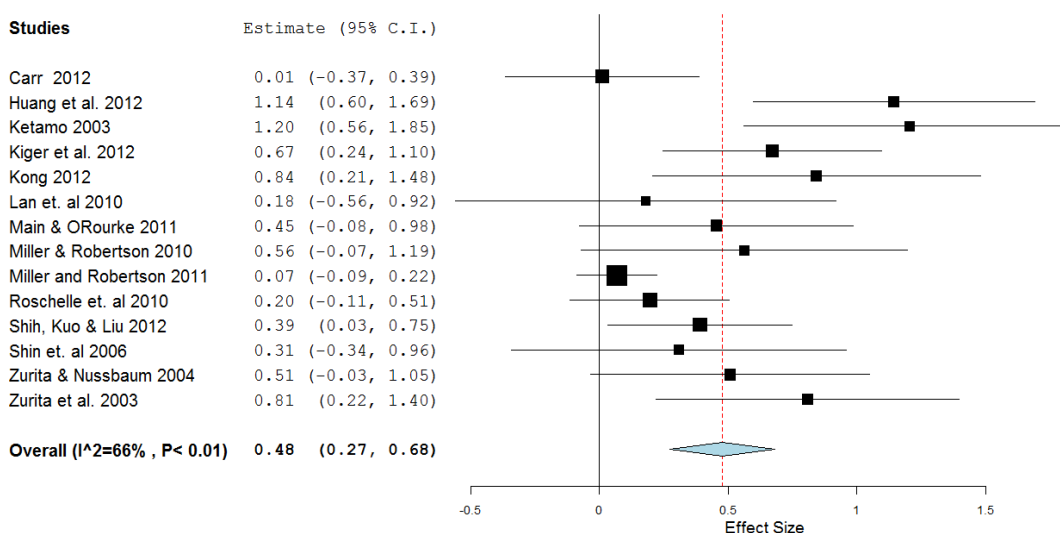


Figure 2-11. Forest plot of effect sizes (elementary studies)

The effect sizes of the studies were also grouped according to characteristics like types of device used and design of the intervention. With regards to device type, PDAs had the highest ES of .62 between six studies, while handheld gaming devices had a smaller ES of .22 between four studies. Phones had no representation in the 14 studies for meta-analysis. In terms of functional use, location-aware use had a moderate ES of .74 between two studies, while collaborative use and interactive use had small ESs of .38 and .30 respectively. With regards to duration of intervention, studies of less than

four weeks had a moderate ES of .55 ( $n = 7$ ) in contrast to the one study that lasted 4 months which had a small ES of .31. A breakdown of the study characteristics and effect size is shown in Table 2-6.

Table 2-6  
*Study characteristic and random effect sizes*

Study Characteristic	Random Effect Size	N	Overall number of participants
<b>By Device Type</b>			
Handheld gaming device	.22	4	768
Tablet	.49	5	353
PDA	.62	6	396
Phones	N/A	0	0
<b>By Functional Use</b>			
Administrative	N/A	0	0
Referential	N/A	0	0
Interactive	.30	14	1517
Microworld	N/A	0	0
Data Collection	N/A	0	0
Location Aware	.74	2	178
Collaborative	.38	4	291
<b>By Learning Strategy</b>			
Explicit instruction	.01	1	104
Drill and practice	.51	8	1065
Formative Assessment	.18	1	28
Game-based learning	.49	11	1328
Visualization of maths concept	.58	9	721
Video creation/podcasting	N/A	0	0
Collaborative learning	.50	4	291
Problem-based learning	.58	2	695
<b>By Duration of Intervention</b>			
< 4 weeks	.55	7	512
4 – 12 weeks	.28	5	921
13 weeks and longer	.31	1	37

*Middle school studies.* Vote-counting in meta-analysis is a process comparing the number of positive studies with the number of negative studies. A vote count of studies conducted with middle school students shows a 5-1 count, with five studies reporting increases in test scores and one study reporting otherwise. Vote-counting is deemed “inappropriate” for reviews as it “ignores sample size and takes little account of study methods and study quality” (Petticrew and Roberts 2008, p.183). Nevertheless, the number of studies is small and quite diverse in implementation. Added to the fact that effect sizes were not possible to compute for most of the studies, this left vote-counting as the only possible way to measure overall effectiveness. There is thus some evidence

that mobile-based activities conducted at middle school level improve student achievement.

Amiratashani (2010) used Salmon's four-group design to check whether the use of SMS-based co-curricular activities had any effect on students' mathematics achievement. While the setup of the study seemed robust, biases existed in the sample and in the treatment of the control group. The sample employed by the study was all female, which questions whether the same results can be expected in a mixed group. For example, Roberts and Butcher's (2009) study which used an SMS-based intervention for high school with both males and females found contrary results. The treatment of the control group is an example of comparing something with nothing. The students in the experimental group were getting the extra help and tailored feedback from their teachers outside classroom hours while the control group did not receive any. The difference between the control group and the experimental group here isn't just "business as usual" versus new technology and new methods but more than that - the experimental group dedicated extra study time beyond the usual offerings.

Goldman et al. (2004) and Vahey et al. (2004) both showed an increase in student performance after 4-5 weeks intervention. However, both studies lack a control group, hence, it can be questioned how much of that increase in student performance was actually affected by time and students' exposure to the material. While both studies had pre-test scores to compare with, it might have been that students improved on the post-test score over one month's repeated exposure to the material.

Kaloo and Mohan's (2011a, 2011b) studies used the same application but different study design. In the first study, there were two designs, firstly students using the mobile device on their own with no prompt from the teachers, secondly the students also received some teacher intervention. In the second study, students were taught in a classroom and the mobile activities were used to augment classroom teaching. A single subject design was employed in the first paper while in the second paper a control group was recruited. The first paper had positive results while the second paper found no difference in performance between the control group and the experimental group. While there are several attributes that might explain the results in the second paper, this difference between the first and the second study points out the weakness in single group designs. It might also be possible that different learning environments will lead to differences in results, which in this case refers to the augmentation of mobile activities to normal classroom teaching in the second paper.

Quite often, the experimental group is compared with a “business as usual” group, but the difference between the two groups is not just the use of new technology, but more of a changed pedagogy. Wu et al.’s (2006) design addressed this gap by using three groups, the experimental group using new technology and new pedagogy, another group applying new pedagogy but leaving out technology, then the third group was the traditional control group. The results were encouraging, with the mobile group showing a significant increase in maths scores. Shih et al.’s (2012) study which used an almost similar intervention (but without the traditional group) conducted over 3 weeks yielded positive results, so it can be asked whether the same results would be had if the study was conducted over a longer period.

Overall, there appears to be some evidence that mobile based activities conducted at middle school level work. However, this finding is tentative and better research methods will make this finding more robust.

*High school studies.* For the high school studies, results were divided between three studies showing positive results (Houghton Mifflin Harcourt, 2012; Project Tomorrow, 2010, 2011) and three studies showing otherwise (Jaciw et al., 2012; Roberts and Butcher, 2009; Roberts and Vanska, 2011). The mobile-based activities did not cause an increase in student performance for the high school studies, but positive effects were observed based on conditions like efficiency on the part of the teacher to implement technology use. Again, these studies are each presented to validate their vote count rather than allowing them to be taken on face value.

Jaciw et al.’s (2012) study and Houghton Mifflin Harcourt (HMH) (2012) study appear to be different studies with similar instruments and strategy, but on closer inspection it becomes apparent that the HMH study was a subset of Jaciw et al.’s. In the fuller report of Jaciw et al.’s study (Toby, Ma, Lai, Lin, & Jaciw, 2012), limitations of the Houghton Mifflin Harcourt report were discussed such as “not using appropriate statistical adjustment” (p. 55) and not allowing for the teacher effect. Nevertheless, it points out how certain desirable conditions (in this case, teachers trained to use technology and the school’s longstanding record of technology use) can lead to a different result. While Jaciw et al.’s overall study found that the use of the application had no impact on achievement, the subset with favourable conditions yielded positive results.

Similar to Jaciw et al.’s study, Roberts and Butcher (2009) also had a subset that performed differently in comparison to other schools within the study. A particular

school in the group claimed that students in the experimental group performed better on test questions related to the project content in comparison to the other Grade 10 students in the school. While scores verify this difference, it does not confirm that the difference was brought about by the intervention. Again, it was argued that a different teacher might have caused the difference in result. A repeat of Roberts and Butcher's study on a wider scale (Roberts and Vanska, 2011) yielded the same results relating to achievement, still showing a decline in student's scores. What the study found, however, was that the decline for students who used the service regularly, was less drastic compared to those who did not use it.

Project Tomorrow (2010, 2011) were two project evaluations of the Project K-nect initiative in North Carolina. In a way, a criticism of these two projects is the intervention itself. The project seemingly changed a lot of the traditional practice, having elements of social networking, blogging, video podcasting, games and mobile technologies. All this makes it quite difficult to pinpoint what exactly caused the improvement. It would have been ideal had the study employed a proper comparison group rather than use all the rest in the district as the basis of comparison.

The studies mentioned above have credits and discredits in vote count. Overall, the mobile based activities did not cause an increase in students' performance for the high school studies, but positive effect was observed based on conditions like efficiency on the part of the teacher to implement technology use or perhaps an overhaul of the approach to mathematics—going beyond the case of a straight substitution.

*Other study findings.* There were also differing results within the experimental groups. Findings related to within-group comparisons are as follows:

- a better improvement in post-test scores in low skill groups than in high skill groups (Ketamo 2003; Shin et al. 2006);
- the longer the time spent using the mobile device for activities, the higher the post-test scores (Kalloo and Mohan 2011a; van't Hooft et al. 2009).
- a change in the standard deviation in the post-test scores (Lan et al. 2010; Main and O'Rourke 2011), explained as a sign of levelling of student skills.

Attitudes and achievement are interlinked. Although the relationship between the two is not being investigated in this review, it was observed that majority of the studies which reported positive results on attitudes towards mobile technologies also obtained positive results in terms of achievement. However, there were cases where students

enjoyed the use of mobile devices and felt that the activity helped them improve their performance in mathematics, but this did not translate into better test scores, as was the case in Roberts and Vänskä (2011).

Comparing the ES with the length of the intervention (from Table 2-6), it can be observed that there is a slight tendency for longer interventions to have smaller ESs. An overall ES of .55 was computed for the seven studies that were less than four weeks, in comparison the overall ES of .28 of five studies that lasted between 4-12 weeks. This pattern may be explained by shorter interventions tending to maximise Hawthorne effects.

**Limitations.** The inclusive nature of the study has led to studies with varying natures of research design and implementation, some had been small-scale studies while others had been large national projects. Smaller sample sizes over-emphasize the results be they positive or negative. For instance, one of Lai et al. (2012) findings is “70 percent of the students show more interest in reviewing maths than before” (p. 285). While 70% appears to be an impressive increase, this is actually just 7 students showing more interest. This illustrates the need for caution in interpreting and consolidating study findings.

Short-term implementations are more exposed to Hawthorne effects. However, the decision to include both short-term and long-term studies had its merits. Small-scale short-term trials were specific in discussing the activities carried out by the students while larger scale long-term studies focused on the results rather than on the activities. The two types of study represent ends of a dimension. The short-term projects helped identify the activities that could be carried out with mobile devices as well as the engagement it elicited from the students while the long-term studies provided more information regarding improvement in student outcome.

A majority of the studies included in this review had medium weights with only 15% of the studies achieving a high score in terms of methodological quality and methodological relevance. A critical reader may find this review to be a summary of mediocre studies, but this also highlights how mobile learning is still in its infancy. Perhaps, in the future, mobile learning studies would have a more rigorous research approach but for now, the quality of the research that has been included in this review has been sufficient to draw some generalisations on how mobile technologies have been used over the past decade.

In addition to the shortcomings listed above, another limitation of this review is its failure to retrieve early studies of mobile learning. There were identified projects on maths and mobile learning that weren't included because information on the project can no longer be retrieved. Examples of this are the Palm Handheld Integration Project (TIC TOC) and TARGET PAALM Grant Project, both from the once extensive list of Palm-funded studies that are no longer available for retrieval after the funding company collapsed. This reflects the highly evolving nature of mobile technology and how studies can become easily outdated.

### **Maths and Mobile Learning Studies 2013-2016**

Since the previous review was conducted, maths and mobile learning literature has seen the publication of two books (Crompton & Traxler, 2015; Meletiou-Mavrotheris, Mavrou, & Paparistodemou, 2015), a systematic review of research trends (Crompton & Burke, 2015) and a special issue of a mathematics education journal on mobile technologies (Larkin and Calder, 2016). Where publications in the previous systematic review were mostly via educational technology journals and conferences, these new publications are evidence that show how mobile learning research is moving towards the mainstream.

As this systematic review was carried out shortly after the data collection of this dissertation, its search criteria slightly vary from the previous review. The first review was inclusive as its goal was to look for evidence and exemplars of mobile learning use in mathematics. It included studies that explored the possibilities of using mobile devices and even studies with very short durations. This later iteration of the review was focused on the effects of students' attitude and performance and as such, was limited to school-based studies. While the general questions of "how has mobile technologies been used for mathematics" and "to what effect has it been used?" remains the same, the specific review aims were slightly varied. These are as follows:

1. To create a descriptive map of mobile learning research for 2013-2016.
2. To evaluate the effectiveness of mobile-supported activities in terms of student achievement.

**Systematic review methodology.** The systematic review process follows the process of the previous research with a few modifications. During the stage for searching and screening of studies, only Cluster 1 in the previous search (search using indexing databases) was conducted. The search term was (*math OR mathematics*) AND

(*mobile OR ipad OR tablet or phone or ipod*) AND (*education or learn\**). Cluster 2 (manual search) and Cluster 3 (identification of research via backward citation) were not implemented due to time constraints. Instead, an additional search strategy was added by using forward citation, a process of identifying studies that cited a specific article using Google Scholar’s “cited by” feature. The modified inclusion and exclusion criteria are listed on Table 2-7.

Table 2-7  
*Exclusion and Inclusion Criteria*

Exclusion criteria	Inclusion criteria
1. Non-empirical studies	1. School-based research studies
2. Non- K-12 participants	2. Studies conducted on K-12
3. Studies that used other mobile devices (e.g. laptops, calculators, GPS, mp3 players, smartwatch)	3. Mobile devices used were either mobile phone or tablet
4. Mobile learning studies on a different subject	4. Student participants used a phone or tablet as part of a maths learning activity
5. Studies that report student achievement based on teacher or researcher narratives	5. The study reported the effects of using mobile technologies to student performance in mathematics as measured by a test.
6. Non-English	6. Studies longer than 2 weeks

**Results.** A total of 786 citations on maths and mobile learning for the period 2013-2016 were found after a search using indexing databases. After removing the duplicate citations, a total of 644 abstracts were screened and 555 of those were excluded for various reasons such as studies conducted in higher level mathematics, mobile learning studies on a different subject or studies that are not empirical by design. This process left 89 full-text articles assessed for eligibility. Articles that cited these studies were identified via Google’s forward citations results. From this process, an additional 353 citations were spot checked for eligibility. Full-text articles of mobile



learning studies identified from the book (Crompton and Traxler, 2015) and the special issue of *Zentralblatt für Didaktik der Mathematik (ZDM)* (Larkin and Calder, 2016) were also reviewed. After applying the inclusion criteria on Table 2-7, 16 studies were included in this synthesis.

***Descriptive map of mobile learning research for 2013-2016.*** Most of the studies were at primary level (n=9), three studies were at middle school level, two in kindergarten and two in high school. Like the pattern of distribution by country in the previous review, most of the studies were conducted in the US followed by Taiwan. Five studies covered topics on geometry while the other eleven studies covered topics on numbers and operations. Table 2-8 lists the studies included and some of its characteristics.

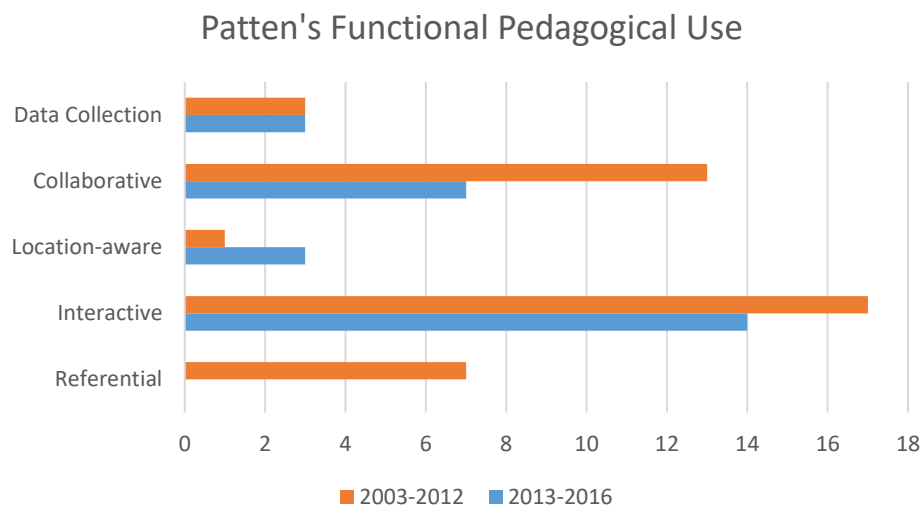
The updated systematic review found more citations (786 over 4 years) on average than the previous review (488 over 10 years). While the current review only has 16 papers as opposed to the 60 papers of the previous one, if the same inclusion criteria had been applied in the first instance, it would have yielded only 19 papers over 10 years, an average that is more than twice the original review. This illustrates the still growing interest in the field of mobile learning, as well an interest in investigating the impact of using mobile technologies. Studies that facilitate context-based mobile learning are still few, but this is an improvement in its own right as previous studies that fall into this category have mostly been exploratory (Eliasson et al., 2010, Spikol and Eliasson, 2010) and have not evaluated how this form of mobile learning affects student performance.

In the previous 2003-2012 review, phones and PDAs were the mobile device used, although the latter years saw an emergence of tablet use. This preference for using tablet devices continued to the current review, with only one out of the 16 studies using a phone and the rest using a tablet. This shows how schools/research have been keener to adapt the bigger form of tablet devices for classroom use, rather than the small form factor of mobile phones.

The design of the studies included in this review varied in terms of sample size (between 12-430 participants) and research design (refer to Table 2-8 for a breakdown). The duration of the studies also varied between two weeks to one year. Compared to the previous study (applying the same inclusion criteria), this was a shift in the duration of the experiment. Where majority of the studies in the previous review lasted between a month to one quarter of the academic year (32%), this is now only 2 out of the 16

(12.5%) studies. Majority of the more recent studies were less than a month long (50%) where it was 23% in the previous review. Six studies (37.5%) lasted between three months to one year and only one of those lasted for an academic year. This shift in duration of mobile learning studies is possibly affected by the shift in focus of mobile learning studies. Where previous studies would have explored how mobile devices can be utilised in a variety of ways over a period of time (Project Tomorrow, 2010), more recent mobile learning studies are tied with specific content that is traditionally taught over a specific timeframe (for example, Crompton's (2015) study on angles).

As for the functional pedagogical use of mobile devices per Patten et al.'s (2006) framework (see Figure 2-12), interactive use is the most popular feature for both systematic reviews. Most of the studies in the current review have looked at mobile game-based learning (Kiili, Devlin, Perttula, & Tuomi, 2015; Papadakis, Kalogiannakis & Zaranis, 2016; Zhang, Trussell, Gallegos, & Asam, 2015), which explains why this feature was mostly used. Current studies have veered away from the referential use of mobile devices (for example using tablets as e-textbooks) and have instead focused on other ways to utilise mobile technologies in the mathematics classroom. Examples of this are the use of mobile devices in the contextualised learning of mathematics in non-classroom settings (Hwang, Lin, Ochirbat, Shih, & Kumara, 2015; Rehm et al., 2015).



*Figure 2-12.* Comparison of functional pedagogical use of mobile devices between the two systematic reviews (note: this is data with the same inclusion criteria applied and not the whole of the 2003-2012 data).

Table 2-8  
*Characteristics of studies included in review*

Authors	Country	School level	Content	Design	Duration	Participants	ES
Al-Mashaqbeh (2016)	Jordan	Primary	Numbers & Operation (Numbers)	Quasi experimental	18 weeks	84	.67
Crompton (2015)	USA	Primary	Geometry	Single group pretest/posttest	2 weeks	60*	Not available
Hwang et al., (2015)	Taiwan	Middle	Geometry	Single group pretest/posttest	2 weeks	20	.38
Kiili et al., (2015)	USA	Middle	Numbers	Quasi experimental	7 weeks	25	.71
Liu (2013)	Taiwan	Secondary	Geometry	Factorial design	3 weeks	316	.25, .92, -1.60
Molenaar and Campen (2016)	Netherlands	Primary	Numbers	Quasi experimental	1 year	430	Not available
Montrieux et al. (2016)	Belgium	Middle	Numbers	Quasi experimental	8 sessions	164	Not available
Musti-rao and Plati (2015)	USA	Primary	Numbers	Alternating treatment	3 weeks	12	Not available
Papadakis et al. (2016)	Greece	Kindergarten	Numbers	Quasi experimental	3 months	256	.27
Perry and Steck (2015)	USA	Secondary	Geometry	Quasi experimental	18 weeks	110	-.61
Pitchford et al. (2015)	Malawi	Primary	Numbers	Randomised controlled trial	10 weeks	283	.36 & .44; .99 & .59 1.32 & .16
Pope and Mangram (2015)	USA	Primary	Numbers	Quasi non-equivalent groups	4 weeks	59	.49
Rehm et al., (2015)	Denmark	Primary	Geometry	Single group pretest/posttest	3 weeks	12	1.12
Schacter & Jo (2015)	USA	Kindergarten	Numbers	Quasi experimental	15 weeks	227	1.09
Yang et al. (2016)	Taiwan	Primary	Numbers	Quasi experimental	13 weeks	51	1.49
Zhang et al., (2015)	USA	Primary	Numbers	Single group pretest/posttest	4 weeks	18	1.03, .37, .48

\*There were 60 students who participated but only 8 students had pre and post clinical interview data

***Learning outcome.*** A meta-analysis of the quasi-experimental studies was conducted excluding studies that are SGPP by design. Montrieux, Schellens, Landeghem and Mouton's (2016) study was also excluded as the ES for that study was computed only on the basis of the post-test data. Where studies grouped their results into several clusters, the effect sizes for each cluster was computed separately. For example, Pitchford, Savage and Flecher-flinn (2015) reported the results for three different levels separately and used two different measures and so, the effect size was computed for each separately as shown in Table 2-8. The meta-analysis yielded a  $\tau^2$  of .42, a Q of 154.24 (df=15) and an  $I^2$  of 92%. The overall random effect size was .42 with an SE of .18. This value is slightly lower than the previously computed effect size of .48 SE of .10 from the 2003-2012 primary level studies.

Grouping the studies by their topics, numbers and operations (n=12 from 7 studies) yielded a random positive effect size of .70 ( $\tau^2 = .12$ ,  $I^2 = 18\%$ ) and geometry studies (n=4 from two studies) yielded a random negative effect size of -.13 ( $\tau^2 = .93$ ,  $I^2 = 83\%$ ). As there are only a few studies in this subsection of the meta-analysis, Higgins and Green (2011) noted that a random effect model provides a poor estimate of the distribution of effect and so, a narrative synthesis of results is presented in lieu of a statistical meta-analysis. By moving into a narrative synthesis of results, this also allows the results from SGPP studies and studies where ESs were not available to be incorporated in the analysis.

The majority of studies presented overall positive results with only two studies reporting a decline in students' performance (Perry & Steck, 2015; Montrieux et al., 2016). Studies included in the review have shown that the mobile learning intervention had a positive small to large effect in students' achievement except for two cases (Montrieux et al., 2016; Perry & Steck, 2015). Perry & Steck, (2015) used the iPads as a virtual manipulative and had their control groups taught using the traditional methods of teacher-centred pedagogy and drill and practice. Both groups had their maths proficiency scores decline but the experimental group had twice as much decrease in score than the control group. The control group of Montrieux et al.'s study (2016), a study that used an adaptive drill and practice system, also performed significantly better than the experimental group but it was not possible to compute for the effect size of this study as the authors have not reported the required data for effect size computation. This

difference was moderated by gender. Girls in the experimental group scored significantly lower than boys and by contrast, girls in the control group achieved significantly higher results than the boys.

Some studies grouped their results depending on some criteria and found some differences in the overall group performance (Liu, 2013; Molenaar & Campen, 2016; Pitchford et al., 2015; Rehm et al., 2015). In Liu (2013), there was a large difference between the control and the experimental groups' low performing students ( $ES = -1.26$ ) with the control group students having better scores than their counterpart. Although there was a small treatment effect in the high performing students ( $ES = .25$ ), this difference was not statistically significant. It was only for the average students where the difference between the control and experimental group was statistically significant ( $ES = .92$ ). In Molenaar and Campen's study, the Grade 2 experimental and control group pupils did not show a significant difference between in their test performances but a significant difference was observed for Grade 4 experimental and control groups. There were also greater gains in test scores was observed from fourth grade high ability students in comparison to the control group's high ability students. In Pitchford et al. (2015), there were no significant differences between the control and experimental groups Standard 1 (first level of primary education) maths content knowledge test and Standard 3 students' maths comprehension test. In Rehm et al. (2015), while the overall results point to significant differences between the control and experimental group, in favour of the experimental group, the groups' performance in level specific questions was not significantly different for higher level items.

All studies that focused on numbers and operations reported positive results except for some subsets of Pitchford's (2015) and Montrieux et al.'s (2016) studies which were reported earlier. Studies that focused on numbers and operation were conducted mostly at primary level ( $n=7$ ). There were two studies conducted in middle school and another two at kindergarten level. Most of these studies used off-the-shelf applications available via the device's mobile market, majority being game-like in design although some studies used applications designed specifically for the intervention (Papadakis et al., 2016; Yang, Chang, Cheng & Chan, 2016).

Studies that focused on geometry have used two common strategies to deliver the lessons, via context aware learning environments (Crompton, 2015; Hwang et al., 2015;

Rehm et al., 2015) and dynamic geometry systems like Cabri3D (Crompton, 2015; Liu, 2013; Perry & Steck, 2015). Crompton (2015), Hwang et al (2015) and Rehm et al. (2015) all observed an improvement in students' performance over time. These studies incorporated context-based learning environment and continued the lesson in class using applications that allow student to link their outdoor activity with formal school-based mathematics.

Studies that used dynamic geometry systems at secondary level had to a degree similar and contrasting results. Liu (2013) and Perry & Steck (2015), both had their control group performing better than the experimental group, although in Liu's case this was only true for the low performing students. However, if only the average level students' scores are considered from Liu's study then their finding contrasts with that of Perry & Steck. Perry & Steck attributed the difference between the control and experimental groups to the layer of difficulty mobile devices add to students' anxiety to learn maths at secondary level. Liu, on the other hand, had majority of their students found the mobile device useful as opposed to finding it as an added layer of difficulty. These two studies adopted the constructivist approach in using technology for learning maths, and so this raised the question of the effectiveness of the constructivist learning approach for this particular topic. However, it can also be argued that it was the usability of the mobile device that gave the additional layer of difficulty for this topic. In Yagmur and Cakir's (2016) usability evaluation of dynamic geometry systems on mobile devices, they found that mobile devices' limited display size, lack of gesture support and difficulty of making precise drawing or editing actions on mobile devices as opposed to their desktop counterparts all affected user interaction with the device. Whether it was the constructivist approach, the usability issues, or the combination of the two that affected the results of the two studies is not clear. In relation to the current review, these two studies were the only studies at secondary level included, and looking at the pattern from the previous literature review, this shows a repeat of inconclusive findings at secondary level mathematics.

Some of the included studies also investigated student perception (Hwang et al., 2015; Liu, 2013; Montrieux et al, 2016; Musti-Rao & Plati, 2015). These studies reported positive student perception about the use of technology to support maths learning including Montrieux et al.'s (2016) study. In that particular study, while

student perceptions about using the tablet were positive, the control group condition performed better than the students using the tablet. Only two studies reported student engagement (Perry & Steck, 2015; Rehm et al. 2015). Perry & Steck which had negative results in terms of student performance also found an increase in students' off-task behaviours during class. Rehm et al. (2015), on the other hand, found positive indicators of student engagement: the children were discussing the game and appeared enthusiastic to participate in the activities.

Few studies have considered discussing students' conceptual development (Crompton, 2015; Rehm et al., 2015). Both studies used the Van Hiele level of geometric thinking as a theoretical framework. Crompton discussed how the mobile learning activity supported students' progress in terms of Van Hiele's levels of development and found that students successfully progressed through the different levels throughout the course of the intervention. Rehm et al. tried to show the same progression by categorising the test results per Van Hiele levels but unfortunately, the participants failed to progress to the higher levels.

Other study findings point to gender difference (Montrieux et al, 2016; Papadakis et al, 2016; Pitchford et al., 2015) and students' self-efficacy (Perry & Steck, 2015). Pitchford et al. and Papadakis et al. did not find a significant difference in the boys and girls performance which contrasts Montrieux et al.'s findings. Perry & Steck (2015) found that while the experimental group had an increase in their perception of self-efficacy over the course of the intervention, the difference was not big enough to produce a significant change.

**Limitations.** A limitation of this review is its less inclusive criteria as opposed to the more open criteria of the first systematic review. By focusing on studies that only reported measured student performance, it has excluded state-of-the-art implementations in mobile learning (for example, Ireland's Bridge21 project, (Bray & Tangney, 2016) and process studies that discuss how mobile technologies supported learning (Sinclair, Chorney, & Rodney, 2015). However, this step was necessary to identify studies that are more aligned with the experiments carried out in this dissertation. Rather than this part be considered as a stand-alone review, its best considered as an addendum to the previous literature review to show a fuller picture. A further limitation is the lack of focus on the quality of the studies included in this

iteration. As all the articles were published in peer-reviewed journals and conferences, the studies were perceived to be of acceptable quality. As the studies were only few, all studies were given equal weights, except for the part of the meta-analysis where weight was a factor of sample and effect size.

### **Summary (for both systematic reviews)**

This review of the literature had the objective of identifying how studies utilised mobile devices for use in mathematics. The findings are summarised according to the four objectives set out earlier in this section.

**Descriptive map of research.** Research on the use of mobile technologies for mathematics has a wide geographical spread and has been increasing over the years. Previous systematic reviews on mobile learning pointed out trends in the field of mobile learning and like the findings of these reviews, the 2003-2012 studies on maths and mobile technologies have a wide geographical spread, with the US and Taiwan having the highest number of publications. The difference is that several countries have also emerged in the list of top sources of publication (e.g. Israel, South Africa and Sweden). The same pattern was observed in the 2013-2016 with additional studies from countries like Netherlands, Greece and Belgium being added into the pool.

The types of mobile devices used in mobile learning studies varied but recent mobile learning literature tend to prefer iPads and tablets in school-based settings. Systematic reviews on mobile learning have reported that the choice of mobile technology use for mobile learning studies up to 2010 were mobile phones and PDAs but may be displaced with time (Wu et al, 2010; Hwang and Wu, 2014). Whilst the 2003-2012 study reflected the same trend, the 2013-2016 studies showed a displacement of mobile phones by tablet in the more recent mobile learning studies.

Most of the studies used the mobile devices in ways combining several functions to do a range of tasks. The majority of research studies used mobile devices to replicate the interactive nature available in traditional computer-based learning activities. A difference in the design of the learning activities is that it also takes advantage of the tablets' form factor and built-in communication tools to facilitate collaborative learning environments. More recent studies have also utilised the sensors built into the mobile device to facilitate mathematics investigation in situated learning environments but similar to Hwang and Wu's (2014) findings, studies that availed this feature are few.



The use of mobile technologies in K-12 is more common at elementary level than high school. In the 2003-2012 review, 50% of the studies included in this review are with elementary participants, 32% with middle school and 18% are at the high school. In the 2013-2016 update, 56% were with primary students, 19% at middle school, 12.5% at high school and 12.5% at kindergarten. Discounting the higher education sample from Wu et al.'s (2012) and Crompton and Burke's (2014) review, this finding shows some similarities with those reports.

**Student attitudes and engagement.** Student attitudes towards the use of mobile technologies in learning mathematics were mostly positive. Although results for this section is mostly from the 2003-2012 review, the 2013-2016 update also showed the same positive student perceptions although from a limited number of studies. Reasons for students liking the mobile-based maths activities can be characterised into three categories: student satisfaction due to technology use, student satisfaction due to the changed pedagogy enabled by the technology, and student satisfaction with their own performance. Due to the limited number of studies with quantitative data, no conclusion can be drawn as to whether the use of mobile devices improves student attitude towards mathematics. What was apparent was that students enjoyed the mobile-based activities, but whether this enjoyment transfers to a better perception of mathematics will need further investigation.

As for engagement, the mobile form factor of the devices encouraged student-to-student interaction. During mobile learning activities, students interacted with each other more while they assisted each other, shared information and engaged in collaborative learning activities. The devices allowed students to move freely and naturally inside the classroom, whereas, in the outdoor learning environment, the mobile device facilitated remote communication between students.

**Achievement.** In the 2003-2012 review, positive gains were found in most of the elementary studies with only three out of 21 studies finding no significant difference between those who used the mobile devices and those who didn't. An effect size of .48 was computed in the meta-analysis. In the middle school level, the same pattern was observed, with more studies supporting the claim that the use of mobile-based activities improves maths achievement. For high school studies, this pattern of more studies reporting gains over studies reporting otherwise was not observed. There were instances

of studies which reported that the use of mobile-enabled maths activities had helped increased maths scores, but there was no consensus on the studies conducted in high school. In the 2013-2016 update, an effect size of .42 was computed from 9 studies (regardless of level). This is slightly lower than the previous review but is still within the same range of magnitude of effect.

### **Gaps in Literature**

In the earlier review of maths and mobile learning studies, gaps were found in terms of the study design. There was a lack of evaluation in terms of student achievement particularly in context-supported learning environments. More recent mobile learning studies have supported this but the three studies identified were carried out with small sample sizes and did not recruit a control group. While the three studies show a pattern of positive results in maths and mobile learning intervention, a control group will help validate the results and this is the direction that Study 2 and Study 3 of this dissertation has taken. The literature update found that there was an increase in the proportion of studies that lasted less than a month. There was still the issue of short interventions as these tend to show novelty effects. Another gap found is the lack of the teacher's voice. This dissertation tried to address these limitations through the research design by incorporating interventions that are more than a month long and including the teacher's voice in all the study iterations.

### **Chapter Summary**

This chapter has set out to identify theories of technology use in mathematics education and theories of mobile learning - both areas had limited theoretical background. Many of the theories were adaptations of more general learning theories, as were the cases of RME with constructivism and the Task Model with Activity Theory. One theory which covers both technology supported maths learning and mobile learning is the constructivist learning theory and this is the theory that this study adopts in terms of the design of learning activities.

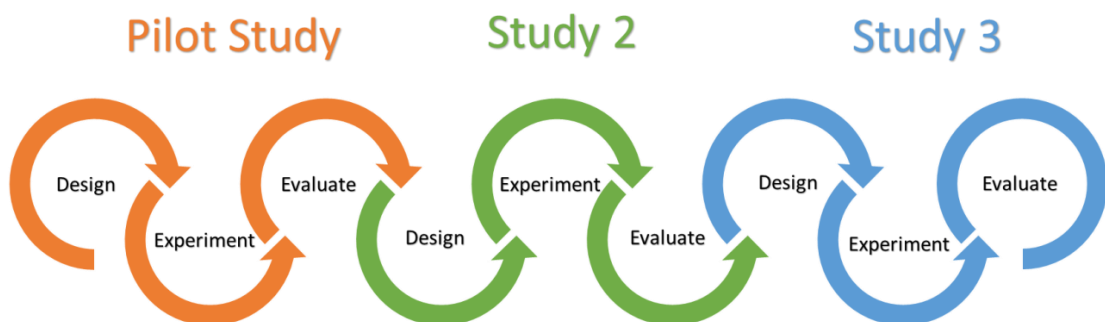
A systematic review was conducted to evaluate the effect of mobile technology use on students' attitude and achievement in mathematics. The review found that most studies reported positive student views about mobile learning but studies of effects on attitudes to maths had contrasting results. With regards to student achievement, the review found a moderate effect on student performance. However, this was mostly for

studies that were mostly classroom based activities (for example, using game based mobile learning). There were a few studies that facilitated context supported learning environments, but only a handful of these studies investigated the effect on student achievement. Moreover, these studies involved very short interventions which would likely have been affected by novelty. A mixed method study that evaluates student engagement and achievement over months rather than days would validate the promising findings of using mobile technologies for context-based mathematics learning.

## CHAPTER 3 GENERAL METHOD

### Research Design

This dissertation follows an iterative design process. Zimmerman (2003) described the iterative design process as “a design methodology based on a cyclic process of prototyping, testing, analysing, and refining a work in progress” (p. 176). Figure 3-1 illustrates the nature of the research conducted. In the first iteration, the systematic review is part of the design process. The aim of the first systematic review was to act as a design guideline for the pilot study. By looking at previous studies, patterns of successful use emerged and issues in the design and implementation of mobile-based activities came to sight. This information was factored into the activities chosen for the pilot study experiment. For example, a gap identified in the literature was the quantitative evaluation of studies carried out outside the classroom and so this was incorporated in the design of the pilot study. During the evaluation stage of the pilot study, several technical and activity design issues emerged in the critical incident analysis and so, these issues were addressed in the design stage of the next study. This same cyclical process was adopted in the changes from Study 2 to Study 3.



*Figure 3-1.* Iterative design process

As for the research design of the experiments in the three studies, a mixed methods approach was used. Johnson, Onwuegbuzie & Turner (2007), defined mixed methods as the “type of research in which a researcher combines elements of qualitative and quantitative research approaches for the purposes of breadth and depth of understanding and corroboration” (p. 123). The choice for mixed methods was driven by the research questions itemised in each study. As mobile learning is an emerging field, the qualitative strand was intended to be able to elaborate on the student learning

experience and identify the breakdowns and breakthroughs of using mobile technologies in different learning contexts. On the other hand, the quantitative data was intended to be able to measure the effect of mobile supported activities on students' attitudes towards mathematics or maths achievement. By mixing quantitative and qualitative data collection strategies, a more comprehensive account is likely to be achieved (Bryman, 2006).

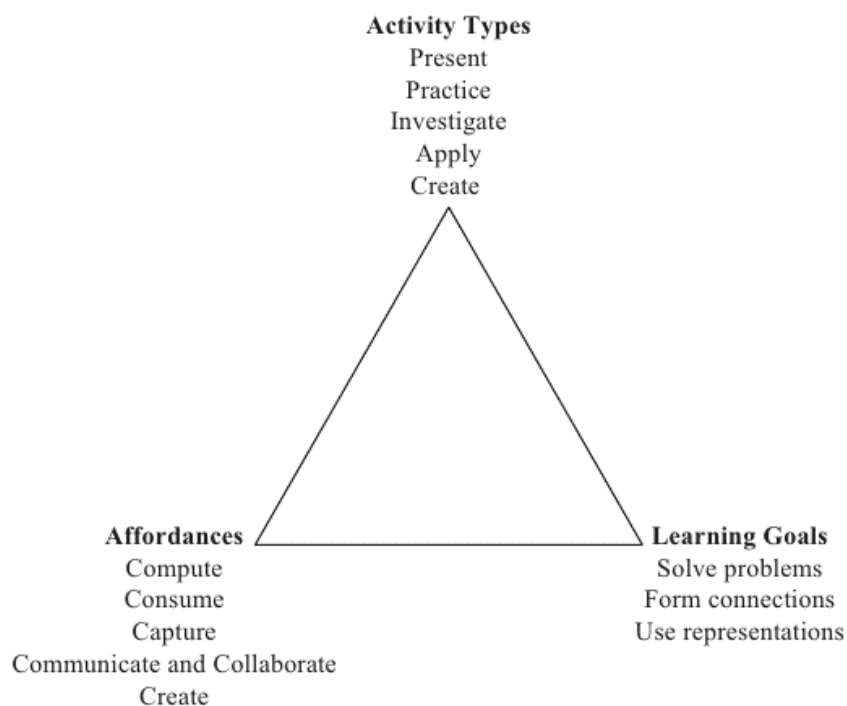
The structure of evaluation carried out in the three studies uses the Micro Meso and Macro (M3) evaluation framework (Vavoula and Sharples, 2009). M3 provides a structured format to assess usability, educational and organisational impact and their inter-relationships (ibid. p. 12) in three evaluation processes of micro-level, meso-level evaluation and macro-level evaluation. At micro level, the focus is on the individual activities and the use of technology; at meso level, the focus is on the learning experience using mobile technologies; at macro level, the focus is on the impact of using mobile technologies on students' attitudes towards mathematics and their performance.

In the original context that M3 evaluation was used, the micro level examined the individual activities of the technology users and assessed the usability and utility of the educational system. This approach was particularly useful as it highlighted problems with the existing application which could be improved as part of the evaluation. In this instance, however, because the applications used are all developed by third party providers, the focus of the micro-level is shifted to individual user evaluation of the technology. Evaluation of the usability of the application is still present at this level, but only for the purpose of identifying problems with the technology that might affect the overall learning experience.

### **Nature of the Intervention**

Sawaya and Putnam (2015) proposed an integrated framework to help teachers design mobile learning activities that had the capacity to bridge classroom mathematics to real-world mathematics. The framework consisted of three issues to consider when designing learning tasks: (a) learning goals, (b) activity types and lastly (c) affordances of the technology in reference to what mobile devices offer to support mathematics learning. A representation of the framework is shown in Figure 3-2. These technology affordances are not unique to mobile devices but it is the combination of these

affordances in a single device that highlights the potential of mobile technologies in supporting various learning activities. For example, if the learning objective is to allow students to form connections between abstract geometric concepts and their concrete representations in the real world, then using the mobile device students can capture images “in the wild” to investigate geometric properties. They then move to the more formal learning environment of the classroom to carry out further investigations on the artefacts they have gathered. Through this multimodality, portability and multi-functionality of the mobile device, learning goals are facilitated in various activity types as students move in and out of different learning spaces, moving from the more active and situated learning activities to the more reflective classroom based activities.



*Figure 3-2.* Framework for the design of mobile learning activities for mathematics (Sawaya and Putnam, 2015)

Students participated in mobile-supported constructivist learning activities that covered topics on geometry and information handling. In the past, the majority of the studies that utilised mobile technologies have used mobile devices as substitutes for computer-based learning activities. The rationale for the design of the activities carried out here was derived from the systematic review. The findings of the systematic review identified that only few studies have capitalised on the unique features of the mobile

devices (for example, mobility, portability and network connectivity. These features were utilised to create a maths learning environment that provided students with hands-on experiences and the possibility to investigate mathematics concepts in their environment. The functional pedagogical uses (Patten et al, 2006) of the technology thus varied - some facilitated interactive use but most were for data collection. The activities were also mapped into Sawaya and Putnam's (2015) design framework.

### **Ethical Considerations**

The five key ethical principles as outlined by the Government Social Research Unit (n.d.) are listed below and the procedures undertaken to uphold the requirements. Copies of ethical approval for the studies are provided in Appendix C.

- a) Sound application and conduct of social research methods and appropriate dissemination and utilisation of the findings.
  - The activities carried out in the research were mapped according to the competencies expected at Key Stage 2 mathematics and have also been discussed with the teacher prior to carrying out the research, so as not to disadvantage the students who participated in the research study (such as missing out the required curriculum).
  - Copies of the research findings were provided to the school and the council.
- b) Participation based on valid informed consent.
  - Consent from the council was sought prior to conducting the research (see Appendix D. Informed consent was secured in writing from the participants (head teachers, teachers and students). Copies of the letters given to participants are available in Appendix E. Parental consent was sought. Participation was voluntary and schools/teachers/student participants were told they could withdraw at any point and for whatever reason.
  - Children who did not consent to the videos/photographs were given instructions to avoid the camera.
- c) Enabling participation.
  - A bank of mobile devices used for the research study was provided for the duration of the research project.

- Teacher involvement was sought prior to the implementation of the intervention and they were provided training on the use of the tablets and the applications.

d) Avoidance of personal harm.

- Steps were undertaken to avoid the chances of unlikely events that may cause harm.
- As some of the activities were carried out outside the classroom but within the school grounds, risk management and health and safety procedures were undertaken, aligned with the school policy. No outdoor activities were carried out in inclement weather conditions.
- Where internet access was needed in the activities, the network was locked down to avoid access to sites not suitable for younger students.
- All the tablets were locked down so that they could only connect to allowed networks (to avoid the chances of tethering from their own devices) and only ran permitted applications.

e) Non-disclosure of identity and personal information.

- Names and gender of students gathered in the instruments were assigned to codes when data was stored on a computer and the paper copy of the instrument was stored securely and was to be discarded shortly after the completion of this project. The reason for using the name was to help identify the same child in the post-test without having to ask the students to make a note of the codes assigned to them. All data was kept secure via a password-protected computer and two-step verification storage.

Project information was provided for teachers, student participants and their parents/legal guardians. Active informed consent was required from student participants and teachers. For parents, following the advice of the head teacher, a passive consent was sought as the activities were considered merely variations of the schools' day-to-day activities. Teachers sent consent forms to the parents. Passive consent required parents to return the form if they **did not** wish their child(ren) to participate in the study. Non-return of the slip was then taken as consent.



## CHAPTER 4 STUDY 1 – A PILOT STUDY

### Introduction

One of the gaps found in the 2003-2012 systematic review was the lack of quantitative evaluation in previously published mobile learning studies, particularly in settings carried out outside the classroom environment. It also highlighted the lack of mobile learning studies in maths that covers effects of using technology to student attitudes. Given the limited literature that explores the effects of using mobile technologies in mathematics, it is the goal of this research to investigate the effects of using mobile technologies on students' attitude and achievement. Specifically, this study aims to answer the following research questions:

- 1) What are the students' views on the use of mobile technology for learning mathematics?
- 2) Is there a change in attitude towards mathematics when mobile technology is used for learning math?
- 3) Is there a change in attitudes towards technology when mobile technology is used for learning mathematics?
- 4) Is there a change in mathematics achievement when using mobile-supported maths learning activities?

### Methodology

#### Research design

The pilot study was a quasi-experimental mixed methods design evaluated using Vavoula and Sharples's (2009) M3 Evaluation framework as outlined in Chapter 3. For the quantitative element of the mixed method design, a single group pre-test post-test (SGPP) design was adopted. An advantage of this design is that it can measure changes that occur from pre-test to post-test. Several studies included in the systematic review used a similar research design (Kong & Li, 2007; van'tHooft et al., 2009; Zurita & Nussbaum, 2004). Admittedly, this design has several threats to validity like maturation, testing and instrumentation but as this study was preliminary, the SGPP design is more economical in terms of time and resources.

For the qualitative element of the mixed method design, teacher and student interviews were conducted. This covered their views and their experience of the mobile

learning sessions. This approach allowed the identification of issues and participant perceptions about the use of mobile technologies for maths. Video intervention data also forms the qualitative element of the research. These video data were used in the identification of breakdowns and breakthroughs in the learning sessions. Table 4-1 maps out the mixed methods design process within the M3 evaluation framework.

Table 4-1  
*M3 Level Evaluation Design*

<b>M3</b>	<b>Instrument</b>	<b>Measure</b>	<b>Frequency</b>
<b>Framework</b>			
Micro level evaluation	End activity evaluation	Student evaluation of the activity.	End of activity
Meso level evaluation	Teacher and student interviews	Teacher and student perceptions of using mobile technologies	Carried out twice (mid and end of intervention)
	Video observation	Critical incidents (breakdowns and breakthroughs).	
Macro level evaluation	Mathematics Attitude Inventory (MAI)	Students attitude towards mathematics	Start, middle (for MAI only) and end of intervention
	Maths Test (MT)	Student performance	

### **Participants**

Participants were recruited by soliciting teachers from within one local authority in Scotland. Participation was voluntary. The teacher participant for this study is a female teacher with five years of teaching experience. The student participants (12 boys, 12 girls), aged between 10-11 years old were the Primary 7 students assigned to the teacher participant of this study. The school, as described by an HMIE report, had students receiving free school meals above the national average and pupil's attendance below the national average. Its immediate surrounding area according to the Scottish Index of Multiple Deprivation had a decile index between 2-6 with decile 1 representing the most deprived 10% of Data Zones and decile 10 the least deprived.

## Instruments

**End activity evaluation.** The End-Activity Evaluation Questionnaire consists of questions derived from Microsoft Desirability Toolkit (Benedek & Miner, 2002) and Lewis's (1995) After Scenario Questionnaire. The Microsoft Desirability Toolkit is a set of 118 reaction cards and works by having users choose five words from the set that best describes the product or how the product makes them feel. This is followed by an individual user interview to allow the user to explain their answers. Whilst the toolkit is a popular choice in user satisfaction surveys, no published reliability and validity scores have been found.

In this implementation, 18 words (to form 3 pairs per element of usability) from the original reaction cards were selected and designed as a semantic differential scale. The selection of 18 words from the original 118 words was done by first clustering alike terms in the reaction card (i.e. meaningful, useful and relevant) and then paired with an opposite word from the reaction card. Afterwards, the paired words were grouped in terms of three factors: (1) usefulness, (2) user satisfaction, and (3) usability, resulting in having 3 paired words per factor.

Two additional items were taken from Lewis's (1995) After Scenario Questionnaire to factor in student evaluation of the overall activity. The original 3-item questionnaire has reported values of reliability coefficients between .90 to .96 across different scenarios. However, as the third item from the test related to support information (e.g. online-line help, messages, documentation) which was not present in the activities, this question was removed.

Having combined the two user experience surveys, the end activity questionnaire consisted of 11 items arranged on a line marking scale with two opposite words at the end. The user marked the scale to indicate their agreement with the statement/word. The nearer the mark to the word the higher the agreement and vice versa. Table 4-2 lists some of the items from the survey and its corresponding category. A full copy is available in Appendix F.

Table 4-2  
*Items from end activity questionnaire grouped by scale*

Scale	Items
Usefulness	<ul style="list-style-type: none"> <li>• Irrelevant vs Useful</li> <li>• Ineffective vs Effective</li> </ul>
Usability or ease of use	<ul style="list-style-type: none"> <li>• Clear vs Confusing</li> <li>• Understandable vs Too Technical</li> </ul>
User satisfaction	<ul style="list-style-type: none"> <li>• Satisfying vs Frustrating</li> <li>• Fun vs Boring</li> </ul>

**Video recordings.** The daily session was recorded using a Google Glass worn by the researcher. As the camera is an eye-wear, it follows the line of vision of the one wearing it. The choice of a wearable camera was made to avoid the difficulties narrated by Lonsdale (2011) in his mobile learning study. In his study, the video footage from three static cameras was not able to capture the student activity with the device. To avoid repeating the same problem, it was decided to use a wearable camera instead.

**Student interviews.** Interviews were designed to draw out student feedback about the activities which might have been missed in the end activity survey. Students recapped the activities that they had done so far and were asked to explain which of the activities they liked and least liked. Their opinion as to what the advantages and disadvantages of doing these types of activities were also sought. They were also asked to share challenges they had experienced during the activities and their views on working on the tablets in a paired activity. Additionally, students were asked to give suggestions on how the use of the tablets could be improved.

**Teacher interviews.** Teacher interview was conducted twice. The first interview was after Phase 1 (indoor activities) and the other was after the end of Phase 2 (outdoor activities). Questions asked include the teacher's view on the mobile learning activities, observations on how the activities affected the students and perceived advantages and disadvantages of mobile learning.

**Mathematics attitude inventory (MAI).** Several scales are available for measuring mathematics attitude. For this study, Lim and Chapman's (2013) shorter version of Tapia and Marsh's (2004) Attitudes Towards Mathematics Inventory (ATMI) as well as Pierce, Stacy and Barkatsas's (2005) scale to measure students learning mathematics with technology were considered.

Tapia and Marsh (2004) devised a 40-item, 5-point Likert Scale Attitudes Towards Mathematics Inventory (ATMI) to measure high school students' attitudes towards mathematics with four subscales: enjoyment of mathematics, self-confidence, value of mathematics and student motivation. The instrument was reported to have an alpha reliability coefficient of .97. Content validity was established in the development of the items by having a blueprint of the domains that needed to be assessed that related to the four variables that were going to be measured. Also, the items were examined by two experienced mathematics teachers.

As the original ATMI scale is particularly long, a shortened version of ATMI (sATMI) by Lim and Chapman (2013) is adopted for this study. The sATMI is a 15-item test narrowed down from the original 40 by removing the redundant items and the questions relating to motivation. It still maintains the other three subscales of enjoyment of mathematics, self-confidence and value placed by students on mathematics and exhibited strong correlations with the original ATMI scale (mean  $r = .96$ ). Internal consistency scores were  $\alpha = 0.93$  and mean  $\alpha = 0.87$  for individual subscales. A test-retest reliability over a 1-month period was deemed satisfactory (mean  $r_{\alpha} = 0.75$ ). The reported completion time for the test is 10 minutes.

Pierce, Stacy and Barkatsas's (2005) mathematics attitude inventory is a 20-item test with 5 subscales on behavioural engagement, confidence with technology, mathematics confidence, affective engagement and learning mathematics with technology. As some of the items overlap with the ATMI scale, only the items relating to confidence with technology and learning mathematics with technology were adopted in the final version of the combined inventory. Reliability of the instrument was not published.

Having combined the two inventories (sATMI and Pierce's et al.), the mathematics attitude inventory (MAI) used for this study is a 20-item test with five subscales that measure the students': (1) enjoyment of mathematics, (2) self-confidence,

(3) value of mathematics, (4) confidence with technology and (5) learning mathematics with technology. Certain items were rephrased from the original scales to have an equal value of positive and negative statement. In addition, a line marking scale was adopted in favour of a Likert Scale to allow analysis of continuous data. Table 4-3 lists some of the items from each subscale. A full copy of the survey is available in Appendix G.

Table 4-3  
*Survey items grouped by subscale*

Subscale	Questions
Enjoyment of mathematics	<ul style="list-style-type: none"> <li>• I have usually enjoyed studying mathematics in school.</li> <li>• Mathematics is a very boring subject.</li> </ul>
Self-confidence	<ul style="list-style-type: none"> <li>• Studying mathematics makes me feel nervous</li> <li>• I am always confused in my mathematics class.</li> </ul>
Value of mathematics	<ul style="list-style-type: none"> <li>• Mathematics is important in everyday life.</li> <li>• Mathematics is an unnecessary subject.</li> </ul>
Confidence with technology	<ul style="list-style-type: none"> <li>• I am good at using computers</li> <li>• I am good at using things like DVDs, MP3s and mobile phones</li> </ul>
Learning mathematics with technology	<ul style="list-style-type: none"> <li>• Mathematics is more interesting when using mobile technologies</li> <li>• Using mobile technologies in mathematics is NOT worth the extra effort</li> </ul>

**Achievement.** The maths test administered at the start and end of the intervention consisted of 10 questions with a maximum score of 40. The questions comprised of topics discussed in the intervention: symmetry, angles, area and perimeter and information handling. These items were from practice exercises in Primary 6 and 7 mathematics textbooks used in Scotland (Heinemann Maths and TeeJay CfE Maths) selected for their match to the activities.

### The mobile learning activities.

This section covers information about the nature of the technology used, a description of the software applications employed and the activities carried out in the mobile learning intervention.

**Technology used.** Mobile devices used in the study were 7-inch Android tablets of different make and model. All tablets were Android 4.2 tablets costing less than £100 each. The justification for the choosing these tablet sizes is that several activities were carried out while students moved around so the small form factor allowed mobility and the medium screen size allowed screen sharing. Various applications/software were used in the study which included free and paid for applications – these are discussed below.

*Skitch.*<sup>1</sup> The application allows the user to make annotations over images captured using the application or images already stored on the device. A screenshot of the application is shown in Figure 4-1. As can be seen from the screenshot, the application allows the user to make notes on an image using arrows, shapes, text and freeform annotation. The software allows these compositions to be saved or shared electronically. While there is a plethora of photo editing tools in the Android Market, Skitch was chosen because of its simple interface and has been featured in other mobile learning studies (Fabian and Maclean, 2014; Song, 2014). Furthermore, the application was ad-free, developed by a reputable company, and one of the more known applications on the Android Market.



Figure 4-1. Screenshot of Skitch with the annotation tools shown in the bottom right corner.

<sup>1</sup> Skitch was withdrawn from the Android and iOS store on January 22, 2016. Information retrieved from <https://help.evernote.com/hc/en-us/articles/214920608-Discontinued-support-for-Skitch-for-Android-Windows-desktop-and-Windows-Touch>

**Mirrord Picture Reflection<sup>2</sup>.** There are several symmetry camera applications on the Android Market. However, a number of these applications only create symmetrical images from pictures already taken (for example Easy Symmetry and Mirror Photo). Mirrord is an application that creates a symmetrical view of an object using the camera's live viewfinder. An example of an image taken with the application is shown in Figure 4-2. The square buttons on Figure 4-2b and 4-2c are the symmetry options (vertical symmetry, horizontal symmetry, diagonal symmetry, symmetry on two axis, rotational symmetry of Order 2). On the left side (Figure 4-2a) is an image taken with an ordinary camera, on the middle (Figure 4-2b) is an image taken with the symmetry camera with vertical symmetry selected. Figure 4-2c shows the same image with the horizontal symmetry option.

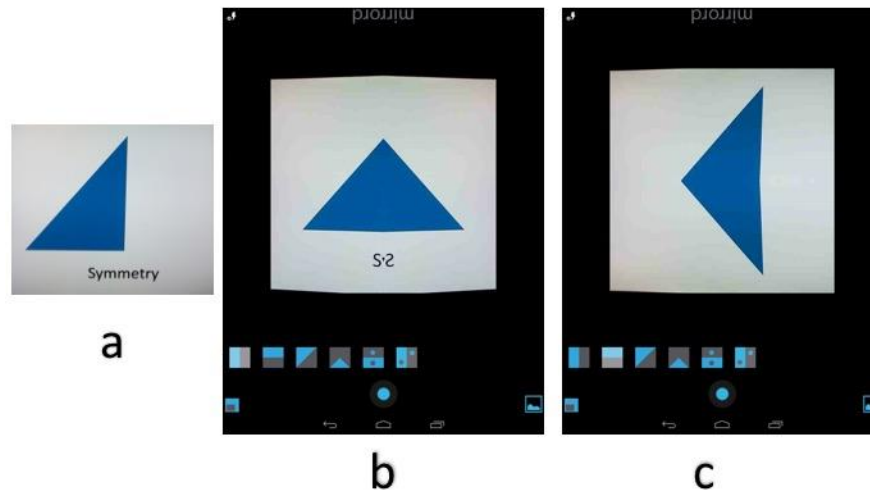


Figure 4-2. Screenshot of the application Mirrord

**Measure Map.<sup>3</sup>** This application allows the user to investigate the area and perimeter of any given place on the map by having the user specify the points to measure as shown in Figure 4-3. After specifying the end points to measure, the area and perimeter of the enclosed figure is displayed. Similar applications are available on the Android Market (for example, Fields Area Measure and Distance Area Measure),

<sup>2</sup> Mirrord Picture Reflection is available from Playstore@  
<https://play.google.com/store/apps/details?id=com.awc.mirrord.v2&hl=en>

<sup>3</sup> Measure Map is available to download from  
<https://play.google.com/store/apps/details?id=com.globaldpi.measuremap&hl=en>



but the free versions of these other applications have advertisements. Furthermore, other applications are limited in functionality, like inability to change the metric system and saving the shapes drawn. Measure Map allows the user to save their drawings, which is a useful feature to allow students to compare areas and perimeters of different places. In addition, the application allows taking snapshots of maps created which is useful for storing and sharing the artefacts created.



Figure 4-3. Screenshot of the application Measure Map showing area and perimeter of enclosed space.

**Area and Perimeter.**<sup>4</sup> Geoboards are manipulatives commonly used by mathematics teachers (Moyer-Packenham, Salkind and Bolyard, 2008), but the Android market only has two applications available for this category: Digital Geoboard and Area and Perimeter. While the Digital Geoboard application is more similar to traditional geoboards, the application has issues with responsiveness. The Area and Perimeter application was chosen mainly for its simple and intuitive interface. This manipulative

<sup>4</sup> Area and Perimeter is available to download from <https://play.google.com/store/apps/details?id=com.andreynadam.areaperimeter>

allows the user to draw various shapes on a grid and the system computes the area and perimeter of the figure drawn as shown in Figure 4-4.

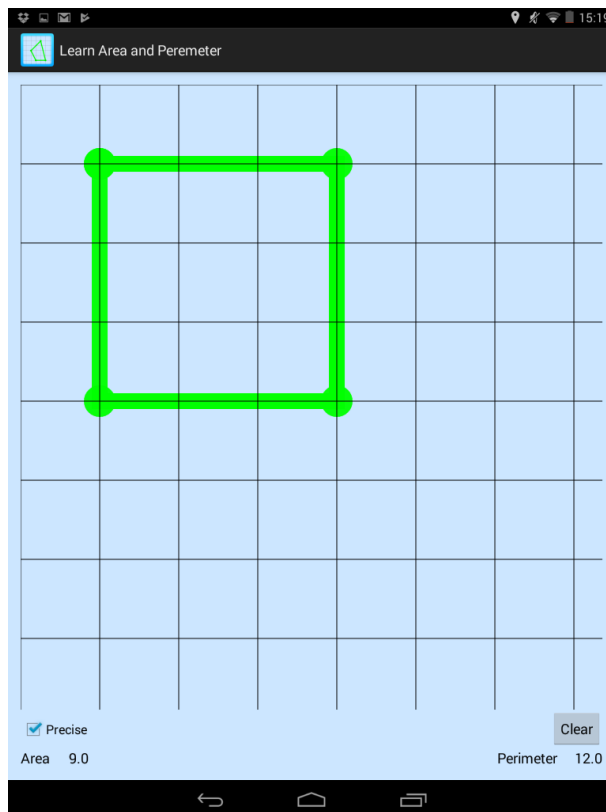


Figure 4-4. Screenshot of Area and Perimeter application.

**InstaSurvey.**<sup>5</sup> The application has a simple interface that lets the user create a survey from different templates, some with visual responses (smiling faces, star ratings, thumbs up and down), and another with a template that allows the user to input their own categories. After creating a survey, the survey can be administered straight away and allows up to 100 responses to be gathered. On completing the data collection, the application displays a bar graph of the results. Several applications such as this are available on the Android market but this application was chosen because it did not require an Internet connection or user registration. Furthermore, it kept a copy of the survey on the tablet, which was a useful feature for checking previously completed surveys. The application also allows the user to create, administer and analyse the survey results within three clicks, following a design principle that states the user

<sup>5</sup> InstaSurvey is available to download from <https://play.google.com/store/apps/details?id=appdictive.instasurvey>. Note that this is a legacy version of the application and is no longer being updated by the developer.

should be able to find information with no more than three clicks. Screenshots of the application is shown in Figure 4-5.



Figure 4-5. Screenshot of InstaSurvey interface showing different views: a) survey design, b) data collection and c) data analysis view.

**Snapshot Bingo.**<sup>6</sup> This application is played in a way similar to Human Bingo, where players look for people that have characteristics the game card asks for. These characteristics are laid out in cells typical of the bingo game card. In the mobile version, the system allows the user to specify the grid size and the contents of each cell. An example of a list of tasks arranged in a grid is shown on the left-hand side image of Figure 4-6. The mobile version requires camera input so that the pictures of the gathered data are displayed in the same grid (refer to the right-hand side image of Figure 4-6). At the time the research was being conducted, this application was the only application that did this function. While there are many applications that take pictures, this was the only application that presented the tasks to the students in that format and allowed students to gather artefacts as they worked on the task.

<sup>6</sup> Snapshot Bingo is available to download from <https://play.google.com/store/apps/details?id=com.yusuke.snapshotbingo>



A blank game sheet



A completed game sheet

Figure 4-6. Screenshot of Snapshot Bingo with blank (left) and completed (right) screens.

**Simple Measure.**<sup>7</sup> The application allows the user to measure the height of a distant object using the tilt-sensor and camera of mobile devices. It requires specification of the height of the user for a more accurate computation of height. The application was chosen due to its compatibility with the mobile device and its simple operation. Other applications (for example, Measure Height and Easy Height) require the user to know their distance from the object being measured in order to approximate the height, but students are not likely to be able to estimate this. On the contrary, Simple Measure only requires the height of the user to make an approximate measurement. Figure 4-7 provides a walkthrough on how to use the application. The first step after setting the user's height is to tilt the tablet towards the base of the object being measured until the base aligns on the line shown on the middle of the screen (Figure 4-7a). When everything is aligned, the user taps on the Bottom button at bottom of the screen. The next step is to tilt the tablet upwards to align the line with the top of the object being measured (Figure 4-7b). The user then taps a button on the screen to lock the measurement. After which, the height would be displayed on the screen as shown in Figure 4-7c.

<sup>7</sup> Simple Measure is available to download from [https://play.google.com/store/apps/details?id=dk.apps.height\\_measure](https://play.google.com/store/apps/details?id=dk.apps.height_measure)

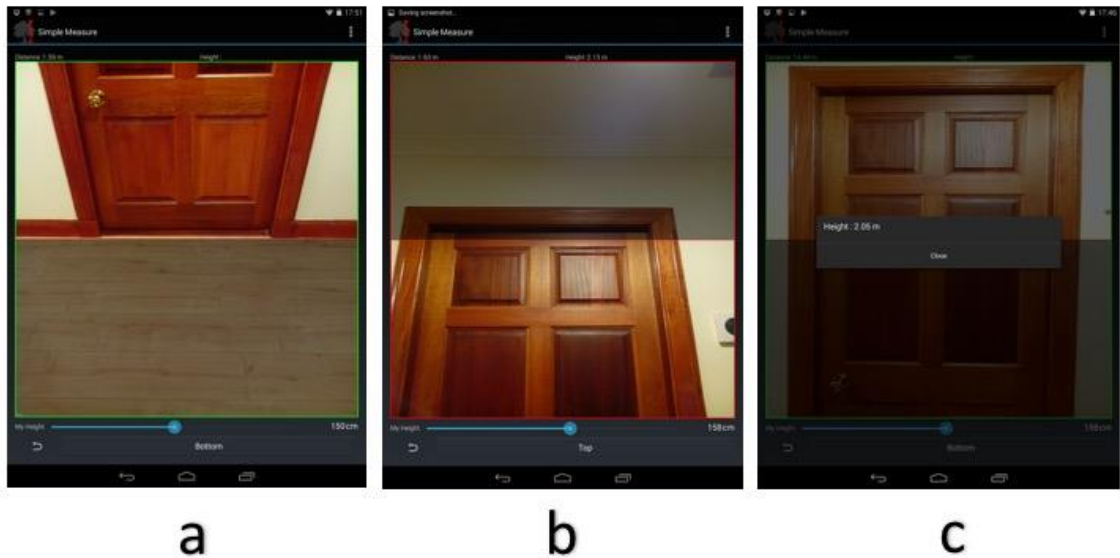


Figure 4-7. Screenshots of Simple Measure showing the steps taken to measure height.

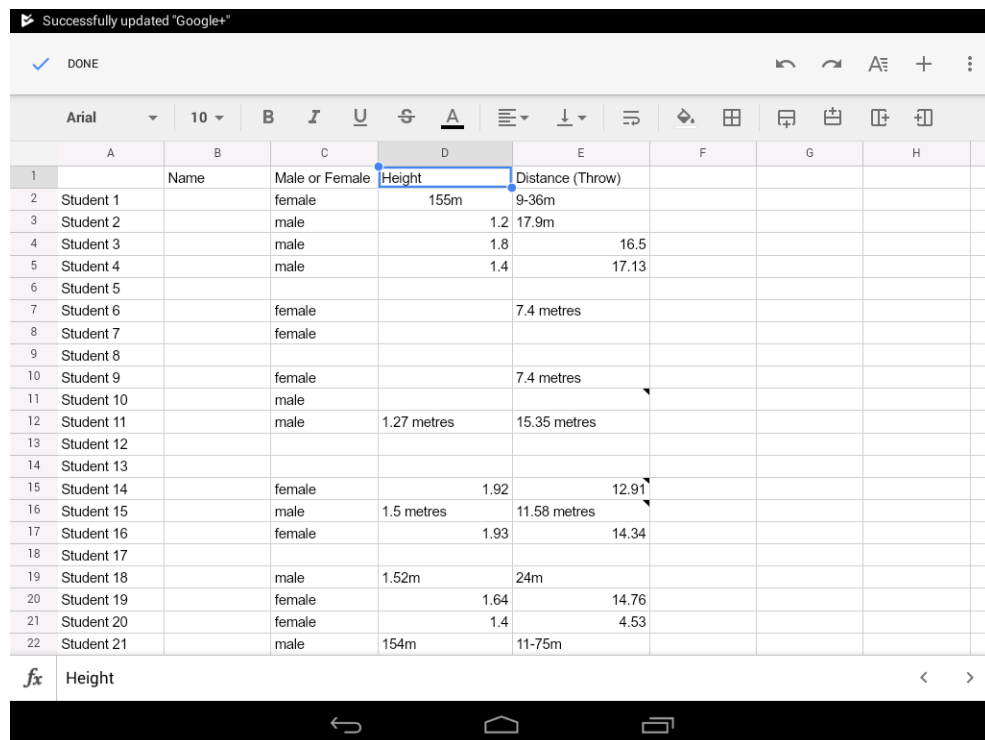
**Smart Distance.**<sup>8</sup> As the title suggests, Smart Distance is an application that measures the distance of an object from the tablet. The application requires the user to know the height of the object being measured. The user then aligns the two green lines of the screen with the object being measured as shown in Figure 4-8. Similar to the rationale for the Simple Measure application, this application was chosen for device compatibility and the simplicity of the interface.



Figure 4-8. Screenshot of Smart Distance application.

<sup>8</sup> Smart Distance is available to download from <https://play.google.com/store/apps/details?id=kr.sira.distance>

**Google Sheets.**<sup>9</sup> Google Sheets is a spreadsheet application that allows different users to simultaneously update a spreadsheet. Users can work separately on the spreadsheet offline and when it connects to the Internet, the information from the various users are coordinated on the online version. Figure 4-9 shows a screenshot of the collaborative spreadsheet. As students were stationed at different areas in the field and were also updating the spreadsheets as they gather the measurement, the collaborative spreadsheet enabled students to work on the same spreadsheet simultaneously. While there are other spreadsheets on the Android market, Google Sheet was the free version that supports this.



	A	B	C	D	E	F	G	H
1		Name	Male or Female	Height	Distance (Throw)			
2	Student 1		female	155m	9-36m			
3	Student 2		male		1.2 17.9m			
4	Student 3		male		1.8 16.5			
5	Student 4		male		1.4 17.13			
6	Student 5							
7	Student 6		female		7.4 metres			
8	Student 7		female					
9	Student 8							
10	Student 9		female		7.4 metres			
11	Student 10		male					
12	Student 11		male	1.27 metres	15.35 metres			
13	Student 12							
14	Student 13							
15	Student 14		female	1.92	12.91			
16	Student 15		male	1.5 metres	11.58 metres			
17	Student 16		female	1.93	14.34			
18	Student 17							
19	Student 18		male	1.52m	24m			
20	Student 19		female	1.64	14.76			
21	Student 20		female	1.4	4.53			
22	Student 21		male	154m	11-75m			

Figure 4-9. Screenshot of Google Sheet used in one of the activities. Names have been removed for anonymity.

In the applications chosen for the intervention, the criteria that was applied in choosing the application was the simplicity of the interface and user interaction required. Mobile devices having small screens benefit from uncluttered user interfaces. Another requirement was the application's ability to save students' work. (Note that although some measuring applications did not have support for saving students' work, the information collected could be stored in the spreadsheet). The other criteria for

<sup>9</sup> Google Sheets is available to download from <https://play.google.com/store/apps/details?id=com.google.android.apps.docs.editors.sheets>

selecting the application was its ability to support the learning activities designed for the application. The next section covers the learning activities by topic and discusses how the application selected supported the lesson objectives.

**Learning Activities.** The activities carried out are listed in Table 4-4 and mapped according to Sawaya and Putnam's (2015) and Patten et al.'s (2006) framework. All the activities are carried out in pairs except for Session 3 and the last activity that required bigger groups. While Table 4-4 only refers to the activity with the mobile device, in all these lessons, the structure follows this sequence:

- a discussion at the start of the lesson that covers an overview of the topic being investigated
- an overview of the mobile learning task and a tutorial on how to use the application
- mobile learning activity
- discussion of the artefacts created with the application.

**Sessions on Symmetry.** Studies have discussed that the concept of symmetry is one of the foundations necessary to understand mathematical concepts and solve mathematical problems (Leikin, Berman & Zalavsky, 2000; Ng & Sinclair, 2015). Knuchel (2004) argues that “showing students that symmetry and its properties surround us in the world we live in gives them a greater appreciation for the wide-reaching arms of mathematics and how we use maths throughout our lives beyond basic adding, subtracting, multiplying, and dividing” (p. 3). However, Ryan & Williams (2007) report that students at primary level struggle with some of the basic concepts of symmetry, like identifying lines of symmetry. As such, the mobile learning activities chosen for this topic align with the objective of having students identify lines of symmetry from objects in their environment.

In Session 1, students used Skitch to take pictures of symmetrical objects with 1 and 2 lines of symmetry. They then identified the line(s) of symmetry for that particular object. These annotated images were stored on their device and were later shared with the rest of the class. The second part of the activity used Mirrord which is a symmetry camera. The application is useful for checking if objects are symmetrical, because if it is symmetrical, the object would look the same in the camera when properly aligned. Students used the camera to check for facial symmetry and observed how their face

changed. Such processes illustrated that the face is ordinarily not symmetrical. The application also creates a symmetric representation of an otherwise non-symmetrical object as was illustrated in Figure 4-2. The created image can illustrate how, via reflection, an image becomes symmetrical, with each point being equidistant with another point. The activities in session 1 align with Van Hiele's Level 1 (visualisation) by allowing students to look for visual representations of symmetrical objects in a 3D world as opposed to the 2D representation afforded in books.

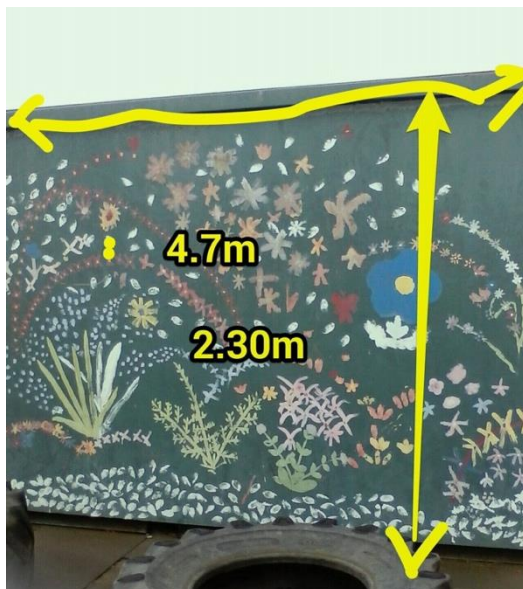
In Session 6 students were tasked to look for symmetrical objects outside their classrooms. All these artefacts were gathered in the same screen using an application called Snapshot Bingo. Unlike in session 1 where they clearly had to annotate each image they had taken with its line of symmetry, the lesson in this session only asked them to take pictures of symmetrical objects that followed certain properties. For example, some of the tasks include finding different objects with two, three and four lines of symmetry. During this part of the activity, students' strategies for finding the object relied on their understanding of properties of different shapes (e.g. a rectangle has two lines, a square has four and a triangle has three). In this exercise, students were operating at Van Hiele Level 2 (analysis), where they analysed the symmetrical properties of different objects that they found based on its geometric shapes. Both Session 1 and Session 2 activities concluded with students and the teacher convening in the classroom to discuss the pictures that they took.

***Sessions on area and perimeter.*** The lessons on area and perimeter investigated the two concepts with a particular focus on the relationship between the two. In Session 2, the lesson started with students investigating the area and perimeter of the nearby areas using the application Measure Map. The task was for students to estimate the area and perimeter of a nearby place and then compare this measurement with the one provided by the application. Aside from providing the measurements, the application also facilitated comparison of area and perimeter of large scale measurements (for example a six-digit measurement of an area, not otherwise provided in textbooks as textbooks example are mostly limited to two-digit measurements to facilitate manual computation). In the second part of the lesson, the focus shifted to properties of area and perimeter. The activity was an investigation of common misconceptions for area and perimeter and students proving or disproving statements. For example, a common



misconception is that dividing a rectangle in half will mean that the perimeter is also halved. Another misconception is that the area grows with the perimeter. Using the Area and Perimeter application, students drew rectangles of different sizes to get the computed area and perimeter. From these data, they proved or disproved whether these statements were true or not. While the activity can be done using gridded papers and having students compute for the area and perimeter manually, such a process takes much longer. With the application, the computation is off-loaded to the technology allowing students to focus on the investigation of the property. The class concludes with a discussion of the common misconceptions just investigated.

In Session 7, the lesson was on computing the area and perimeter of nearby rectangular objects/places found in the school ground. The Smart Distance application was used to compute the vertical distance of a space (for example, the playground) and the Smart Measure Application was used to measure the vertical height of an object (for example, a wall). Students then take a picture of the object/place that they have measured using Skitch and annotate the picture with the measurement that they have gathered. An example of this work is shown in Figure 4-10. The lesson concluded with students sharing their work with the rest of the class. This activity provided the students with an opportunity to visualise area and perimeter in relation to their environment. The lesson also showed how mobile technologies can function as measuring tools.



*Figure 4-10.* An example of student work showing the measurement of the length and height of a rectangular object

**Session on angles.** The tasks in Session 4 and 5 comprised of students finding representations of different types of angles in their environment. The sessions focus on Van Hiele levels of visualisation (identifying geometric figures based on appearance) and analysis (analysing geometric figures in terms of their components and properties). The aim of the sessions was to provide students with an opportunity to link the abstract concept of angles to their environment. In Session 4, the tasks were encoded in Quick Response (QR) codes. A QR code is a two-dimensional barcode that can be read by barcode readers on mobile devices. When scanned, the QR codes can directly connect the user to a website, input phone numbers for quick dialling, play multimedia files or display texts hidden encrypted in the code. Encoding the task in QR code rather than giving it as a list of items added a game-like aspect to the activity, similar to how ordinary lessons are sometimes structured in a game-like environment (e.g. a scavenger hunt), rather than giving the students the task outright. On scanning a QR code, students were presented with the task they had to do (which were to find the different types of angles: acute, obtuse, reflex, straight, supplementary and complementary). They used Sketch to take pictures of objects and marked the pictures to show the angle. An example of a completed task is shown in Figure 4-11. At the end of the lesson, the teacher called on some of the students to share the angles they found. In Session 5, students continue to investigate how angles were present in the man-made and natural environment. This investigation was carried out in the school grounds. Students use the application Snapshot Bingo to gather the different images of angles on the same screen. At the end of the activity, students convened back in the classroom and presented their work to the rest of the class by connecting the tablets to a bigger screen. In both activities, the tablets' primary function was to enable students to gather and present artefacts from the environment.

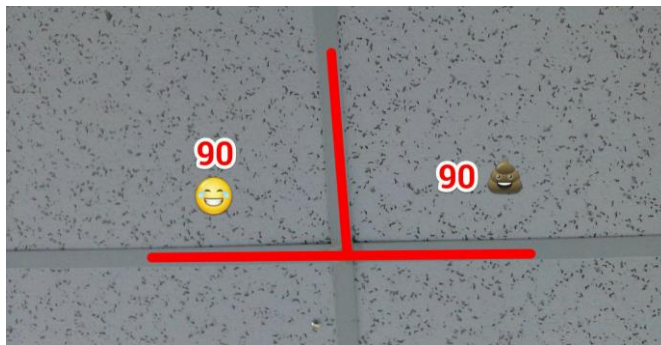


Figure 4-11. An example of students' work showing supplementary angles.

***Session on information handling.*** Information handling is normally delivered via investigations. In Session 3, the activity was survey design and data analysis. Using the application InstaSurvey, students created a survey which they administered to the rest of the class by passing the tablets from one group to another. At the end of the survey, students analysed the results using the bar graph generated by the application. They then took turns to share their results with the rest of class. A discussion of what makes a good and a bad survey also followed.

In Session 8, students worked outdoors in groups of four to measure the class average height and length of throw. Using the Simple Measure Application, students measured their height. As the Simple Measure application requires a reference height to be able to measure height, students used a meter stick to establish an initial reference point to hold the tablet. These height measurements together with their name and gender were recorded in Google Sheet (refer to Figure 4-9 for a screenshot of the spreadsheet). They then measured how far they could throw an object by throwing a rubber ball and measuring the throw's distance from the origin using the Smart Distance application. The class convened back in their classroom to analyse the graph created in Google Sheet. They also discussed errors in measurement and how these might have affected the result.

In both sessions, the activities demonstrated the multi-functionality of mobile devices as they supported students in their investigations. In Session 3, students carried out the whole inquiry process on the mobile device. In Session 8, the mobile device was used as a measuring tool. While the measurements from the mobile device showed some errors, the process allowed for a rich discussion of elements that affected information handling.

This section has covered the different applications used in the mobile learning activities and discussed the justifications for choosing the applications used. It has also provided an overview of the mobile learning activities carried out. Table 4-4 provides a summary of these activities mapped into Sawaya and Putnam's (2015) framework and Patten et al.'s (2006) functional pedagogical uses of mobile devices.

Table 4-4

*Activities carried out mapped into Sawaya and Putnam's (2015) design framework*

<b>Session</b>	<b>Mobile Learning Activity</b>	<b>Functional Use</b>	<b>Affordances</b>	<b>Activity Type</b>	<b>Learning Goals</b>
Session 1 - Symmetry (Phase 1)	Students took pictures of symmetrical objects and annotated it with its line of symmetry using Skitch. Using Mirrod, they also created symmetrical pictures of non-symmetrical objects in their environment.	Interactive, data collection, location aware	Capture Communicate and collaborate Create	Practicing maths skills Investigating Creating content	Solve problems Form connections Use representations
Session 2 - Area and Perimeter (Phase 1)	Students investigated area and perimeter of surrounding environment using MeasureMap. They also investigated properties of area and perimeter of objects using the manipulative Area and Perimeter.	Interactive	Compute Communicate and collaborate	Practicing maths skills Investigating Applying mathematical problems	Solve problems Form connections
Session 3 - Information Handling (Phase 1)	Students administered surveys using an application called InstaSurvey. After which they interpreted the data collected and shared these findings with the class.	Interactive, data collection, collaboration	Compute Capture Communicate and collaborate Create	Investigating Applying mathematical problems Creating content	Form connections Use representations
Session 4 - Angles (Phase 1)	Tasks were encoded in QR codes. Using Skitch, students took pictures of objects that corresponds to certain types of angles. They annotated the pictures to show the angle and its' angle type.	Data collection, location aware	Capture Communicate and collaborate Create	Practicing maths skills Investigating Applying mathematical problems Creating content	Solve problems Form connections Use representations

<b>Session</b>	<b>Mobile Learning Activity</b>	<b>Functional Use</b>	<b>Affordances</b>	<b>Activity Type</b>	<b>Learning Goals</b>
Session 5 - Angles (Phase 2)	Students looked for examples of the different types of angles in their environment, one example for a man-made angle and another natural angles. These artefacts were gathered using Skitch and were later discussed in class to compare man-made and natural angles.	Data collection, location aware	Capture Communicate and collaborate Create	Practicing maths skills Investigating Applying mathematical problems Creating content	Solve problems Form connections Use representations
Session 6 - Symmetry (Phase 2)	Using SnapShot bingo, students looked for specific objects in their environment that follows specific symmetrical properties. These objects were later shared with the rest of the class.	Data collection, location aware	Capture Communicate and collaborate Create	Practicing maths skills Investigating Creating content	Solve problems Form connections Use representations
Session 7 - Area and Perimeter (Phase 2)	Using an application called Smart Distance (for measuring horizontal length) and Simple Measure (for measuring vertical length), students measured the area and perimeter of various objects in their environment.	Data collection, location aware	Compute Communicate and collaborate Create (for outdoor activity only)	Practicing maths skills Investigating Applying mathematical problems	Solve problems Form connections
Session 8 - Information Handling (Phase 2)	Students used the application Simple Measure and Smart Distance to compute for the height and length of throw of each student. Data were encoded in a Googlesheet and were analysed collectively.	Data collection, location aware, collaboration	Compute Capture Communicate and collaborate Create	Investigating Applying mathematical problems Creating content	Form connections Use representations

## **Procedure**

A pre-test of MT and MAI was completed by the participants. The time-scale for the both tests was 40 minutes. Following the tests, there was an introductory session to brief the participants about the nature of the activities to be carried out. The class participated in eight weekly hour-long sessions of mobile learning activities spread over a period of three months (including the term break and off-school in-service days). There were two phases in the study. Phase 1 consisted of mobile learning activities carried out indoors and Phase 2 activities were carried out outside the classroom. End activity evaluation was carried out at the end of every activity in Phase 1 and at the end of every other activity in Phase 2. The frequency of the measure was changed as a response to students' feedback about the frequency of the evaluation. Midway through the programme (end of Phase 1), the group completed the MAI test again. An interview with select students was also conducted. Students went on a two-week spring break afterwards. They continued with Phase 2 of the intervention after the break and participated in four more weekly sessions. At the end of the programme, the students took the MT and MAI post-test. An interview with the teacher and student participants of the experimental group was also carried out at the end.

## **Data Analysis**

For the micro level evaluations, the end activity evaluation was analysed using descriptive statistics. Adjective pairs that had the positive adjective on the right and the negative adjective on the left were reverse scored. The higher the score, the higher the agreement with the positive adjective. Video recordings of the sessions were analysed using critical incident analysis. Critical incident analysis has been used by several mobile learning studies (Vavoula & Sharples, 2009; Lonsdale, 2011). The purpose of this process is to identify the breakdowns and breakthroughs of the learning activities. Breakthroughs refer to the “observable critical incidents which appear to be initiating productive new forms of learning or important conceptual change” and breakdowns are “observable critical incidents where a learner is struggling with the technology, is asking for help, or appears to be labouring under a clear misunderstanding” (Vavoula & Sharples, 2009, p. 56).

The student and teacher interviews from meso level data evaluations were analysed using theoretical thematic analysis. Theoretical thematic analysis is an analyst-driven thematic analysis as opposed to the more data-driven inductive approach (Braun

& Clarke, 2008). The themes identified in the study closely matched the interview questions: 1) student perception of the tablet activities, 2) advantages of using the tablets and 3) disadvantages of using the tablets and 4) issues encountered. Responses were compared to the end interview data to see if there was a change in perception of the tablet use. The teacher interview was used to help validate the findings.

For the macro level evaluation, the MT pre-test and post-test scores were analysed using paired t-test. The MAI scores for each subscale was analysed using repeated measure analysis of variance (ANOVA).

## Findings

### Micro-evaluation

**Student evaluation.** A 5-point semantic differential scale was used in the activity evaluation. A score close to five means an agreement with the positive adjective and a score close to zero means agreement with the negative adjective and a score that falls closer to 2.5 means a neutral score. Of the total 2414 item responses from the six end-activity evaluations, 63% fell above 3.0, 17% fell below 2.0 and 19% fell between 2.0-3.0. The mode 5.0 (n=743) was 31% of the item responses in comparison to the frequency of the lowest score (n=146) which was at 6%. This shows that majority of the item responses were in the positive adjective range, but there were also items where students were more in agreement with the negative adjective.

The average scores for all the activity ratings range from 1.65 to 4.64. For example, in the Angles (Phase 2) session, a mean score of 4.6 in the paired item *boring vs fun (tablet)* means that the average student rating found the use of the tablet fun as opposed to boring. Similarly, the mean score of 1.65 for the paired item *ineffective vs effective* on Information Handling (Phase 2) means that the students found the use of the tablet ineffective as opposed to effective for that activity. Student evaluation of the activities is shown in Figure 4-12. It can be noted that the ratings are mostly to the right-hand side of the graph which indicates that student ratings for both activity and the use of the tablets were mostly positive. The graph also shows that the symmetry activity which also happened to be the first activity had higher ratings than the rest.



Figure 4-12. Average of end activity evaluation grouped by session



### Meso-evaluation

**Critical incident analysis.** A critical incident analysis was carried out using the video data from the sessions. Although there was a total of 8 sessions, one session had corrupted video data and this was not included in the analysis. Session 7 only have half of the class covered in the video as the students were dispersed in two locations, one with the teacher and one with myself. In addition, the last session also had a partially corrupted data which only includes around 9 minutes of video data rather than the full session. Table 4-5 gives the amount of time allocated for the hands-on activity. From these videos, a total of eight breakthroughs and (19 occurrences) and 21 different breakdowns (53 occurrences in total) from seven sessions were identified. For a detailed description of these breakdowns and breakthroughs, refer to Appendix H. Admittedly, there were fewer breakthroughs identified because the focus of the incident analysis is to identify issues within the pilot study. These breakdowns were identified during the activity proper with the mobile device, any discussion that comes before and after the activity were not included.

*Table 4-5*

Video data in minutes

Session	Minutes
Session 1 - Symmetry (Phase 1)	21 minutes
Session 2 - Area and Perimeter (Phase 1)	16 minutes
Session 3 - Information Handling (Phase 1)	15 minutes
Session 4 - Angles (Phase 1)	20 minutes
Session 5 - Angles (Phase 2)	13 minutes
Session 6 - Symmetry (Phase 2)	No available data
Session 7 - Area and Perimeter (Phase 2)	24 minutes
Session 8 - Information Handling (Phase 2)	9 minutes (Partial data only)

**Breakdowns.** The breakdowns were categorised into three headings, technical, social and activity design issues. Table 4-6 lists the issues encountered and the category for the technical breakdown. Technical issues refer to problems with the use of the tablet like application stability, responsiveness and network connectivity. Activity design issues refer to problems caused by the learning activity (for example, students not being clear about what to do next or students not having a good grasp of the topic covered). Social issues relate to problems that are related to the social layer of the activity (like collaboration and participation in the activity). There were 10 distinct technical issues, nine activity design issues and two social issues identified.

Table 4-6  
*List of issues identified and its category*

<b>Breakdowns</b>	<b>When did it occur</b>	<b>Category</b>
Tablets were not charged	Session 1, CID 1 Session 2, CID 2 Session 4, CID 2	Technical
It was not possible to check on students' work remotely	Session 1, CID 9	Technical
Stability of the applications being used	Session 1, CID 14 Session 1, CID 21 Session 2, CID 7 Session 3, CID 2 Session 3, CID, 3	Technical
Access to applications	Session 1, CID 15 Session 2, CID 3 Session 5, CID 2	Technical
Difficulty in handling the tablets with the cases	Session 1, CID 3	Technical
Network connectivity issues	Session 1, CID 9 Session 2, CID 1 Session 4, CID 7	Technical
Visibility of the screen in outdoor conditions	Session 5, CID 1 Session 8, CID 2	Technical
The measurement given by the tablet was not accurate	Session 7, CID 2 Session 8, CID 5	Technical
There is no way to verify the app measurement	Session 7, CID 6	Technical
In a collaborative worksheet, it was not possible to track student input	Session 8, CID 6	Technical
Too many handouts confuse the students	Session 1, CID 2	Activity design
Students were not clear about what to do	Session 1, CID 4 Session 1, CID 10 Session 4, CID 9 Session 7, CID 1 Session 7, CID 4 Session 7, CID 8 Session 7, CID 9	Activity design

<b>Breakdowns</b>	<b>When did it occur</b>	<b>Category</b>
Students were not clear about the meaning of some words used and the symbols used in the application	Session 2, CID 4 Session 2, CID 6	Activity design
Some students do not have a good grasp of the topic.	Session 1, CID 6 Session 1, CID 11 Session 2, CID 5 Session 5, CID 3 Session 7, CID 5	Activity design
Students were not sure how to use the application	Session 1, CID 7 Session 1, CID 12 Session 7, CID 3	Activity design
Students use the tablets for non-activity related tasks	Session 1, CID 18	Activity design
Weather condition was not suitable for the activity	Session 7, CID 10 Session 8, CID 1 Session 8, CID 4	Activity design
Students did not finish on time	Session 3, CID 4 Session 8, CID 7	Activity design
Students get tired of repetitively switching between applications	Session 4, CID 3	Activity design
Students are not participating in the activity.	Session 4, CID 5 Session 5, CID 4 Session 5, CID 6	Social
Students are not collaborating.	Session 3, CID 1 Session 7, CID 7 Session 8, CID 3	Social

Note: CID refers to case id. Details of the breakdown is available in Appendix H.

There were far more technical issues identified in the first activity than in the succeeding activities which shows that although students are already familiar with the use of the tablets, the transition to using these devices for learning activities still required some training. It's also possible that fewer issues were identified because students have learned to troubleshoot issues themselves as was seen in some footages where more tech-savvy students help students encountering technical problems. This matter was also noted by the teacher in the teacher interview---that students were initially worried about all the technical glitches but have adapted over time.

Some incidences occurred only once (for example, the problem of not being able to check students work remotely, the issue with handling the tablet fitted with a case). It's possible that these issues were no longer raised because participants have accepted it as a shortcoming and managed to work around it (for example, after having asked once if it's okay to remove the cases because it was difficult to use, in the succeeding sessions students simply took it out of the case to facilitate better handling of the tablet).

The most common technical issue is the stability of applications being used and this problem has impacted students work. When the tablets or the application malfunctions, students work were not always recovered and would require students to re-do the work. As one student phrased it:

*“If it doesn't work then all that you've done is gone unlike when you're working with paper. If you've got sheets there will always be spares but with tablets, you don't... so you do it again, then you get bored of it (Lorraine).”*

This issue is problematic particularly for activities that require data gathering as the instability of the tablet would make students lose a significant amount of work. For activities that are chunked into several steps, while this is still an issue, its effect is not as much as that only require going back a few steps. As one student explains, *“It's okay sometimes coz we got through it, you just have to turn your tablet on and off and then it works. (Barry)”*

Of the nine activity design issues identified (25 occurrences), 14 issues were flagged in the indoor sessions and 11 issues flagged in the outdoor session but it is likely that more activity design issues were experienced outdoors (because of the corrupted video data for Session 6 and Session 8). The most common activity design issue is that students were not clear what to do next (n=7). There were several instances that students started working on the tablet but end up not being clear about the task and this required an intervention from the teacher to get the class's attention and pause for a

while so that the teacher can walk them through again about the task that they needed to do. This problem typically occurred when students used several applications in one session. For example, in session 1 (Appendix H, CID 10) there were two activities and two different applications used. Students were given an orientation on what they needed to do at the start of the session. They went on to do the first task with Skitch, but got confused on what they had to do next because it required a different application.

Another common issue refers to students' grasp of the topic (n=5). In some instances, students appeared to lack the foundations to be able to work on the activity. For example, in the symmetry activity, although the concepts were covered before the activity, some students were not clear what symmetry was (Appendix H - Session 1, 3 min, CID 6). Although this is a breakdown, because the teacher could observe what the students were doing, this breakdown was resolved by a brief explanation from the teacher, clarifying what is symmetrical and what isn't.

In the outdoor setup, the weather was a contributing factor in the implementation of the activity (n=3). During the area and perimeter session outdoors (Session 7), the weather condition started satisfactory for the students to work on the activity outdoors. Towards the three-quarters point of the session, it started to drizzle and the tablets were getting wet, which affect the screen sensitivity of the tablet. In the information handling activity (Session 8), the activity was to use the tablet to measure the distance of a throw and input the results in a class spreadsheet. It was very windy on the open field which affected the data gathered by the students. Nevertheless, this issue allowed a rich discussion of information handling and the possibility of errors in data collection. In Session 6 where students had to look for different objects subject to different geometrical properties, the weather condition towards the middle of the session turned chilly. The video data for this session was not available but during the session, some students were observed to be taking shelter and not working in the activity. When asked if they were okay, a pair replied that they were cold but started working on the activity again. Another pair of students who stopped working said that they've finished although what this meant was that they finished the objects that they could easily find but did not push through looking for those that were not so obvious. In these three examples, weather conditions affected mobile learning activity outdoors and illustrated the need for contingency plans should the weather not be permitting.

There were two issues in the social layer: students not participating in the activity and students not collaborating. Both categories related to student disengagement. In the

first, students were not participating because of difficulties they encountered in the activity. For example, one student did not complete the activity because the technical difficulty she encountered required that she had to do the activity again. In the second issue, there were cases where students were observed not to be collaborating probably because they were not the ones operating the tablet. Both categories can be argued to be a result of failings of the technology and a shortcoming in the design of the activity.

**Breakthroughs.** In the earlier part of this chapter, breakthroughs were identified as “observable critical incidents which appear to be initiating productive new forms of learning or important conceptual change.” This section thus focuses on the observed advantages of using mobile devices.

One of the observed advantages of using mobile technologies is that they facilitate contextual learning. This was observed in several of the learning activities. For example, in Session 4, CID 4, a student was observed discussing with a partner how the pattern on the ceiling fits a particular angle property. The same goes for Session 1, CID 5, students discuss what object would have two lines of symmetry. Having identified that a rectangular object would meet the requirement, a student went up to find something in the classroom that fits the property being asked.

Another advantage is that it facilitates visualisation of abstract maths concepts. For example, in Session 1, CID 8, the students were not clear when would objects have two lines of symmetry, so, a teaching assistant tried to explain this by holding up a notebook and pointing out its line of symmetry (see Figure 4-13). Students then took a picture of this object and annotated it with its line of symmetry using Skitch. The same harnessing of teachable moment was observed when the teacher went up a chair to point out the existence of complimentary angles on the ceiling as shown in Figure 4-14. (Session 4, CID 1) which students then took a picture of.



*Figure 4-13.* Teaching assistant showing line of symmetry



*Figure 4-14.* Teacher uses ceiling line as an example of supplementary angles

There were also evidences where students think about the abstract maths concepts and paired it with concrete representations in their environment. In cases where there was not a readily available representation, students tried to create a concrete representation of these abstract concepts. For example, in the angles learning activity, students adjusted the object in their environment to fit the properties that they need (see Figure 4-15). This illustrates another benefit of mobile learning in terms of allowing “abstract (representational) and concrete (environmentally-situated) knowledge to be integrated (Joint Information Systems Committee (JISC), 2011).”



*Figure 4-15.* Students working on an activity.

The activities were set up as paired or group activities and this allowed students the chance to work collaboratively using the tablets. For example, in Session 5, CID 7, a pair of students found something that matches the property being asked for, the student then approached another group to share that finding. At the end of the session, when

students were sharing pictures of their work with the rest of the class, the object that the student pointed out appeared several times. Collaboration is not limited to the learning activity but also evident in students working together to overcome a technical difficulty. Some students have acted as technical helpers and helped other groups without being asked to do so.

Another advantage of the activities is its capacity to promote active learning environments. The activities provided in the session are all hands-on activities which have been mostly received positively, technical breakdowns aside. In Session 1, for example (CID 22), students have completed the task but continue to explore the different features of the application, thereby letting them explore different properties of reflective symmetry.

The breakthroughs discussed in this section match the potential benefits of mobile learning. The mobile learning activities facilitated active networked learning, but also facilitated visualisation of maths concepts as students matched the abstract maths concepts with their concrete representations. While these activities could have been delivered in the same way without a mobile device, the mobile device in these instances allowed students to create artefacts which they shared with the rest of the class at the end of the activity. The artefacts also served as records of how abstract maths was situated in the environment. In addition, the mobile devices facilitated the activities as students moved in and out of the different learning spaces, from gathering artefacts “in the wild” and creating new content as they annotated the artefacts they had gathered, to sharing these new artefacts with other members of the class.

**Student interviews.** Results from the two interviews carried out, one mid-study and the other at the end of the intervention are as follows.

**Mid-study interview.** (Where names are given, please note these names are fictitious and are used to represent gender or identify continuity in student responses.) Of the 10 students interviewed, one student preferred to step back and not reply to any of the questions while another student only answered in agreement to another student’s reply (i.e. *I’m the same*). The other students explained that these two students were quiet by nature. Student feedback during the mid-interviews has been mostly positive. They found the activities so far as easy to understand (n=3), fun (n=2) and see the flexibility of the tablet as an all-around resource (n=2). When asked about activities they liked, students referred to the angles session (n = 3) for various reasons. One noted that it’s a straightforward activity, another sees its attempt to link angles to everyday life



while the other student sees it as an active learning activity “*instead of standing back and getting it all in (Diane)*”. There was one student, however, who felt differently about this session, mainly because the student explained that she doesn’t know what angles are. The session that was not well liked is the area and perimeter session (n=2), and again, this is because of the complexity of the topic.

Students were asked what they think are the advantages of the tablet. One of them thought it made them smarter, another felt that they were more engaged, one felt that it was fast-paced, and two students said it made maths easier. When asked for the disadvantage, students referred to the technical issues that they encountered (n=3) but did not really put much emphasis on this. They were asked to relate challenges that they encountered and some students found the content as a challenge (n=5) in addition to the technical issues (n=4), for example, unresponsiveness of the application and tablets not being charged. Overall, however, students felt positive about the activities despite the challenges. As one student explains, “*it was easy to understand because when we’re doing maths normally, everyone tends to get just stressed out but I think they are less stressed out with the tablets.*” Another student even referred to a classmate who has learning difficulties and narrated how that classmate doesn’t like maths but ends up liking maths when they were using the tablets.

Recommendations to improve the intervention include working in bigger groups (n=2) and a clearer overview of what they must do during the activity. Another student referred to the frequency of the end-evaluation which resulted in the change in frequency that this survey was conducted.

***End-study interview.*** Student feedback about the use of the tablets has been altered except for three students who maintained that this style of learning maths is better than their usual maths offerings. For those with altered views, while most of these students (n=3) still thought positively about the tablets, their feedback now incorporated the technical issues that they encountered. For example, in the mid-intervention data, a short reply of “*useful*” to the question about how they found the intervention has been altered to “*I like the tablets it's just sometimes they're not working*” and the short reply “*fun*” becomes “*It was fun but some of the technology didn't work and basically all the battery are dead.*” There were three students with altered views. Diane, for example initially thought that the use of the tablets was fun but during the last interview was not sure about how she felt about the tablets. Bianca initially liked the tablet activities even with the technical issues but a continued experience of technical issues up to the end of

the intervention resulted in a more negative outlook on the use of the tablet. She explains, “*every time that I got a tablet, the app would not work, I had to use a camera.*” In Eric’s case, his previous feedback that of “*I’m the same [it was easier]*” now takes more note of the technical difficulties. These changes in feedback show that students have considered the use of the tablets in a more thoughtful manner. Initially, their comments would be how fun and easier it was in comparison to their usual maths session but towards they end also considered the technical difficulties they encountered and how it affected the learning experience.

**Teacher interview.** The teacher indicated that the students enjoyed being part of the experiment and although there were technical experiences encountered she said that the students were “*quite keen and motivated*” during the intervention. This observation ties with the end activity evaluation results and the student interviews where students rated the activities positively even with the technical difficulties encountered.

The teacher, however, had mixed views about the use of the tablets. The teacher described the tablets as a “*good hook because they are kind of novelty factor*” but also considered its overall place in the maths classroom and her classroom. The issue of differentiation in the activities offered to the whole class was a concern for the teacher because the students were at different levels of maths. This issue was repeatedly emphasised in the interview. She found that students working on the tablet all at one go can be challenging and by offering differentiation will not only accommodate different student characteristics but also be helpful in class management.

As a teaching tool, the teacher was not very sure about the role of the tablet in the classroom. She noted that the advantage with the tablets was that “*it’s very clear whether they understand or not what’s being asked of them*” referring to the artefacts that students produce as part of the tablet based activity but she asked, “*is the question, can mobile technologies teach maths, are the mobile technologies assisting maths, or are the mobile technologies an assessment tool?*”

The teacher noted that the activities might not be a good fit for all the students in class. There are students that can link the skills from the activities with what they are learning but not all students in the class are able to do that. The nature of the class as well has much to do with the success of the activity. She noted that more than half of the class have additional support needs including academic, social and emotional support:

*“You’ve got these students who 75% of them are already frustrated with themselves and their abilities and then you add in something else that is going to cause them more frustration add to which the tablet and then you add in a partner which is going to cause them more frustration so basically managing that”.*

For example, she noted that the group does not have as much tolerance and resilience as other kids so *“if it is cold they can't just think, oh it is cold I need to get this done”* but would end up stopping instead or *“if it’s not working, they would instantly just miss it instead of persevering with it.”* This partly explains why the students were observed to not engage in the activity in some sessions as discussed earlier in the Critical Incident Analysis section.

When asked for the disadvantages of using the tablets the teacher noted that students were being asked to do too many things not just the maths but how to work out the tablet as well. She explained that:

*“it’s quite complicated sometimes with a lot of instructions to follow and lots of things to remember in terms of like some of the processing difficulties that they have and dyslexic difficulties, that’s then quite hard.”*

This is related to the activity design issues flagged in the CIA (for example, students not being clear with what to do, students not being clear how to use the application and students not having a good grasp of the topic) and again relates to differentiation to meet individual learning needs.

Nevertheless, the teacher noted that the programme was a good experience for the students. She noticed the students improved in behaviour and were less anxious about technical difficulties towards the end in comparison to how they were at the start of the program. She does, however, recommend that differentiation and a better integration with the lesson rather than the once a week event would probably improve the overall programme.

### **Macro-evaluation**

**Mathematics attitude inventory.** A repeated measures ANOVA was conducted for each of the MAI subscales. The descriptive statistics for the MAI subscales is shown in Table 4-7. The repeated measures ANOVA results showed that the results did not statistically differ between time points (pre-test, mid-test and post-test) for the subscale enjoyment ( $F(2, 34) = .974, p = .388; \text{partial } \eta^2 = .054$ ); self-confidence ( $F(1.455, 24.741) = 1.050, p = .361; \text{partial } \eta^2 = .058$ ); value of mathematics ( $F(1.463, 23.411) =$

.034,  $p = .967$ , partial  $\eta^2 = 0.002$ ); and confidence with technology ( $F(2, 34) = 2.304$ ,  $p = .115$ ; partial  $\eta^2 = .119$ ). For the subscale value of mobile technology, a repeated measures ANOVA with a Greenhouse-Geisser correction determined that students valuation of mobile technology statistically differed between time points ( $F(1.541, 26.189) = 3.935$ ,  $p = .029$ ; partial  $\eta^2 = .188$ ). Post hoc tests using the Bonferroni correction revealed that there was a slight reduction in students' valuation of mobile technology from pre-test to mid-test.

Table 4-7

*Mean pre-test, mid-test and post-test scores.*

Variable	Pre-test	Mid-test	Post-test
Enjoyment (EN)	2.95 (1.44)	3.11 (1.32)	3.08 (1.44)
Self-Confidence (SC)	3.14 (1.4)	3.42 (1.26)	3.34 (1.22)
Value of Maths (VM)	3.68 (1.15)	3.76 (1.19)	3.61 (0.94)
Confidence with Technology (CT)	4.55 (0.86)	4.38 (0.99)	3.95 (1.1)
Value of Mobile Technology (VMT)	4.11 (0.69)	3.72 (1.18)	2.94 (1.26)

A correlation matrix of the usability scores with the MAI technology related scales is shown in Table 4-8. There was a significant positive correlation between students' perceived ease of use of the tablet with perceived usefulness, user satisfaction and value of mobile technology. The same is true for the usability scores and post-test VMT scores, except for the usability subscale usefulness. Students' confidence to use technology had no significant correlation with how the students perceived the usability of the activities, neither was it correlated with the perceived value of mobile technologies for math.

Table 4-8

*Correlation matrix of usability scores and MAI technology related scales*

	1	2	3	4	5
1 Ease of use	-				
2 Usefulness	.794**	-			
3 User satisfaction	.893**	.806**	-		
4 CT (post-test)	.255	.277	.321	-	
5 VMT (post-test)	.485**	.297	.557**	.302	-

\*\*significant at .01 level (1-tailed)

**Mathematics achievement.** A paired t-test for maths test showed a significant difference from pre-test ( $M=12.37$ ,  $SD=5.77$ ) to post-test ( $M=15.42$ ,  $SD = 7.10$ ),  $t(18)=2.971$ ,  $p = .008$ ,  $ES = .70$ . Differences in the gain scores of male ( $M=1.40$ ,  $SD=5.23$ ) and female ( $M=4.89$ ,  $SD=2.67$ ) students was also checked but no significant difference,  $t(14)=-1.858$ ,  $p=.085$ ,  $ES =.83$  was found. Gain scores were also compared by students' performance in the pre-test. There was no significant difference found between students who scored low at pre-test ( $M=2.38$ ,  $SD=4.66$ ) and those who were at the upper group ( $M=3.55$ ,  $SD=4.50$ ),  $t(17)=-.552$ ,  $p=.588$ ,  $ES=.26$ ).

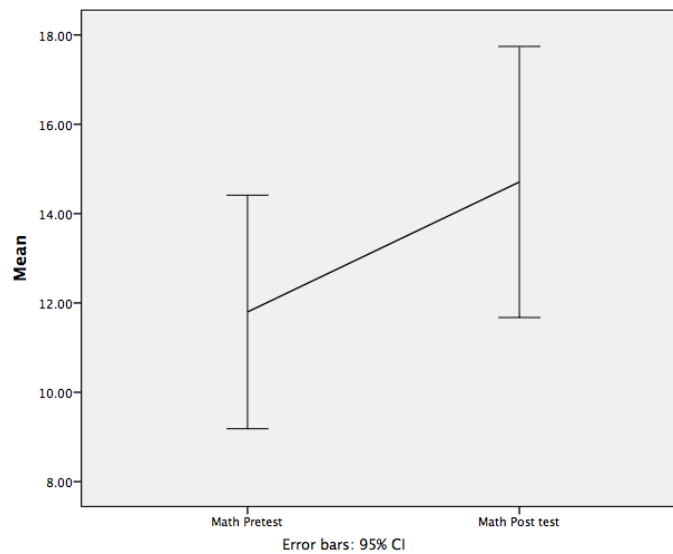


Figure 4-16. Graph of pre and post maths test scores with error bars shown.

### Discussion

What follows is a short discussion of the results. How these findings relate to the mobile learning literature and technology supported mathematics learning is covered in Chapter 7.

Student views of the intervention have been overall positive although towards the end students have also been mindful of the issues they encounter with the tablet and how it affects the learning experience. This is reflected in their end activity evaluation and how they rated the first activity high and the last activity comparatively lower. Student narratives during the interview has changed from “*it was fun*” to “*it was fun but sometimes it didn't work.*” In general, users who had technology issues during the session tended to rate the activity and the tablet on a lower scale. One possible explanation is that in most of these activities, the mobile device is the medium to carry out the learning activity. For example, in session four, when a mobile device had issues

scanning a QR code, it was impossible for the students in that pair to carry on with rest of the activity until after some technical assistance. One of the students, at that point refused to finish the activity on a different tablet while the other student carried out doing the activity on her own. The student who refused to continue with the activity gave a lower rating in both tablet and activity while the student who continued with the task still gave a higher rating for the tablet and the activity and did not account the technical failure earlier experienced.

While the use of the tablets has been overall good, the technical difficulties experienced in some of the activities caused some stress to the students and in some cases deterred students from participating. The issues encountered possibly explains the students' lower post-test scores on the Confidence with Technology Scale of the MAI and Value of Mobile Technology. In the interviews conducted, students explained that while they had used the tablets before and had access to similar devices at home, the nature of use varies with how the tablets were used in the activities. It would be worth investigating whether these changes in confidence with technology and attitudes towards mobile technology will change with a longer intervention that allows enough time for students to adjust to this alternative way of learning maths.

Student enjoyment of the tablet-based activities did not translate to significantly better attitudes towards mathematics for the subscales enjoyment, self-confidence and value of mathematics. There was a slight positive gain during mid-test for enjoyment and self-confidence but this was possibly due to novelty effect as these values went down slightly at post-test, although still higher than the pre-test score. As for the variable value of mathematics, this declined at post-test in comparison to their mid-test and pre-test scores. Micro-level results show that students rated mobile technologies positively but these results do not explain the decline in how they perceived the usefulness of mobile technologies for maths. Students explained that they like using the tablets but sometimes it does not work and this is reflected in their post-test scores.

As for the effect of mobile technologies to their performance in a maths test, there was an observed significant improvement from their pre-test scores. Students explained that they found the activities fun and easier and this positive attitude might have contributed to their increased score. This finding, however, is quite limited due to the absence of a control group and other limitations discussed below.

### **Limitations of Current Study**

Several limitations regarding the design of the intervention are present in this study. The self-reporting data given that the participants of the study are younger students is one limitation. To mitigate this issue, steps have been taken to ensure that students understand the questions whenever they complete an evaluation at the end of each activity. Time and again, students are also reminded about the purpose of the study.

Another limitation was the use of a wearable camera to collect video data. As the video recording device is worn by the researcher who also provides technical support to the students when they need help, a majority of the events captured are the technical issues encountered. This also means that when there is an interesting event being captured with one group, and a technical issue with another group has been raised, the video focus shifts from the group activity to the problem that needs solving. In some ways, this has been an effective way to record the technical issues but it also makes the identification of breakthroughs more difficult.

There are threats to validity present in single group pre-test post-test design. Being a preliminary discussion of an ongoing research, it is acknowledged that the small sample size and the lack of control group presents issues on the generalisability of the results. These issues are addressed in the next iteration of the study.

### **Summary and Next Direction**

This study was an initial investigation on the use of mobile technologies to support learning mathematics. Students had positive evaluations of mobile learning but some breakdowns experienced have affected the learning experience. Breakdowns of mobile learning as identified by the critical incident analysis were either technical issues, activity design issues or social issues. These issues appear to have affected students' views on the usefulness of mobile technologies. Nevertheless, there was a slight improvement to students' enjoyment of mathematics as well as a significant positive difference in students' achievement.

Several issues have been flagged by the students and teacher during the interview and during the critical incident analysis. Recommendations for design changes are outlined in Table 4-9. Among these changes include provision of extra tablets, network connectivity, and changes to the lesson structure. These changes were considered in Study 2.

Table 4-9  
*Design changes*

<b>Breakdowns</b>	<b>Design Implication</b>
Tablets were not charged	Teachers need to make sure that the tablets are properly charged before the session. Extra tablets would also be useful in case some of the tablets are not working.
It was not possible to check on students' work remotely	As the teacher suggests, it would be better if it's possible to see the students work in one place. However, the process of a teacher going around the class to check on students' progress has also been useful particularly in spotting misconceptions right then and there. So, it would be good to have a folder where all students work is stored but this doesn't override the need for the teacher to check each group as they work on an activity.
Stability of the applications being used	Proper tablet testing with the specific application is necessary. Because the current study used different tablets, this was not checked for every device. It was not expected that the tablets would behave differently. Rather than a variation of tablet brands, using the same brand would limit the amount of testing needed.
Access to applications	Ensure students have access to the application and provide backup access in cases that it's not available. Also, make sure that the locks on the tablet do not block the students from being able to switch to different applications.
Visibility of the screen in outdoor conditions	This would have been better addressed during the purchase stage of the tablet as screen clarity in outdoor condition is a frequent problem with the mobile device.
The measurement given by the tablet was not accurate	The app measurement was off because it was not calibrated correctly or because the tablet position was moved rather than tilted. This can be solved by a longer orientation before students proceed with the activity proper and by explaining how the measurement is an estimate and not the actual measurement.
Too many handouts confuse the students	Rather than producing a guide that outlines how to use an app, a more thought out orientation on how to use the application would be useful. Taking steps to make sure that students know how to use the application before they start the group activities will minimise the need of having to repeatedly explain the process once the students have split into smaller groups.



<b>Breakdowns</b>	<b>Design Implication</b>
Students were not clear about what to do	Students have to be clear about the activities that they have to do before they start carrying out the activity. It might also be useful to limit the number of tasks rather than introduce a different application midway in the session.
Students were not clear about the meaning of some words used and the symbols used in the application	Ensure that the vocabulary used in the activities matches the level of the students. Having a teacher onboard during the design stage would help target language issues. Importing applications to be used in the classroom means that the level of the language might not always match the language used in class. When language used doesn't match, this needs to be covered in the orientation.
Some students do not have a good grasp of the topic.	A review of the concept that covers the activity is useful. An after-activity discussion to see students output is also useful to check for misconceptions.
Students were not sure how to use the application	Students need a more detailed training on how to use the applications at the start of the session.
Students are not collaborating.	Tablets have small screens designed for one user. Using the tablets in a collaborative setup requires consideration of student pairings.
Students are not participating in the activity	Consider how activities can be designed to keep students engaged.
Students did not finish on time	Consider in advance how much time it would take students to finish the tasks and add to that some allowance for issues that might arise.
Students get tired of repetitively switching between applications	Simplify student tasks by not requiring them to constantly switch between application.
Student refuse to work with the tablet	Consider backup activities to offer to students who are not comfortable working with technology.
In bigger groups, some students are not clear about their roles	Student roles must be clarified at the start of group activities.
Weather condition was not suitable for the activity	This highlights the need for alternative lesson plans.

## CHAPTER 5 STUDY 2 – A QUASI-EXPERIMENTAL DESIGN

### Introduction

Study 2 builds on the work of Study 1 and focuses on the same research questions itemised below with the addition of item *e* which looks at gender differences:

- a) What are the students' views on the use of mobile technology for learning mathematics?
- b) Is there a change in attitude towards mathematics when mobile technology is used for learning maths?
- c) Is there a change in attitudes towards technology when mobile technology is used for learning mathematics?
- d) Is there an improvement in mathematics achievement when using mobile-supported maths learning activities?
- e) Are there differences in maths attitude, achievement scores, and evaluation of mobile learning between boys and girls?

To build on the research design limitation of the first study, the second study recruited a control group to allow comparison between groups. It also addressed the issues identified in the critical incident analysis by changing the way the activities were carried out. A summary of the changes follows:

- 1. Use of 3G network.** As with Study 1, it was not possible to use the school's network and this caused problems in terms of the teacher not being able to check the students' work remotely and also limited some of the activities that require network connectivity (for example the Measure Map activity in Study 1, Session 2). In study 2, the tablets used a 3G network connected via a portable mi-fi device. This allowed a maximum of 10 tablets to be connected to the same network.
- 2. Use of tablets with the same make and brand.** An issue in Study 1 was the stability of the applications used and the way different tablets handled the application. This also meant that troubleshooting problems required somewhat differing steps as various tablet brands would have different interfaces. To make the experience more uniform, the tablets used in this study were of same make and model.
- 3. Groupings and tablet distribution.** In the previous study, students were free to choose whom to work with and the tablets were randomly allocated. In Study 2,

the teacher assigned a pair of students to a specific tablet over a period of time and only shuffled once after the mid-term break.

4. **More time allocated to orientation.** In Study 1, students were given a short orientation and a handout for them to review should they forget how to use the application. The handouts rather than being helpful caused confusion to some students so in Study 2, more time was allocated to the brief before the activity proper. This also allowed the teacher to check whether the students not only know how to use the application but also check that the students know what is being asked of them.
5. **Task breakdown.** In the previous implementation, the lesson was structured into four sequential segments: (1) review of the topic, (2) orientation of the use of the application(s), (3) task-based activities with the tablets and (4) discussion. Study 2 follows the same format but if there are two tasks that require different applications, then app orientation and time allocated for each task are done separately. An example of the structure of the symmetry lesson (Session 1) is shown in Figure 5-1.

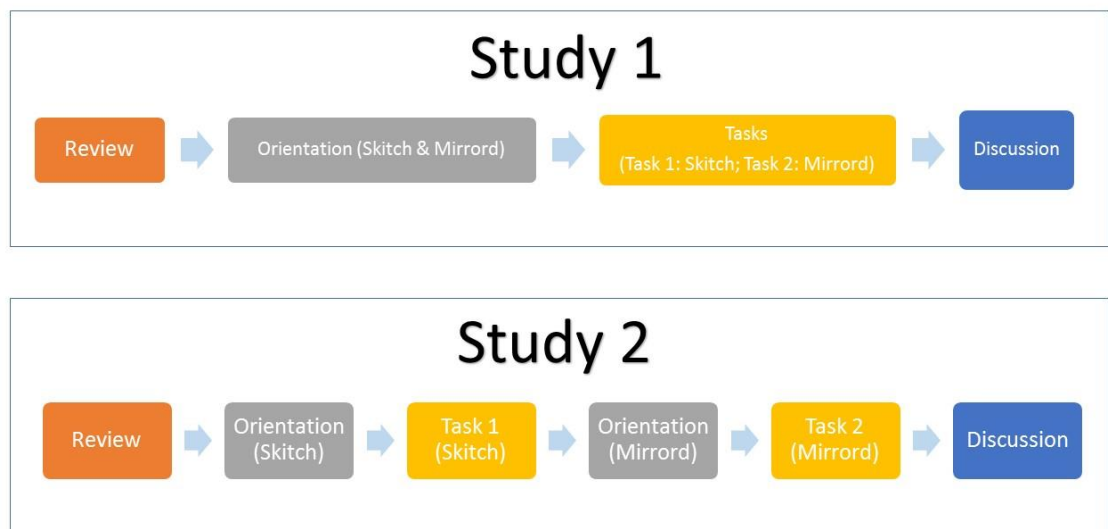


Figure 5-1. Comparison of lesson structure between Study 1 and Study 2.

## Methodology

### Research Design

The nature of the activities used for this study are the same as Study 1 and only varied in implementation to solve the issues identified in the critical incident analysis. The research design, however, adopted a different approach. The study used a quasi-experimental mixed method design with the experimental group working on mobile

learning activities and the control group following their normal curriculum covering the same topic. The evaluation was carried out using the same M3 level evaluation carried out in Study 1. Table 5-1 outlines the research design following the M3 level framework and shows which groups are involved at each evaluation framework.

Table 5-1  
*M3 Level evaluation framework*

<b>M3 Level and Purpose</b>	<b>Instrument</b>	<b>Participants</b>
<i>Micro-level</i> Evaluate individual user experience of the technology	End activity evaluation	Experimental group only
<i>Meso-level</i> Examine student experience	Group interviews Teacher interview	Experimental group only
<i>Macro-level</i> Evaluate the effect of using mobile on students' attitude and performance	Pre-post design for mathematics attitude inventory and maths tests	Experimental and control Group

## **Participants**

The participant classes were obtained by soliciting voluntary teachers from within one local authority in Scotland. Two teachers from the same primary school agreed to participate in the research. The teacher of the experimental group has more than 12 years of teaching experience. The teacher for the control group is a senior teacher but specific data on teaching experience was not available. The experimental and control group participants were the respective students in these teachers' classes. A total of 52 Primary 6 and 7 students aged between 9-11 years old participated in the study, with 24 students in the experimental group (11 boys and 13 girls) and 28 students in the control group (14 boys and 14 girls). The experimental group is an inclusive composite Primary 6/7 class with two students identified as having additional support needs. The control group students are all in Primary 7. The school, as described by an Education Scotland report, had students receiving free school meals around 40% less than the national average and pupils' absences roughly 10% below the national average.

## Instruments and Measures

**End activity evaluation.** The end activity evaluation used for this study is the same as the one used in Study 1. In this instance, however, the reliability scores of the subscales are computed. The computed Cronbach alpha reliability scores in Table 5-2 show that the subscale ratings varied throughout the intervention. For example, the subscale “ease of use” with reference to the activity had internal consistency scores of .13 to .93, whereas the subscale “usefulness” had internal consistency scores of .71 to .81.

Table 5-2  
*Reliability scores of end activity evaluation by subscale*

	Symmetry Activity (Indoors)	Area and Perimeter Activity (Indoors)	Information Handling Activity (Indoors)	Angles Activity (Indoors)	Information Handling (Outdoors)	Angles (Outdoors)
Usefulness Activity	0.72	0.74	0.71	0.8	0.77	0.81
Usefulness Tablet	0.62	0.86	0.84	0.81	0.87	0.76
Usability Activity	0.65	0.13	0.35	0.8	0.93	0.23
Usability Tablet	0.73	0.41	0.61	0.71	0.85	0.35
Satisfaction Activity	0.77	0.73	0.83	0.84	0.82	0.88
Satisfaction Tablet	0.81	0.69	0.71	0.88	0.74	0.76

**Maths attitude inventory (MAI).** The maths attitude inventory was the same inventory used in Study 1. The reliability scores were computed for the current study and were as follows: *enjoyment of mathematics* (.83), *self-confidence* (.83), *value of mathematics* (.61), *confidence with technology* (.68) and *learning mathematics with mobile technology* (.61). Admittedly, some of these new reliability scores are lower than acceptable and this is considered in the data analysis and discussion.

**Maths test (MT).** Please refer to Study 1.

**Interviews.** Group interviews were designed to elicit student feedback about the activities which might have been missed in the end activity survey. Students reflected

upon the activities that they had completed and were asked to explain which of the activities they liked and disliked. Their opinion on the advantages and disadvantages of doing these types of activities were sought. Students also related the challenges they had experienced with the activities. Discussions were audio recorded and transcribed.

A semi-structured teacher interview was also conducted. Questions asked were the teacher's view on the mobile learning activities, observations on how the activities affected the students and perceived advantages and disadvantages of mobile learning. The interview was audio recorded and transcribed.

### **The mobile learning activity**

Mobile devices used in the study were 8-inch Acer 810 Android 4.2 tablets costing less than £100 each. Similar to Study 1, several activities were carried out while students moved around so the small form factor allowed mobility and the medium screen size allowed screen sharing. Unlike in Study 1 where the tablets were of different brands, this study used tablets of the same make and model to facilitate uniformity and ease in providing technical support. The activities of Study 2 closely followed Study 1 and so, to avoid repetition, only the changes are mentioned in this section. The angles (Session 4 and 5) and information handling (Session 3 and 8) activities were the same, so refer to Study 1 for details. What follows is a discussion of the activities that were revised as a result of the breakdowns identified in Study 1.

In the symmetry session (Session 1) of Study 1, a breakdown that was identified was that some students tend to forget what they had to do when they juggled tasks carried out using different applications. In response to this problem, the lesson structure was re-organised so that the orientation on how to use an application came just before the students had to use it. This was discussed in the introduction section of this chapter and illustrated in Figure 5-1. Apart from that change, the applications used were the same.

In the area and perimeter sessions, Session 2 remained the same but Session 7 was modified. The new task was to create augmented reality representations of area and perimeter of nearby objects using an application called Aurasma. Aurasma is an augmented reality application on mobile devices. What sets this application apart from other augmented reality applications was that at the time, it was the only application that allowed creation and sharing of augmented realities on tablets. Other applications required a computer to setup augmented realities. An example is shown in Figure 5-2.

The left side of the image is the actual object, the middle shows the Aurasma overlay and the right side of the picture shows how the overlay is shown on the screen when the tablet points to the object.



*Figure 5-2.* An illustration of how Aurasma works.

Using Sketch, students took pictures of objects and annotated these images with its measurement as shown in Figure 5-2. It became apparent in Study 1 that students had some difficulty using the measuring application, so for this session, rather than off-load the measurement to the mobile device, students measured the dimensions of objects using standard measuring tools like a ruler or meter stick. They then created an overlay on Aurasma so that when the tablet pointed to the actual object, the area and perimeter of that object was shown. These augmented realities were saved online and allowed other members of the class to view the objects created, such that any tablet using Aurasma would see the annotated image. The activity allowed students to create visual representations of area and perimeter in a 3D world as opposed to the 2D version of textbooks.

As discussed in Study 1, the objectives of the mobile learning activities carried out in these sessions was to provide a link between abstract maths concepts and their concrete representations in the real world. Using the mobile devices, the artefacts gathered “in the wild” were discussed in the classroom to link to the formal mathematics that the curriculum covered. The mobile device’s portability and networked features facilitated the investigations and the sharing of these artefacts.

## Procedure

A pre-test of MT and MAI was completed by the experimental and control group at the start of the intervention. Following the tests, an introductory session with the experimental group was conducted to brief the participants about the nature of the activities to be carried out.

The experimental group participated in eight hour-long sessions of mobile learning activities spread over a period of three months. A variety of mobile-supported collaborative learning activities were carried out within and outside the classroom. Students completed an End Activity Evaluation questionnaire at the end of an activity. Midway through the programme, the experimental group completed the MAI test again and afterwards went on a two-week spring break. After the break, they continued with the intervention for four more sessions. At the end of the programme, both groups took the MT and MAI post-test. An interview with the teacher and student participants of the experimental group was also carried out at the end.

## Data Analysis

**Micro-evaluation.** The ratings on the end activity evaluation were grouped into three categories of usability: usefulness, ease of use and user satisfaction. These were further grouped into tablet and activity ratings. Each subscale score was the average of the item ratings for that category, thus giving a range score between 0 – 5. A high subscale score indicated a good usability rating and vice versa. The tablets' usability was analysed using descriptive statistics. Gender difference was examined via an independent t-test

**Meso-evaluation.** Student perceptions about the learning experience were analysed from the group interview. Student responses to questions raised in the group interviews were analysed into themes: 1) student perception of the tablet activities, 2) advantages/disadvantages of using the tablets, 3) opinions on group/paired work, and 4) issues and challenges in using tablet devices. Teacher perceptions about the mobile learning activity were used to give further information.

**Macro-evaluation.** Macro-evaluation included the MAI and MT pre-test, and mid-test and post-test scores of the control group and the experimental group. A repeated measure analysis of variance (ANOVA) was conducted to compare the experimental and control group at MT pre-test post-test. This was also intended for the MAI scores but several conditions for running an ANOVA were not met so a paired t-



test on MAI pre-test and post-test scores by group was conducted instead. To look for differentiations between the control and experimental group, an independent t-test of the gains in MAI was also conducted. The same statistical analysis was used for gender differences in MT and MAI, and the differences in the performance of low and high scorers.

## Results

This section is divided into the three evaluations carried out in this study: 1) micro-evaluation that corresponds to the tablets' usability test; 2) meso-evaluation which represents the student evaluation of the learning activities; 3) macro-evaluation which covers the quantitatively measured effects of using the tablets on students' attitudes and achievement

### Micro-evaluation

A graph of the semantic differential ratings for the evaluated sessions is shown in Figure 5-3. A higher score means agreement with the positive statement while a lower score means otherwise. A score that lies somewhere in the middle (between 2 and 3) means a neutral rating. For example, in the activity with areas and perimeters, an average rating of 4.0 on the item *irrelevant vs useful* meant that students found the activity more useful rather than irrelevant. From the graph, it can be observed that most of the activity ratings fall within the positive ratings with a range between 2.6 and 4.8. Of the total 2614 item responses, 86% agreed with the positive, 5% agreed with the negative adjective and rest were neutral ratings. Thus, the majority of students evaluated each of the activities positively.

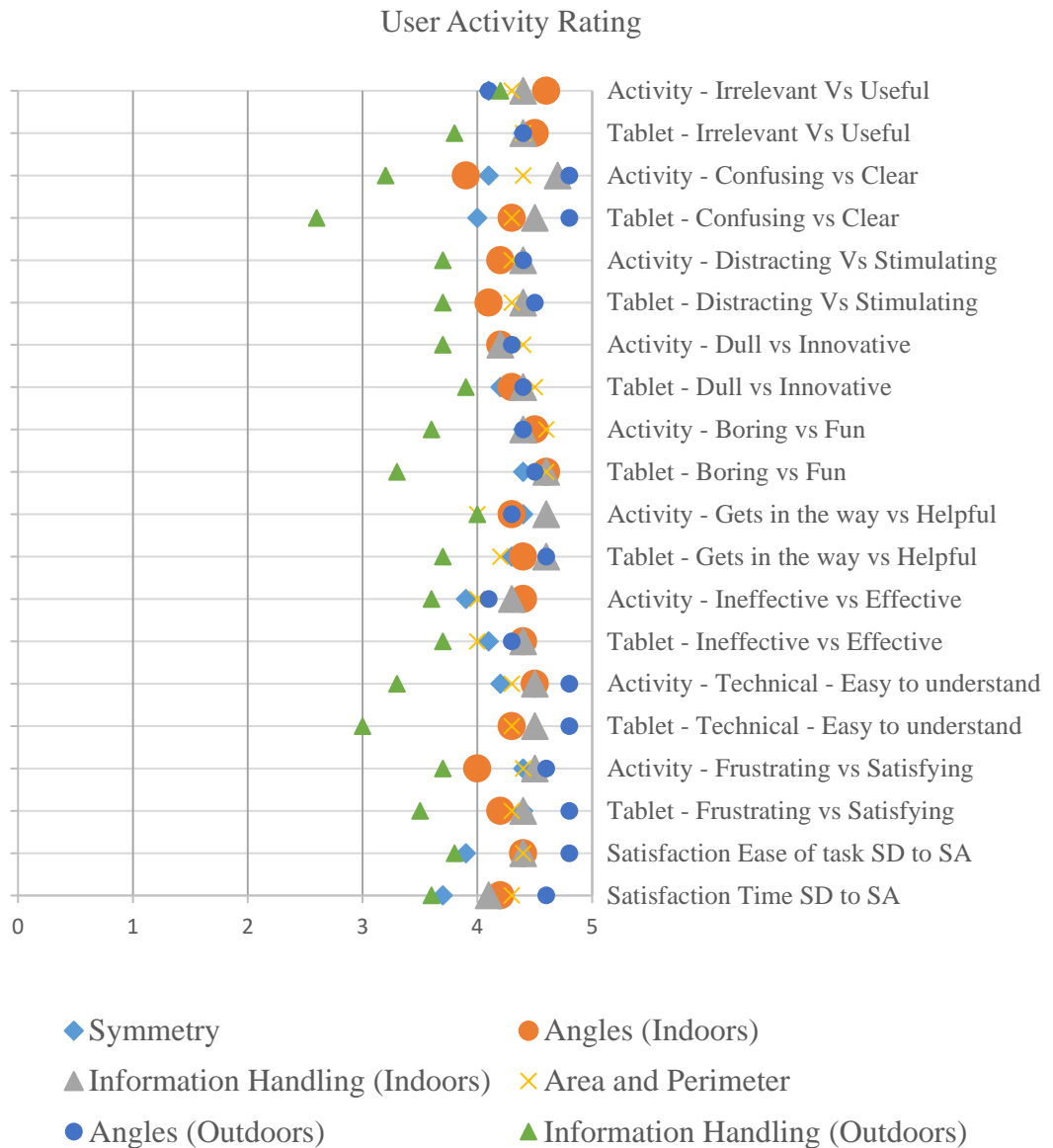


Figure 5-3. End activity evaluation.

The end activity ratings in Figure 5-3 were grouped into three subscales of usability: usefulness, user satisfaction and ease of use; and further grouped into tablet ratings and activity ratings. The tablet rating and the activity rating for each subscale all had significant positive correlations.

The activity ratings were divided into male and female ratings as shown in Table 5-3. An independent t-test of the ratings by gender showed no significant gender difference in all categories.

Table 5-3  
*Summary of activity ratings grouped by gender*

	Gender	Symmetry (Indoors)		Area and Perimeter (Indoors)		Information Handling (Indoors)		Angles (Indoors)		Angles (Outdoors)		Information Handling (Outdoors)	
		<i>n</i>	<i>M (SD)</i>	<i>n</i>	<i>M (SD)</i>	<i>n</i>	<i>M (SD)</i>	<i>n</i>	<i>M (SD)</i>	<i>n</i>	<i>M (SD)</i>	<i>n</i>	<i>M (SD)</i>
<b>Ease of use (Activity)</b>													
	Male	10	4.38 (0.54)	10	4.11 (0.71)	11	4.51 (0.41)	10	4.23 (1.18)	10	4.69 (0.36)	9	3.66 (1.64)
	Female	10	3.94 (1.15)	12	4.24 (0.53)	12	4.59 (0.48)	12	4.41 (0.83)	12	4.7 (0.43)	10	3.32 (1.82)
<b>Ease of use (Tablet)</b>													
	Male	9	4.24 (0.74)	10	4.13 (0.71)	11	4.41 (0.51)	10	4.35 (0.69)	10	4.71 (0.35)	10	3.07 (1.68)
	Female	11	4.04 (1.14)	12	4.31 (0.63)	13	4.53 (0.63)	12	4.19 (0.92)	12	4.73 (0.39)	10	3.12 (1.62)
<b>Usefulness (Activity)</b>													
	Male	9	4.11 (0.75)	10	4.4 (0.64)	11	4.58 (0.37)	10	4.13 (1.14)	10	4.15 (1.17)	10	4.11 (1.4)
	Female	11	4.14 (0.96)	12	4.47 (0.51)	13	4.26 (1)	12	4.04 (1)	12	4.21 (0.94)	10	3.78 (0.75)
<b>Usefulness (Tablet)</b>													
	Male	10	4.52 (0.5)	10	4.6 (0.43)	11	4.61 (0.72)	10	4.23 (1.1)	10	4.53 (0.55)	10	3.79 (1.62)
	Female	11	4.06 (0.75)	12	4.27 (0.85)	13	4.32 (0.86)	12	4.18 (1.11)	12	4.31 (1.01)	10	3.64 (1.64)
<b>Satisfaction (Activity)</b>													
	Male	10	4.22 (0.63)	10	4.31 (0.55)	11	4.16 (0.97)	10	4.37 (0.81)	10	4.37 (1.11)	10	3.6 (1.39)
	Female	11	4.05 (0.99)	12	4.24 (0.67)	13	4.45 (0.56)	12	4.46 (0.51)	12	4.7 (0.44)	10	3.77 (0.95)
<b>Satisfaction (Tablet)</b>													
	Male	10	4.6 (0.32)	10	4.4 (0.5)	11	4.42 (0.71)	10	4.56 (0.61)	10	4.47 (0.7)	10	3.47 (1.4)
	Female	11	4.06 (0.91)	12	4.35 (0.7)	13	4.48 (0.69)	12	4.35 (0.86)	12	4.66 (0.51)	10	3.65 (1.06)

### Meso-evaluation

**Student perception of the tablet activities.** The whole experimental group participated in the group interviews, except for two students who were not available for interview at the time. Students were not required to answer all the questions and they could opt not to participate. Of that sample, 80% gave positive feedback, 15% gave mixed feedback and just 5% gave negative feedback. Students found the use of the tablets fun (n=11), made learning easier (n=5), were useful (n=3) and better than their usual maths lesson (n=3).

*“I found that I understood it more. When the teacher describes something to you, I don't really get it, but with the tablets I understood it more and it was really fun.” (Female student)*

Students with mixed feedback (n=3) found the activities fun but the technical problems encountered lessened the positive experience they had. For example, a female student explained that *“it was good, and it was fun but sometimes the app didn't work and then you got annoyed.”*

Students who scored low on the maths pre-test found the activities fun (n=2) and better than their usual maths lesson (n=2). Similarly, students who scored high on the maths pre-test found the activities fun (n=4), more engaging (n=3), helpful, easier and better than their usual maths (n=7).

*“It makes you look forward to maths like I know that every 11 o'clock every Thursday I was gonna get good maths. No, not good maths... I mean more fun maths... better maths.” (Male student)*

**Perceived advantages/disadvantages of doing tablet activities.** Students were asked what they thought were the advantages of the tablet and most of the responses were in relation to how they would normally do mathematics without these tools. Students felt that it was better than their usual maths lesson because it was more fun (n=4), engaging (n=5), made learning mathematics easier (n=2), and more active (n=2), with the activities allowing them to move about and engage with their environment. Students also thought that it was a good opportunity to be able to use technology while learning maths (n=4).

*“It was really fun and also when I use the tablets I understood it more when I kept using it but when I just write it on a jotter, I still don't know what's happening.” (Female student)*

*“It’s helping me understand more, like with perimeter I don’t understand it but when we used them, I was like, oh that makes more sense now.”*

*(Female student)*

When asked for disadvantages, only two answers were given: one student highlighted that the main disadvantage of using the tablets was the cost involved, while another student highlighted that it was more challenging because they had to remember more.

**Working in pairs and in groups.** Overall response to the group work conducted was positive (n=15). Students felt that being able to work in pairs made the task easier. A female student explained, *“I find it easier to work in pairs so you could discuss it with your partner.”* There were, however, cases where some students considered that working in pairs using the tablet was not always good because it led to some discussions over control of the device (n=7).

*“Sometimes people can do all of it and not give the other person a shot and it could also be the opposite way, if you really like it, you’d be bad at not giving the other person a shot. Sometimes when you’re with someone who doesn’t understand then you’d want to do it all and if you’re with someone that does it all then it annoys you as well.”* *(Female student)*

Several students (n=6) who scored low in *confidence with technology* made more reference to the negative aspects of doing collaborative work with mobile technology than those who scored high in this subscale. While students understand the value of collaborative work, there were cases where students who were more competent with technology took over control of the device.

*“Sometimes my partner takes over and I had nothing to do and sometimes I wanted to have a go and she’s like sometimes, just wait a minute but that’s the disadvantages with working with a partner but the advantages they know what they’re doing and you don’t and sometimes you know what you’re doing and they don’t but they’re not letting you have a go at it.”* *(Female student)*

Students who had low self-confidence scores at pre-test found working in pairs advantageous in making the mobile learning activity easier.

*“It was much easier because if you had ideas to reflect off your partner... if you get stuck you're not sitting there like (not knowing what to do) and you'll be more like... how do you do this.” (Female student)*

Students with high self-confidence scores at pre-test found working in groups better than working on their own (n=9). There was, however, negative feedback (n=5) about group work from students who had higher self-confidence scores. Some students said that their partners could get in the way at times.

**Challenges encountered.** Several challenges were encountered during the intervention including internet, software, and battery issues. The tablets were connected to a mi-fi 3G device rather than the school's network but this type of connectivity is not very stable and so sometimes caused tablets to be disconnected from the network. In one outdoor activity where internet connection had been necessary to create augmented realities, students were finding it difficult to keep connected as they would sometimes wander off in non-connected areas. Students resolved this issue by moving the mi-fi device with them then passing on the device to another group once they had finished their task. Although the process of moving the wireless network solved the issue, this, however, caused a delay to some groups as they had to wait for the others to finish before they can get connected with the network and carry on with their work. In a separate activity, a male student commented: *“a couple of the tablets won't link. I can't send it to the teacher. I'm sitting next to him and I can't send it.”* Students reflected that these technology issues were the downside of doing the tablet activities. They explained that sometimes the applications on the tablet would close for no apparent reason. Students dealt with this issue by relaunching the application and starting over, which solved the issue most of the time, but sometimes the instability of the application left students frustrated as they lost work that they did for the session.

**Teacher interview.** A semi-structured teacher interview was conducted with the teacher. Like the students, the teacher was also positive about the intervention. The teacher describes the mobile learning sessions as fun and was able to set a reference on how to use the school's mobile devices not just for maths but for other subjects as well.

*“It was really good fun and even though the tablets were Android, as soon as we kind of set a reference using a piece of technology I got straight on to the iPad and tried to find an equivalent which we can use at school so that we can pass that through the whole school and be on the same page about using or how to use the tablets to enhance learning.”*

The teacher confirms that the students were positive about the mobile learning session and would look forward to these sessions. He notes that the students already know how to use the tablets *“so it's really just a case of pointing them to the tools that help them learn and ensure that they are interesting and in a collaborative way.”* From the teacher's perspective, the benefits of using the tablets included: engagement with learning and practice with transferable technology skills. For example, he notes that at the start of the program, one of the girls wouldn't engage with technology but through the intervention, this student *“had been more willing to have a go with technology”* which is something that the student herself has confirmed during the student interviews. The teacher also observed that students were able to see how they could use the applications used in the maths intervention into other areas of the curriculum.

*“My class has already been down to Primary 1 and was showing how they can use mobile technology to support French and the Primary 3 class helped my class to set up all the auras [tagged information using the application Aurasmas] for the parents night. It's kind of putting the whole school on board.”*

In terms of the tablet's usefulness to learning maths, the teacher notes that there's the element of ownership of learning.

*“when they were doing the task on angle, it's one that [they] found, [one] that they considered following certain criteria for being a certain angle, and one that they found rather than, you know, the textbook identified... here they were able to find their own one.”*

He adds that assessment also had a big role in the activities as he could see straight away what the students are doing and provide guidance where necessary.

The sessions had its own set of technical glitches but this is something that the teacher had anticipated. For example, the sharing facility of the tablets using Dropbox did not initially work but the teacher opted to connect the tablets to a bigger display manually (via wired connectors) to facilitate sharing. This was an alternative solution which the teacher was able to implement straight away and also shows the flexibility of the teacher in using technology. He notes: *“you expect certain things to not run smoothly, then you troubleshoot when it happens... it's not one that actually bothers me that much because the advantages outweigh the disadvantages.”* This statement also

shows the positive outlook of the teacher in terms of handling technology issues but the teacher also acknowledges that this is an issue that can't be overlooked.

*“If a staff member is not perhaps up to speed with technology, if they come across two or three tablets that don't do immediately what they're supposed to do, that would put them off the whole lesson and it might even for some of them say I'm not doing that again. whereas a different teacher expects it and then move on.”*

This raises the question of how to get the whole school onboard so that students are offered a consistent learning experience.

There is also the need to adapt technology use rather than take it as an out of the box experience. To the teacher, he says that *“there is a need to identify right at the very start to identify how are these technologies going to enrich the lesson.”* This was a step he took at the start of the research project. For example, there was no differentiation offered in the lesson plans provided for the intervention and all students were expected to do the same thing. These lessons had to be tweaked a bit to accommodate the differences in class. The activities provided to the teacher became the core learning session but the teacher implemented it in such a way that challenges both the advanced students and those that struggle a bit.

While the intervention received positive feedback, the teacher adds that the sessions have been busy content-wise. The variety of the content has posed some challenge for the teacher as this required covering different maths topics on a short period of time. For example, when the students did the weekly session on symmetry, they were also studying a different topic during their normal maths period and then, a week later, the topic on symmetry would have moved to area and perimeter, which is a different topic altogether. He suggests that it might be worthwhile focusing the intervention to a set of related topics rather than a spread of different maths topics.

### **Macro-evaluation**

**Student achievement.** A repeated measures ANOVA was conducted on the performance of the experimental and control group. There were no outliers in the data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. The maths test scores were normally distributed for both interventions at all time points (pre-test and post-test), as assessed by the Shapiro-Wilk's test ( $p > .05$ ). There was homogeneity of variances, as assessed by Levene's test of homogeneity



of variance ( $p > .05$ ) and homogeneity of covariance, as assessed by Box's test of equality of covariance matrices ( $p = .393$ ).

There was a statistically significant interaction between group and time,  $F(1,43) = 8.834, p = .005$ , partial  $\eta^2 = .170$ . The effect for time indicated that there was a statistically significant difference in maths test scores between control group ( $M = 27.71, SD = 6.66$ ) and experimental group ( $M = 19.64, SD = 8.45$ ) at pre-test,  $F(1, 48) = 14.309, p < .001$ , partial  $\eta^2 = .230$ . At post-test, this difference in MT scores between control group ( $M = 31.32, SD = 6.50$ ) and experimental group ( $M = 27.91, SD = 6.82$ ) was no longer significant,  $F(1,45) = 3.077, p = .086$ , partial  $\eta^2 = .064$ . A t-test of the gain scores between groups showed a significant difference,  $t(43)=4.57, p = .005$ ,  $ES = .89$ , in favour of the experimental group. Figure 5-4 shows a graph of the gain scores of the experimental and control group

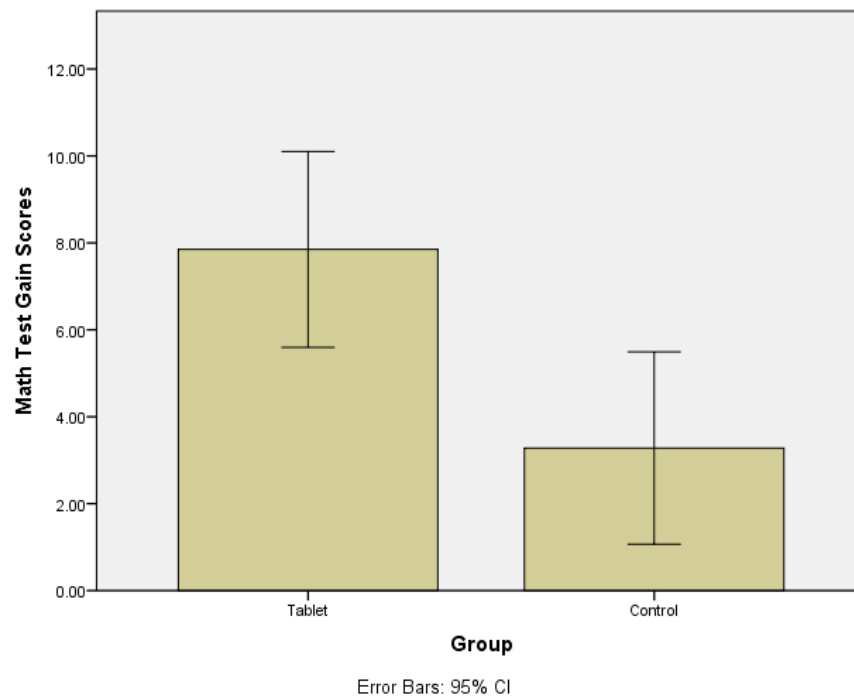


Figure 5-4. Gains scores of experimental and control group.

Gender differences within groups were also examined. Descriptive statistics of MT scores by gender and grouping is shown in Table 5-4. There was no significant difference in the scores of male and female students in the experimental group before and after the intervention,  $t(22)=.118, p=.907, d=-.05$  and  $t(22)=-.874, p=.391, d=-.36$ . There was no significant difference in the gain scores,  $t(22)=-1.567, d=-.64$ . For the control group, there was an observed significant difference between male and female students at pre-test,  $t(26)=.033, p=.033, d=-.85$  and post-test,  $t(26)=-2.944, p=.007, d=-$

1.11 but there was no significant difference in the gain scores  $t(26)=-.465$ ,  $p=.646$ ,  $d=-.18$ .

Table 5-4.  
*Descriptive statistics by gender*

	Experimental Group1			Control Group		
	Boys M(SD)	Girls M(SD)	t-value, <i>d</i>	Boys M(SD)	Girls M(SD)	t-value, <i>d</i>
MT pre-test	20.23 (9.23)	19.82 (7.57)	.118, $d=-.05$	25.07 (6.01)	30.36 (6.39)	-2.255, $d=-.85$
MT post-test	26.4 (8.2)	28.77 (4.9)	-.874, $d=-.36$	28.08 (6.38)	34.29 (4.64)	-2.944, $d=-1.11$
Gain scores	6.18 (4.37)	8.95 (4.25)	-1.567, $d=-.64$	3.01 (6.16)	3.94 (4.15)	$t=-.465$ , $d=-.18$

An independent t-test of the gains in maths test score between male students in the experimental group and male students in the control group found no significant difference,  $t(23)=1.441$ ,  $p = .163$ ,  $d=.58$ . There a significant difference between female students of the experimental group and the girls in the control group,  $t(25)=3.098$ ,  $p = .005$ ,  $d=1.19$ . A graph of these differences in gain scores by gender and grouping is shown in Figure 5-5.

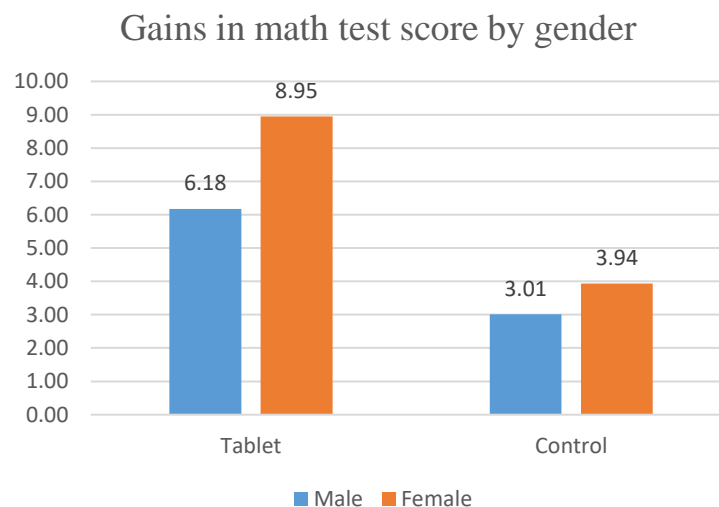


Figure 5-5. Gain scores grouped by gender

To check whether there were differences in the gains based on the maths pre-test score, the MT pre-test scores of the groups were divided into low and high halves. Descriptive statistics is available in Table 5-5. An independent t-test of the gain scores showed a significant difference in the gains of students in the lower half in comparison with the higher half,  $t(22)=3.522$ ,  $p=.002$ ,  $d=1.44$  while the control group had no significant difference. Figure 5-6 shows a graph of the difference of the gain scores between the lower and higher group in the two setups.

Table 5-5  
Descriptive statistics by MT(pre-test) ranking

	Experimental Group (Low = 12, High = 12)				Control Group (Low = 13, High = 15)			
	Pre	Post	Gain	t-value, <i>d</i>	Pre	Post	Gain	t-value, <i>d</i>
Low	13.5 (5.04)	2.76 (0.98)	10.29 (4.51)	3.522**, <i>d</i> =1.44	22.15 (4.3)	27.93 (6.54)	5.78 (5.49)	2.372, <i>d</i> =.90, NS
High	26.52 (4.73)	3.27 (1.55)	5.07 (2.46)		32.53 (4.00)	34.01 (4.70)	1.48 (4.08)	

\* $p < .05$ , \*\* $p < .005$ , NS not significant

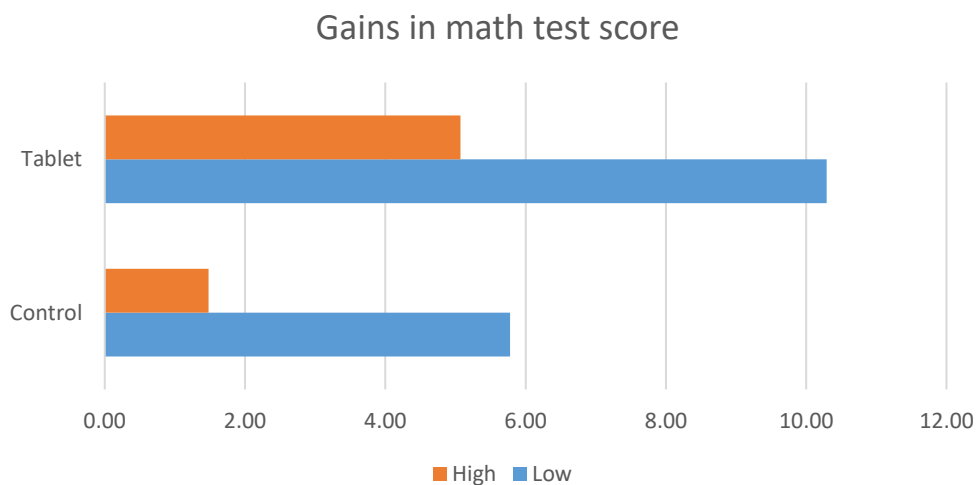


Figure 5-6. Gain scores grouped by MT(pre-test) ranking

**Mathematics Attitude Inventory.** A mixed ANOVA was initially planned for the each of the MAI subscales, however, the data did not fit the criteria for an ANOVA so, an independent t-test was conducted for the gain scores and a paired t-test to compare the scores at different times. The descriptive statistics for Mathematics Attitudes Inventory (MAI) and its subscales are shown in Table 5-6. The paired sample t-test for the experimental groups' pre-test and mid-test score showed no significant difference in all subscales. The paired sample t-test for pre-test and post-test scores also showed no significant difference in all subscales except for enjoyment, where there was a significant decrease in score for the control group,  $t(24) = -2.680$ ,  $p = .013$ ,  $ES = -.55$ . An independent t-test of the MAI gains between the experimental and control group resulted in no significant difference in all subscales of the MAI. There was, however, a small effect in the subscale *self-confidence* ( $ES = .21$ ).

**Gender differences in MAI scores.** A summary of the MAI scores by group and gender is displayed in Table 5-7. An independent t-test of the male and female students score at varying time points per group indicated that there is no significant difference in all the five subscales being investigated except for the experimental group's VMT pre-test score where boys scored significantly higher than girls,  $t(22)=3.130$ ,  $p=.005$ ,  $d=1.28$ . This difference, however, did not manifest in the subsequent tests. An independent t-test of the gain scores from pre-test to post-test grouped by gender and treatment showed no significant difference for all subscales except for VMT scores of the control group,  $t(26)=-2.802$ ,  $p=.009$ ,  $d=.37$ .

Table 5-6  
*MAI scores of experimental and control group*

	Experimental Group				Control Group			Between Groups	
	Pre-test	Mid-test	Post-test	Gain Score	Pre-test	Post-test	Gain Score	p-value	ES
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)		
Enjoyment (EN)	3.58 (0.79)	3.72 (1.18)	3.03 (1.35)	-0.45 (1.11)	3.06 (1.21)	2.59 (1.36)	-0.54 (1.01)	.780	.09
Self-confidence (SC)	4.05 (0.91)	4.17 (1.06)	3.83 (1.17)	-0.03 (0.86)	3.67 (1.06)	3.42 (1.39)	-0.22 (0.95)	.488	.21
Value of Maths (VM)	4.40 (0.51)	4.66 (0.49)	4.17 (0.88)	-0.11 (0.6)	4.34 (0.75)	4.08 (1.13)	-0.24 (1)	.591	.16
Confidence with technology (CT)	3.80 (1.04)	3.77 (1.04)	4.04 (0.99)	0.31 (1.04)	3.92 (1.11)	4.06 (0.99)	0.17 (0.94)	.648	.14
Value of mobile technology (VMT)	3.64 (1.09)	3.96 (1.2)	3.85 (1.33)	0.21 (1.51)	2.99 (0.95)	3.27 (1.35)	0.23 (1.17)	.947	-.02

Table 5-7  
MAI Scores by Gender

		Experimental Group (Male = 11, Female = 13)					Control Group (Male =14, Female = 14)				
		Pretest	Midtest	Post-test	Gain Pre-Post	t-value, <i>d</i>	Pre-test	Post-test	Gain Pre-Post	t-value, <i>d</i>	
Subscale	Gender	M(SD)	M(SD)	M(SD)	M(SD)		M(SD)	M(SD)			
EN	Male	3.64 (0.69)	3.72 (1.35)	3.22 (1.25)	-0.42 (1.41)	0.469,	2.99 (0.96)	2.39 (1.16)	-0.61 (1.22)	-0.909,	
	Female	3.49 (0.84)	3.73 (1.08)	2.84 (1.36)	-0.65 (0.95)	<i>d</i> =-.19	3.13 (1.46)	2.88 (1.38)	-0.25 (0.82)	<i>d</i> =-.49	
SC	Male	4.22 (0.57)	4.26 (0.92)	4.11 (0.9)	-0.11 (0.97)	0.521,	3.76 (0.71)	3.42 (1.13)	-0.34 (1.03)	-0.63,	
	Female	3.86 (1.06)	4.09 (1.21)	3.55 (1.25)	-0.31 (0.9)	<i>d</i> =.21	3.59 (1.35)	3.47 (1.51)	-0.11 (0.9)	<i>d</i> =.04	
VM	Male	4.43 (0.43)	4.64 (0.54)	4.24 (0.63)	-0.19 (0.7)	0.233,	4.24 (0.71)	3.8 (1.39)	-0.45 (1.26)	-1.037,	
	Female	4.37 (0.54)	4.67 (0.47)	4.1 (1.01)	-0.26 (0.87)	<i>d</i> =.10	4.44 (0.8)	4.37 (0.5)	-0.07 (0.54)	<i>d</i> =-.55	
CT	Male	4.02 (0.91)	3.89 (0.97)	3.92 (0.95)	-0.1 (0.9)	-1.504,	4.08 (0.98)	4.37 (0.64)	0.29 (0.63)	0.901,	
	Female	3.62 (1.07)	3.68 (1.12)	4.13 (0.97)	0.51 (1.05)	<i>d</i> =-.62	3.76 (1.24)	3.74 (1.09)	-0.01 (1.11)	<i>d</i> =.70	
VMT	Male	4.23 (0.75)	4.33 (1.07)	4.24 (0.86)	0.01 (0.73)	-1.127,	3.32 (0.83)	3.21 (1.32)	-0.1 (0.96)	-2.802*,	
	Female	3.09 (0.99)	3.66 (1.26)	3.73 (1.29)	0.64 (1.72)	<i>d</i> =-.46	2.65 (0.98)	3.63 (0.85)	0.97 (1.06)	<i>d</i> =-.37	

**Usability scores and technology related scales.** A correlation matrix of the usability scores with the MAI scales (CT and VMT) is shown in Table 5-8. There was a significant positive correlation between students' perceived ease of use of the tablet with perceived usefulness, user satisfaction and value of mobile technology. The same is true for the usability scores and post-test VMT. Students' confidence to use technology had no significant correlation with how the students perceived the usability of the activities but it is correlated with the perceived value of mobile technologies for math.

Table 5-8

*Correlation matrix of usability scores and MAI technology related scales*

	1	2	3	4	5
1 Ease of use	-				
2 Usefulness	.455**	-			
3 User satisfaction	.647**	.844**	-		
4 CT (post-test)	.159	.123	.220	-	
5 VMT (post-test)	.401*	.473*	.493*	.522*	-

\* correlation significant at the .05 level (1-tailed)

\*\* correlation significant at the .01 level (1-tailed)

## Discussion

Here we discuss briefly the responses to the research questions using the results from the micro, meso and macro-evaluations.

### **Students' attitudes and perceptions about maths and mobile technology**

In general, students had a positive view about the use of mobile technologies and they found the learning activities fun, engaging and useful. While there was an attempt to separate the ratings between technology and activity, the positive correlation between the two suggests that students might not have objectively evaluated the two separately. Novelty appears to be a contributing factor to student satisfaction. Students contrasted the mobile learning activities with what they usually did and although challenging to some students, student satisfaction with the activities remained positive.

There was a slight positive change in students' enjoyment, self-confidence and value of mathematics a month after the intervention has started. These gains, however, had reversed in direction by the end of the intervention. One possible reason is that the increase in scores during the early days of the intervention was mainly due to novelty

effects. As students progressed through the intervention and having taken the same instrument third time in three months, they might have become more reflective of their attitudes towards mathematics. It is also possible that some of the novelty wore off.

Although there was a decline in students *EN* scores in both experimental and control group, the decline was only significant for the control group. This decline in enjoyment, however, was contrary to the interview results, where students described the tablet activities as fun and engaging. A comparison of the individual interview data with *EN* scores showed that the interview results corroborated the individual *EN* findings with some students but not all. For instance, several students explained that they found the activities fun and this was evidenced by the gains in *EN* score. However, there were cases where the students explained that it was more fun and interesting but this did not translate into gains in *EN* scores.

Evidence of self-confidence is apparent in some of the student narratives as they explained how the use of the tablets helped them understand abstract concepts, however, the test scores show a decline in this subscale. While this change in self-confidence is not statistically significant, there was a small effect between groups for this variable. The self-confidence scores of students in the experimental group had declined by .03 whereas the control group had a decline of .22. It can also be assumed that the decline in students' self-confidence with maths may be partly due to the increasing difficulty of the maths that they had to learn. The pre-test was carried out in February and the post-test was carried out towards the end of the school year, where more difficult topics are taught.

There was no significant difference found in both groups' *confidence with technology* and *value of mobile technology* but there were small positive effects found with the experimental group. While the quantitative data showed no significant improvement in student scores, the teacher testimony that students had been using the technology skills that they had learned in other subjects is a positive outcome.

### **Mathematics achievement**

Students explained that the activities made them recall the topics better and helped them visualise the concepts being learned. Some students felt that this new way of doing maths had helped them grasp abstract maths concepts and as a result helped them remember better. These narratives were supported by a significant improvement in *MT* scores and further supported by the significantly higher gains of the experimental



group in comparison to the control group. It is worth noting, however, that results of this study could have been confounded by other variables such as novelty and research design. This is discussed further in the limitation section of this chapter.

### **Gender differences**

In the micro-evaluation stage, there were no gender differences found in students' evaluation of the mobile learning activities. Within the macro-evaluation stage, there was also no gender difference found except for the control groups' perceived usefulness of mobile technologies. The female students in the control group evaluated the use of tablets better than their male counterpart. Possible reasons for this are the close proximity of the control group and the experimental group and the interaction of the two groups outside class. Students in the control group can observe students in the experimental group running out and about the classroom, doing the different mobile activities and there was an occasion where a female student in the experimental group was observed sharing with another female student what they did in class. It is possible that the students in the experimental group have related their positive experience and this might have made the female students in the control group evaluate mobile technologies better. In terms of the maths test, there was no significant gender difference found in the gain scores by group but a cross comparison of the scores by group and gender found a significant difference in the gain scores of female students in the experimental group with the female students in the control group.

### **Limitations of the study**

Dependence of data on self-reports given the age of the participants was a shortcoming. This was minimised by repeatedly discussing with the students what the words meant whenever they had to evaluate the session. Students were also encouraged to ask for clarification whenever they were not sure what the question meant, which was particularly an issue for double negative statements.

Other threats to validity are in relation to sample size, research design, instrument reliability, and novelty. The small sample is a threat to the validity of the results, so effect sizes were also provided to give an idea of the magnitude of the difference between the groups investigated. The no-treatment control group is a limitation of the design. While this was not the original intention of this study, it had been particularly difficult to recruit schools willing to involve a control group who would follow a similar programme to the experimental group. The time allocated to run the activities was also a

design issue. While the activities were marked for an hour session, some sessions ran over the recommended time to allow everyone to finish and this might have influenced the overall results.

Another threat to validity was the low-reliability scores for some scales of the mathematics attitudes test and the end activity evaluation. Nielsen (1994) quotes that “reliability of usability tests is a problem because of the huge individual differences between users (p. 166).” Novelty is also a possible threat to validity. While three months of intervention is longer than other mobile learning studies, this is still relatively short compared to other interventions that use more established technologies. Still, the use of the M3-Level evaluation framework has been valuable for data validation and triangulation. It is difficult to know which of the results can be attributed to novelty, to the nature of the activities or to the use of the mobile device.

### **Summary and Next Direction**

This study set out to investigate the effects of using tablet devices for mathematics learning in terms of student attitudes, perception, and their achievement. The design of the activities carried out in this study featured mobile technologies being used for active, collaborative learning activities. It also illustrated how these technologies can be used to allow students to engage with their environment as they explore maths concepts. There was a modest difference in students’ performance in a maths test but the weekly use of the tablets did not show a positive increase in students’ overall attitudes towards mathematics.

Several limitations of the study point to the instruments used. The low reliability of the VMT subscale was a design flaw given that the item only had two questions, so this is considered in the next iteration. The same goes for the end activity evaluation where there were double negative items which young students might have been confused with. Changes to these instruments are considered in the next study.

There is also the need to address the research setup. In this iteration, the experimental and control group were two sets of students at two different year levels. The control group was also a non-treatment control group so for the third iteration, the target was to have a control group that would work on similar activities with the experimental group.

One of the recommendations of the teacher during informal catch ups were the format of the lesson. Students engaged in indoor activities first then proceeded with the

outdoor activities next. The teacher felt that it would be better if the activities on the same topic were closer to each other rather than be grouped by where it happens. It was also suggested whether it's possible to focus on specific topics rather than include several areas, as was the case in this study which included lessons in information handling and geometry. These suggestions are considered in the next iteration.

## CHAPTER 6 STUDY 3 – A RANDOMIZED CONTROLLED TRIAL DESIGN

### Introduction

Study 3 builds on the work of Study 1 and 2 focuses on the same research questions itemised below:

- a) What are the students' views on the use of mobile technology for learning mathematics?
- b) Is there a change in attitude towards mathematics when mobile technology is used for learning maths?
- c) Is there a change in attitudes towards technology when mobile technology is used for learning mathematics?
- d) Is there an improvement on mathematics achievement when using mobile-supported maths learning activities?
- e) Are there differences in maths attitude, achievement scores and evaluation of mobile learning between boys and girls?

Study 1 was a pilot study and focused in some respect on the breakdowns and breakthroughs of using mobile devices. Study 2 recruited a control group to allow comparisons between mobile and non-mobile use. The control group, however, were a grade older than students of the experimental group and followed a no-treatment design. So, to address Study 2's design limitation, this iteration followed a randomised controlled trial where Primary 6 and 7 students were randomly allocated to either experimental or control group. Both groups also followed closely matched activities with the primary difference being the use of the mobile device. Recommendations by the teacher from Study 2, issues identified during the previous iterations and issues arising from the new setup were also factored into this design iteration. The list of changes are as follows:

- 1. Fixed time allocation.** In Study 2, because the experimental group were under the same teacher for the rest of the day, there were occasions that the sessions ran over the hour allocated. This extension allowed students to complete the mobile learning activities and facilitated discussion after the activity. Study 3, however, was from three different classes and didn't have the time flexibility given by the teacher in Study 2. It was important that the groups finished on time so that they could go back to their respective classrooms at set times. The

sessions were allocated 50 minutes but this included the five-minutes movement time before and after the maths period.

- 2. Outdoor Setup.** There were no outdoor-based activities in Study 2. This change was due to several reasons. Study 3 was timed for November-December where outdoor weather conditions were not ideal. The classrooms were not at ground level and required more time to move students. As an alternative to the outdoor setup, the outdoor-based activities were confined to the shared workspace available outside the classrooms.
- 3. Topic coverage.** Topics included in the previous studies covered angles, symmetry, data collection and area and perimeter. One of the recommendations of the teacher was to cover fewer topics and explore more possibilities of using the mobile device to cover the same topic, rather than having a one-off session with symmetry or angles. This recommendation was taken on board and so, Study 3 focused on geometry topics of symmetry, angles and area and perimeter.
- 4. Session sequencing.** In previous studies, the indoor-based activities and outdoor-based activities were bundled together, as it was originally intended to compare student feedback between the two settings. Both teachers felt that this separation was not necessary, so the new setup included two sessions covering symmetry, two sessions on angles, two on area and perimeter then the last two sessions covering an overlap of the three topics.

## **Methodology**

### **Research Design**

The study used a randomised controlled trial design. Similar to previous studies, evaluation was carried out using the same M3 level evaluation. Table 6-1 outlines the research design following the M3 level framework and shows which groups are involved at each evaluation.

Table 6-1  
*M3 Level evaluation framework*

<b>M3 Level and Purpose</b>	<b>Instrument</b>	<b>Participants</b>
<i>Micro-level</i> Evaluate student perceptions about each activity	End activity evaluation	Experimental and control group
<i>Meso-level</i> Evaluate student experience Evaluate student engagement	Group interviews Teacher interview Video recording (in pairs)	Experimental group only
<i>Macro-level</i> Evaluate the effect of mobile use to students' attitude and performance	Pre-post design for mathematics attitude inventory and maths tests	Experimental and control group

### **Participants**

The participant classes were obtained by soliciting voluntary teachers from within one local authority in Scotland. Three teachers who co-teach Primary 6 and 7 mathematics from the same primary school agreed to participate in the research. Two teachers (the Primary 6/7 teacher and the Primary 7 teacher) were assigned to the control group while the Primary 6 teacher and a teaching assistant were assigned to the experimental group. Seventy-four students were randomly assigned by the teachers to the experimental and control group. There were 35 students in the experimental group and 39 students in the control group. The reason for the unequal number of participants is that one student was automatically assigned to the control group because a parent declined to have their child participate, the other student that was supposed to be in the experimental group did not participate because he/she had to participate in an advanced maths class. The school, as described by an Education Scotland report (2015), had 20% of students receiving free school meals, around 8% less than Scotland's national average. Pupils' absences were roughly 5% higher than the national average of 3.8%.

### **The mobile learning activities**

**Technology used.** The technology used for the intervention included two models of tablet, Acer A1-810 and A1-830. Both tablets were 8-inch Android tablets but the latter was the newer version. The A1-810 tablets were the same tablets used for Study 2. However, these tablets were no longer available to purchase for Study 3 so the next similar model was used. Most of the software applications used in this study were similar to Study 1 and 2. This included Skitch, Mirrord, Measure Map, Snapshot Bingo

and Aurasma. For a discussion of most of these applications, refer to Study 1. For details on Aurasma, refer to Study 2. The new applications introduced for this Study are discussed below.

**Pixel Touch.**<sup>10</sup> There are several sprite drawing applications on the Android market but most of these applications contain advertisements while the other applications were not optimised for the tablets used in this study (e.g. Pixel Station and Pixel Art editor). Pixel Touch, by contrast, is ad-free and compatible with the system. The other advantage of Pixel Touch is its simple interface and additional functionalities like symmetry, copying a part of an image and image rotation. The latter two are useful functions for investigating rotational symmetry. For an illustration of the interface of Pixel Touch, a screenshot of a completed work by a student is shown in Figure 6-1.

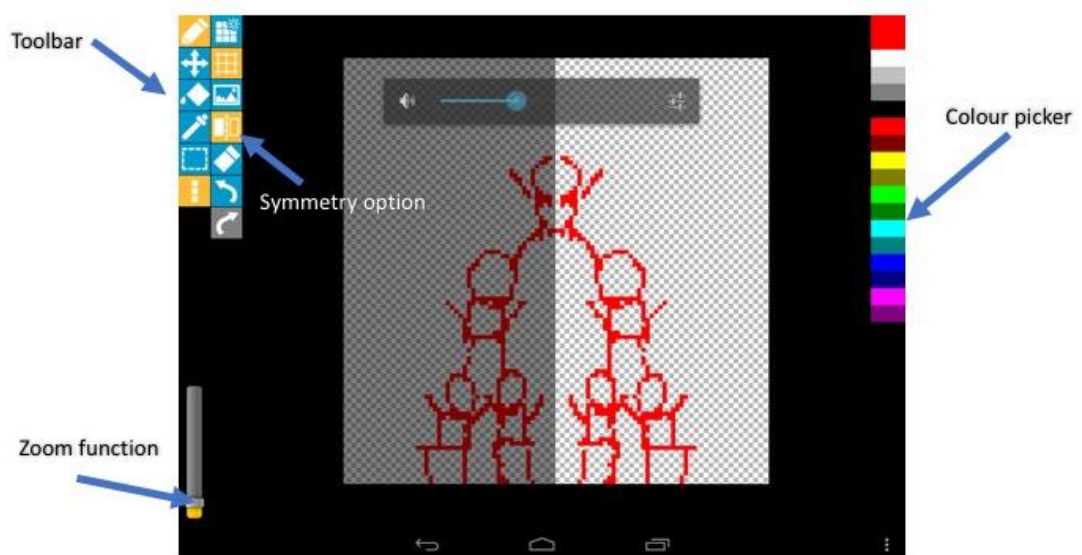


Figure 6-1. Screenshot of Pixel Touch shown with an example of students' work

**Material Protractor.**<sup>11</sup> At the time of research, protractor applications on the market were quite limited. The criteria for choosing a protractor application is its ability to overlay the protractor on images. One of the applications considered was On Protractor<sup>12</sup> which allowed augmenting the angle measurement with the live camera

<sup>10</sup> Pixel Touch is available to download from <https://play.google.com/store/apps/details?id=drawing.sprite.app>

<sup>11</sup> Material Protractor is available to download from <https://play.google.com/store/apps/details?id=com.materialtools.app.protractor>

<sup>12</sup> On Protractor is available to download from <https://play.google.com/store/apps/details?id=com.pandaz.protractor>

view, but the application had an intrusive advert which covered the entire screen. Another application considered was Protractor<sup>13</sup>, but the application was incompatible with the mobile device being used. Due to device compatibility, the applications available to choose from became limited. This left Material Protractor from the list of remaining applications considered. While this application has advertisements, the adverts were displayed on the bottom of the screen and were not intrusive. It also had a camera function which allowed the user to take a picture of an object for angle measurement later on in the lesson. In addition, the application had a save and share function which allowed the user to share their completed work with other members of the class. A screenshot of the application is shown in Figure 6-2.



Figure 6-2. Screenshot of Material Protractor shown with an example of a students' work.

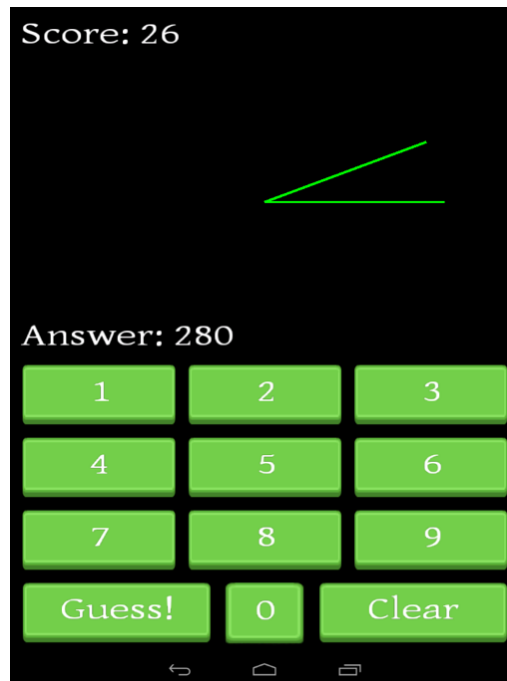
**Angle Reader.**<sup>14</sup> This application is a game-based application that asks the user to estimate the given angle. At the time, this application was the only application that

<sup>13</sup> Protractor is available to download from <https://play.google.com/store/apps/details?id=com.pineapple4.protractor>

<sup>14</sup> Angle reader is available to download from [https://play.google.com/store/apps/details?id=com.chelseaf.Angle\\_Reader](https://play.google.com/store/apps/details?id=com.chelseaf.Angle_Reader)



allowed the user to practice estimating angle measurement. The application worked by showing a picture of an angle. The user then keyed in an estimate of the measurement. If the user answered within 30 degrees of the actual measurement, they scored a point depending on how close their answer was to the correct answer. The user was then shown a new angle to estimate. The game ended when the estimate fell outside the 30 degree plus/minus range. A screenshot of the application is shown in Figure 6-3.

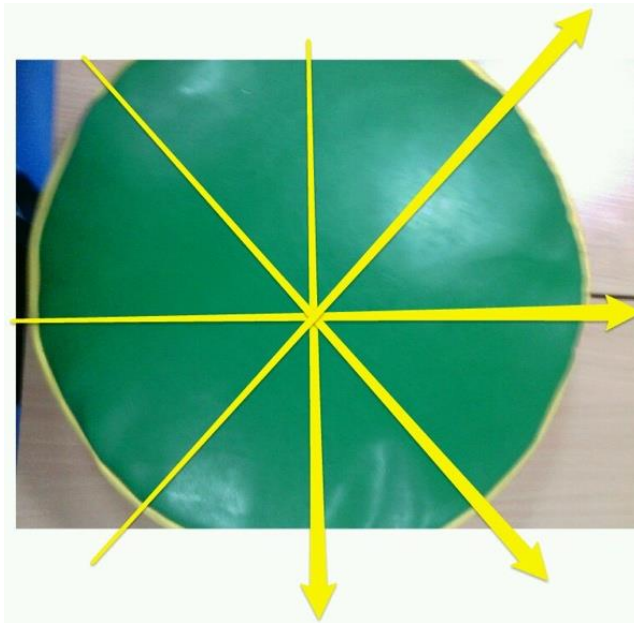


*Figure 6-3.* Screenshot of angle reader application

The criteria set for the additional applications chosen in Study 3 were the same criteria applied to the selection of applications used in Study 1 and 2. These were in relation to the user interface, support for saving one's work and the capability of the application to support the learning activities. What follows is a discussion of the mobile learning activities.

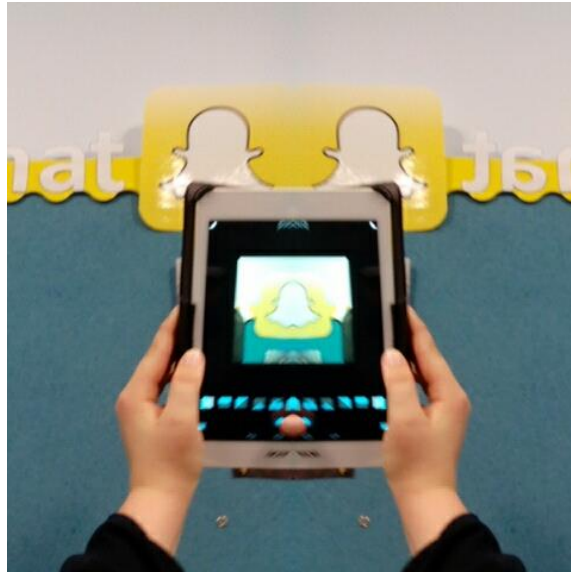
**The learning activities.** The activities carried out in this study were similar to the activities in Study 1 and 2 but the information handling activities were taken out. The structure of the lesson remained the same. It began with an introduction to the topic being investigated followed by an orientation to the day's activity, then by the mobile activity itself. A discussion of students' output was always carried out at the end of the session. All activities were carried out in pairs and students worked with the same partner for the duration of the research. A more detailed explanation of the mobile learning follows.

**Activities on symmetry.** There were two sessions covering symmetry. Session 1 was very similar to Session 1 of Study 1 and 2. The learning objective was for students to identify lines of symmetry on symmetrical objects found inside and outside the classroom. Using Skitch, students took pictures of symmetrical objects. This activity focused on the Van Hiele level of visualisation and by having the students have a visual record of their understanding of symmetry, the teacher was able to identify areas of misconception. For example, in Figure 6-4, the students work clearly shows a misconception on circles and its line of symmetry and so, this prompted the teacher to discuss the mistake.



*Figure 6-4.* An example of student misconception that circles have finite lines of symmetry.

In Session 2, students investigated symmetry further by using the application *MirrorD* that was discussed in Chapter 4. The application allowed the students to see how objects would look like if they were symmetrical. It also facilitated an investigation of how symmetrical objects would look the same on the symmetry camera as shown in Figure 6-5.



*Figure 6-5.* An example of a student's work showing how a symmetrical object still looks the same under a symmetry camera.

In Session 1 and the first part of session 2, the control group was also tasked to investigate symmetry in their environment. However, the control group was limited to making notes of which object were symmetrical and which objects were not. Both groups investigated symmetry in the environment and both groups were supposed to have a discussion and sharing of images/artefacts found, but obviously the control group was limited to describing what they found whereas the experimental group had their annotated images to support their findings.

The second part of the session focused on students creating artworks that were symmetrical. In a non-technology enhanced classroom, this activity is typically carried out by having students design their artworks using gridded papers, which was the activity for the control group. The experimental group, on the other hand, used the application Pixel Touch. The application facilitates the creation of artworks in a more efficient manner by allowing the user to start creating straight away and if need be, undo steps that do not fit with what they had planned. A non-mobile version, however, is limited in the sense that it is difficult to undo a mistake (they either have to erase or start again). An example of a completed work by students in the experimental group is shown in Figure 6-6a while Figure 6-6b shows part of the work started by students in the control group. Note that there were only two partially completed worksheets that came back from the control group, so it was assumed that majority of the student pairs had not started their work.

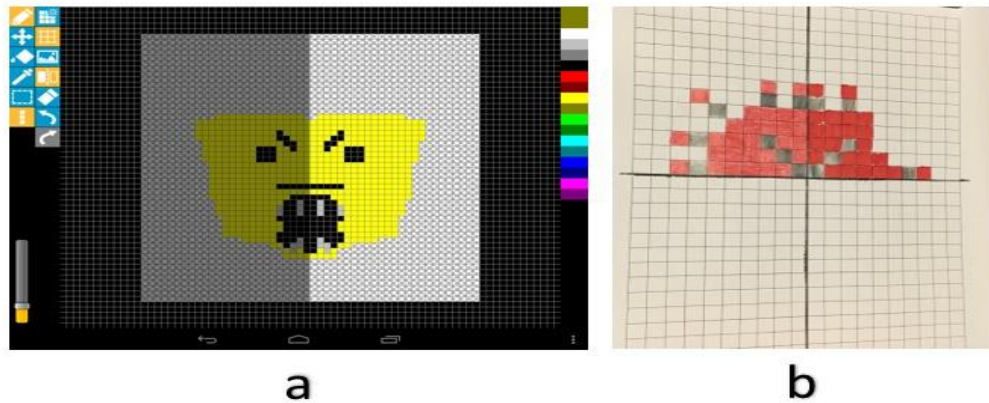


Figure 6-6. Examples of a students' work: (a) experimental group (b) control group

**Activities on angles.** Session 3 closely followed the lessons outlined in Study 1 and Study 2. The objective of the activity for both the control and experimental was to look for different angles in their environment and classify these angles according to their angle type. This activity aligned with the Van Hiele level of visualisation and analysis. In the control group, students were given a worksheet that listed all the angles they had to find. They were tasked to either draw or describe the object that fitted the angle type being asked for. In the experimental group, the tasks were delivered to the students by scanning a QR code as shown in Figure 6-7a. Using Skitch, students took pictures of objects and annotated the picture to show the angle and the angle type as shown in Figure 6-7b. At the end of the session, the teachers called on students to share some of their work with the rest of the class. It was assumed that the control group teacher did the same as this was outlined in the lesson plan for the control group.

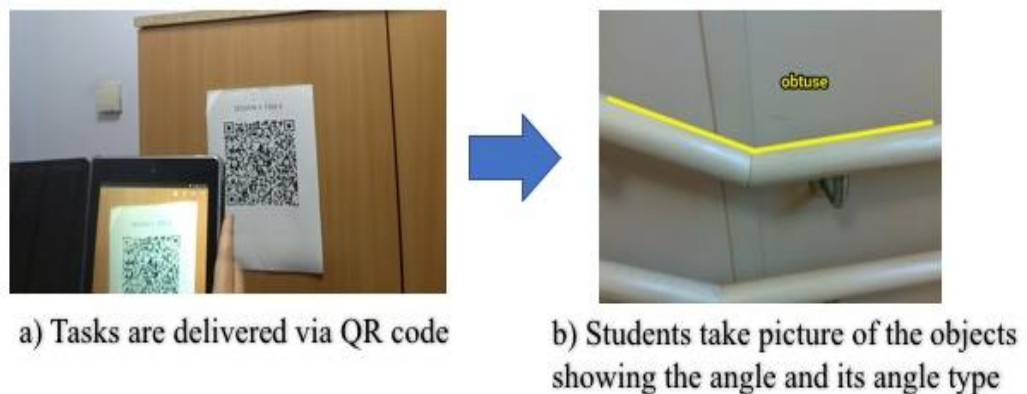


Figure 6-7. An illustration of the mobile learning activity for Session 3.

In Session 3, students classified the different angles by how they looked without measuring them. In Session 4, students referred back to the pictures they composed in Skitch and measured its angle. An example of a completed work is shown in Figure 6-2. This activity facilitated the Van Hiele level of analysis as the students were looking at the geometric properties of angles in relation to their angle measurement (for example, an obtuse angle would have an angle measurement between 90 degrees and 180 degrees). Students also investigated common misconceptions relating to angles. One misconception is that the length of the lines of the angle affects the angle measurement. Using the application Material Protractor and the pictures that they had previously gathered, the students observed that the length of their annotation in Skitch (as shown in Figure 6-7b) did not have an effect on the angle measurement as shown in Figure 6-2. Another misconception is that the size of the angle has an effect on the image. The Material Protractor application also allowed students to pinch and zoom on the image they created in Skitch, allowing them to observe that the size of the picture did not affect the angle measurement. Using the mobile device, students were able to do further investigation on the images they had gathered in Session 3 and this provided continuity to their learning activity. In the control group, these additional manipulations and measurement were not possible - it was not possible to build on the work that they did in the previous session as the worksheet contained words and crude drawings that could not be measured. The misconceptions were instead discussed via direct instruction.

After doing their investigations on angles, students engaged in a game-based learning activity that allowed them to estimate the angle measurement. The Angle Reader application as discussed provided students with an infinite amount of practice on estimating angle measurement based on how the angle looked. Students worked on this activity in pairs. By contrast, while the control group also used a game-based learning activity, the students worked on this as a class as there was only one computer in the classroom. It can thus be argued that the mobile activities provided students with individual practice as opposed to the whole class in the control group.

***Activities on area and perimeter.*** Session 5 was similar to the Session 2 activities of Study 1 and 2. Students used Measure Map to measure the area and perimeter of nearby areas and the mobile learning application provided examples of large scale units not otherwise covered in textbooks. The Area and Perimeter application allowed the students to offload the computation of area and perimeter to the manipulative, allowing them to do further investigations on area and perimeter (for example, finding out if the

area grows with the perimeter and if there are instances where the perimeter increases but the area decreases). Refer to the mobile learning activities session of Study 1 for details on how the experimental group session was carried out. As for the control group, they also did the same investigation of properties of area and perimeter but without the manipulative, and so all computations were manually done by the students.

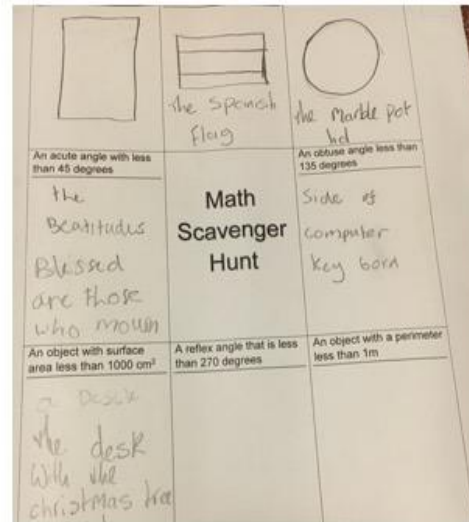
After investigating the properties of area and perimeter in the previous session, Session 6 included activities on solving word problems relating to area and perimeter. Students were given task sheets that were encoded with augmented realities. In this activity, the mobile device provided an alternative way to visualise the word problem overlaid on a two-dimensional representation. The control group, on the other hand, was limited to the task sheets provided and did not have that additional visualisation afforded by the tablets.

***Activities on combined topics.*** Session 7 combined the topic of symmetry and area and perimeter. Students used the maths manipulative Area and Perimeter to find the 12 different shapes that make up a pentomino, a shape made out of five equal sized squares placed side by side. This activity illustrates how perimeters can vary but the area remains the same. As some of the shapes created are symmetrical and some were not it provided some practice on identifying reflective symmetry. It also allowed students to practice rotational symmetry as the task was to look for distinct shapes and rotations were not accepted. Using the manipulative, students off-loaded the computation onto the mobile device and focused on the investigation at hand. The control group, by contrast, had to do the computations by hand.

In Session 8, the task was to look for representations of geometric properties in the environment. Using the application Snapshot Bingo, students took pictures of these geometric representations. These findings were later on presented to the rest of the class on a bigger screen. Examples of completed work are shown in Figure 6-8. On the left the figure shows a student from the experimental group discussing their work. On the right is an example of a worksheet completed by the control group. In both the control group and the experimental group, the activity was to look for geometric representations “in the wild.” In the control group, evidencing was based on students’ drawings and description, while in the experimental group this was via pictures that allowed for a discussion at the end of the session.



a) Example of experimental group's work



b) Example of a completed worksheet from the control group

Figure 6-8. Samples of completed work in (a) experimental group (b) control group

The objective of the mobile learning activities carried out in these sessions was to provide a link between abstract maths concepts and their concrete representations in the real world. The lessons were also delivered together with activities that were more aligned with typical classroom activities (for example, the design of symmetrical pattern in Session 2, the angle estimation game in Session 4, and use of manipulatives in Sessions 5 and 7). The mobile device facilitated the learning activities from the less formal and more active activities carried out outside the classroom to the more formal and structured activities done in class. A short summary of the activities carried out is listed in Table 6-2. The table also outlines how the activities fall within the substitution, augmentation, modification and redefinition (SAMR) hierarchy (Puentadura, 2006).

Table 6-2  
 Summary of learning activities mapped into SAMR (Puentadura, 2006) framework

Session	Mobile Learning Activity	Learning Activity (Control Group)	SAMR Framework
Session 1 and 2 Symmetry	Using Skitch, students took pictures of symmetrical objects and annotated it with its line of symmetry.	Students identified the lines of symmetry of everyday objects that can be found in the classroom.	This activity can be classified as <i>modification</i> under the SAMR framework. The mobile device afforded the students to capture artefacts from their environment which they were able to discuss later on in class. The non-mobile version did not have that opportunity of further discussion.
	Using Pixel touch, they also created designs that are symmetrical.	Using a graphing paper, students created designs that are symmetrical.	This activity falls under <i>augmentation</i> . The mobile learning application facilitated an easier process of designing the symmetrical design through its functionality. The undo/redo button also afforded the students to be flexible in their design. The non-mobile version, however, did not have this feature and as it turned out, only few students from the control group have started their designs.



Session	Mobile Learning Activity	Learning Activity (Control Group)	SAMR Framework
Session 3 and 4 Angles	<p>Tasks were encoded in QR codes to provide a game-like activity. These tasks encoded in QR codes instructed the students to look for different types of angles predetermined by the teacher. Each QR code contained one task (for example, one QR code asks the students to look for examples of acute angles while another QR code asks students to look for examples of reflex angles). Students took pictures of objects that corresponds to certain types of angles. The objects were not pre-allocated and students were free to choose any object provided that it meets the condition. They annotated the pictures (using Skitch) to show the angle and its estimated angle measurement. Using pictures that they had taken the previous week, they use Material Protractor to measure the angles. This was followed by a teacher guided activity to investigate common misconceptions on angles.</p> <p>Using Angle Reader, a game-based tablet application, students worked in pairs to estimate the measurement of an angle</p>	<p>Students work in pairs and look for different types of angles in their environment. They then sketch/draw the objects they found in the worksheet provided. In the next session, students used a folded circle as a manipulative to estimate angles. As a class activity, the teacher discussed with the students' misconceptions of angles using pictures of everyday objects and a protractor to measure the angle measurements of these objects.</p> <p>As a class, students played a web-based game on estimating angle measurement.</p>	<p>As described in the control group activity, the activities could be carried out without the use of the mobile device; however, the technology in this instance mediated the activity better as it allowed the students to continue their investigations outdoors to the investigations that they did relating to misconceptions on angle. As such, this can be classified at the level of <i>modification</i> in the SAMR model.</p> <p>The mobile learning activity in this example falls under <i>augmentation</i> on the SAMR model. While the activity can also be carried out with standard computers, the mobile device facilitated the paired work as opposed to the one-computer classroom setup of the control group.</p>

Session	Mobile Learning Activity	Learning Activity (Control Group)	SAMR Framework
Session 5 and 6- Area and Perimeter	Students investigated area and perimeter of surrounding environment using Measure Map. They also investigated properties of area and perimeter using a manipulative and completed task cards that contain word problems on area/perimeter tagged with visual representation using augmented reality.	Students investigate area and perimeter and their relationship using the worksheet provided. They also completed task cards to solve word problems relating to area and perimeter.	<p>The first part of the activity is classified as <i>modification</i> on the SAMR model. For that activity, the mobile device facilitated investigation of area and perimeter of nearby areas. The control group on the other hand did not have that opportunity because of the lack of technology to support it, and so, rather than investigate the properties themselves, this linking of real life measurement to area and perimeter was only in the form of an introduction given by the teacher.</p> <p>For the activity where students used a manipulative to investigate properties of area and perimeter and solve word problems, the mobile device facilitated ways to visualise area and perimeter and also off-loaded the computational task from the student. However, this only falls under <i>augmentation</i> on the SAMR spectrum as the mobile activities were merely enhancements of the paper version.</p>

Session	Mobile Learning Activity	Learning Activity (Control Group)	SAMR Framework
Session 7 (Area and Perimeter; Symmetry)	Using Area and Perimeter, a maths manipulative application, students work in pairs and look for the 12 different shapes that make up a pentomino, identify its line of symmetry, area and perimeter.	Students worked in pairs and looked for the 12 different shapes that make up a pentomino. They drew these shapes on a graphing paper then identified its line of symmetry, area and perimeter.	By the same rationale given for the area and perimeter sessions, this activity falls under <i>augmentation</i> on the SAMR model.
Session 8 (Symmetry, Angles, Area and Perimeter)	Following a scavenger hunt theme, students used Snapshot Bingo to look for objects in their environment that represented specific geometric properties. These gathered artefacts were later presented to the rest of the class.	Following a scavenger hunt theme, students looked for objects in their environment that contained specific geometric properties. The objects they were to find were listed in a worksheet and students were tasked to draw or describe their findings. At the end of the session, the teacher called on a few students to give examples of what they found.	While the activities of the control group closely match the experimental group, the output that the two has provided was very different. The technology in this instance facilitated data gathering which enabled the sharing session that was done in class. Based on the images presented, it was easy to identify whether these were right or wrong. For the control group, because they were limited to describing and drawing, if what they found was outside the classroom wall, it was not possible to verify whether it was a correct representation or not. And so, this activity is classified as <i>modification</i> on the SAMR hierarchy.

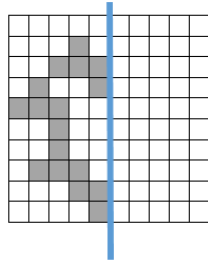
## Instruments and Measures

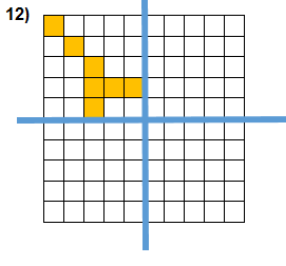
**Maths attitude inventory (MAI).** The maths attitude inventory was the same inventory used in previous studies but incorporated a few changes. Double negative statements had proven to be a problem for some students and so they were revised to simpler statements. For example, the statement “Using mobile technologies in mathematics is NOT worth the extra effort” was revised to simply state “Using mobile technologies in mathematics is worth the extra effort.” This affected the balance between positive and negative statements in the previous version, but rather than keeping the balance it was deemed more important that students understood the question at a glance. Some wordings were also simplified. For example, the statement “I am always under a terrible strain in a mathematics class” was changed to “I am always under pressure in a mathematics class.” As the questionnaire only included minor changes, this version was not piloted prior to the study.

The full published version of the scale was used for this iteration as opposed to only a part of the published scale used in Study 1 and 2. The reliability scores of the MAI subscales *confidence with technology* and *learning mathematics with mobiles* in the previous design iteration were relatively low compared to the published reliability of .79 and .89 respectively so this prompted to use the full published scale.

**Maths test (MT).** Items on the maths test have similarities to study 1 and 2 but questions relating to information handling have been taken out. The test has four topics: symmetry, angles, area and perimeter and questions that combine the previous topics. Some test items on student misconceptions (Harris, 2000; Hansen, 2014) on each of the topics were added to the test to check whether the hands-on nature of the activities addressed common errors in the topics covered. Sample test questions are shown in Figures 6-9a to 6-9c.

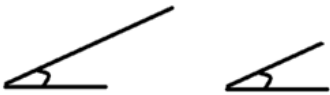
Shade the boxes to create a reflection of the image shown. The line of symmetry is shown.


11) 


12) 

(a)

Identify whether the angle on the left is smaller, bigger or equal to the angle on the right. Write your answer on the space provided.

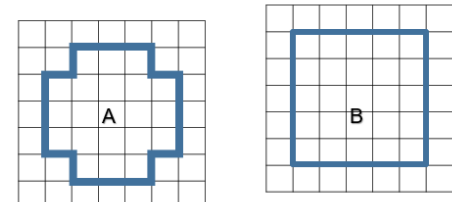
20)  \_\_\_\_\_

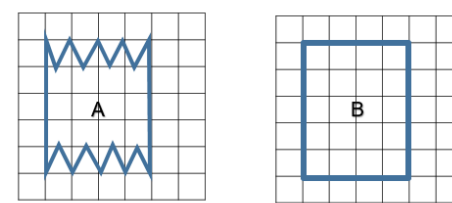
21)  \_\_\_\_\_

22)  \_\_\_\_\_

(b)

Identify whether the **perimeter** of the object on the left is **smaller, bigger or equal** to the object on the right. Write your answer on the space provided.

25)  \_\_\_\_\_

26)  \_\_\_\_\_

(c)

Figure 6-9a-c. Sample test items on (a) symmetry, (b) angles, (c) area and perimeter

Harris (2000) noted that misconceptions stem from lack of awareness or poor understanding of geometric properties. For example, one typical misconception in angles is that the length of the ray affects the angle measurement, and some students would incorrectly assume the larger image in item 20 in Figure 6-9b would be bigger

than the one on the right. The mobile learning activity requires them to take pictures of different angles, annotate these pictures to show the angle, then measure these angles afterwards. It is expected that students will be able to realise that making the picture bigger or that changing its orientation (see Figure 6-10 below) does not affect the angle measurement.

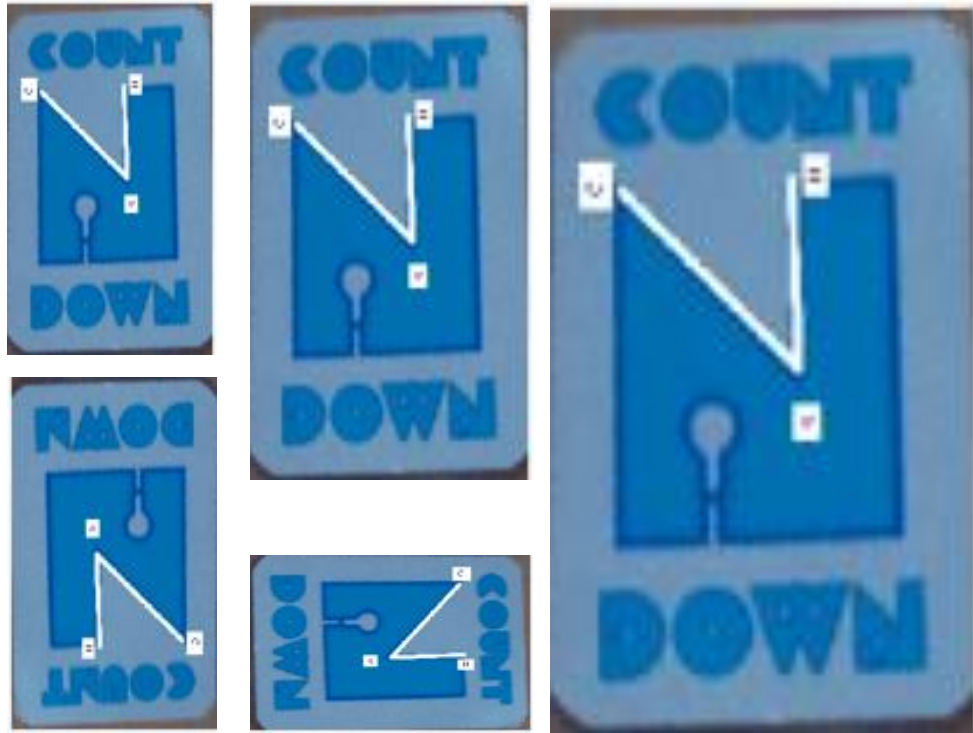


Figure 6-10. An example of an annotated picture showing angle at different size/orientation

**End activity evaluation.** Similar to the maths attitude inventory, some of the wordings were simplified to make it easier for the students to understand and also to provide a more appropriate antonym for the word. For example, the word *irrelevant* was changed to *not useful*, and the previous word pair of *easy to understand vs too technical* was changed to *easy to understand vs difficult*. As the control group also worked on a similar activity, the end activity questionnaire was also administered to the group but with questions relating to tablet use omitted.

**Interviews.** Please refer to previous study.

**Video recording.** Wearable clip-on cameras were used to record interactions between student pairs. The wearable cameras were attached to the participant's collar to allow the camera to capture the tablet view, hand gestures and a view of their partner. Lonsdale (2011) noted that standard cameras had limitations in capturing mobile

learning activities both indoors and outdoors. Indoors, even with the strategic positioning of a standard camera, students tend to obstruct the camera view as they work on the mobile device. Outdoors, the issue is that of mobility and the need for a camera to follow students as they work on an activity. This wearable camera allowed video to be captured as students moved about during the mobile learning activities. At the same time, it also captured conversation between pairs of students with little background noise as the video microphone was always close to the speaker.

**Observation protocol.** The New Outcomes: Learning Improvement in Mathematics Integration Technology (NO LIMIT) project, (NO LIMIT, 2002) listed the following as worthwhile mathematical tasks:

- Students are engaged
- Students communicate about the maths tasks at hand
- Students make conjectures, generalise and ask questions

These tasks were broken down into observable behaviours adapted from the Baker Rodrigo Ocumpaugh Monitoring Protocol (BROMP) (Ocumpaugh, Baker & Rodrigo, 2015) and Baines' (2008) list of communication skills in group work. Student disengagement and off-task behaviours were also added in the observation protocol. A summary of the observation protocol mapped into the NO LIMIT's list of mathematical tasks is listed in Table 6-3. Validity and reliability of these measures were not published but BROMP has provided a guidance of 0.6 as an acceptable measure of inter-rater agreement. Five-percent sample of the videos were randomly selected to test for inter-rater reliability. Each of these video samples was one minute long taken from each of the mobile learning sessions. An independent coder with 12 years of maths teaching experience also coded all the sample videos. This yielded an inter-rater agreement of 75%.

Table 6-3  
*Observation protocol*

Category	Item
Students are engaged	<b>On-Task Conversation:</b> refers to a student who is working towards his or her assignment while having a conversation with the teacher or another student about the subject matter or learning task.
	<b>On-Task Help Seeking:</b> refers to a student who has paused work, but only because he or she is seeking help from another student or the teacher
	<b>On Task Listening:</b> students appear to be listening to the teacher. If the view is off-camera, camera angle will remain fixed and no audio from students would be heard while the teacher's voice is playing on the background
	<b>On-Task Tablet Use:</b> Student is working on the assigned activity on the tablet (this includes activities like reading what's on screen and manipulating the tablet)
	<b>On-Task Non-Tablet Use:</b> Students are working on the assigned activity but not using the tablet (examples of this include investigating their environment to look for symmetry, or writing on the companion worksheet).
	<b>On Task (Passive)</b> to student who appears to be on task but not exactly taking an active role. For example, if the two students are walking about, one student is actively using the tablet while the other student is following along.
Students communicate about the maths tasks at hand	<b>Planning:</b> This includes all conversation discussing procedures about what they should do (for example, discussing who's doing which task)
	<b>Making and asking suggestions about the activity</b> (this only includes suggestions about the topic but not procedural suggestions like what to do next, or whose turn it is)
	<b>Giving and asking help</b>
Students make conjectures, generalise and ask relevant maths questions	<b>Expressing, explaining and evaluating ideas</b> (this only includes ideas about the topic but not ideas on how to organise the activity)
	<b>Asking questions</b> (this only includes questions about the topic but not procedural questions like what they should do next, or whose turn it is)
Students are disengaged	<b>Off-Task Passive:</b> refers to a student who is off task but not interacting with anybody or doing much of anything. For instance, the student may be sleeping or staring into space.
	<b>Disengaged tablet use:</b> Students are using the tablet not related to the activity for example browsing the internet, taking pictures of random objects.
	<b>Off-task social:</b> student conversation does not involve planning about the activity or discussing the class material.
	<b>Off-task disagreements:</b> students are not in agreement with what to do (for example, about whose turn it is, or a partner nudging their partner to work).
	<b>Off-task disruptive behaviour:</b> refers to students who are off-task and causing disturbance to other students



## Procedure

A pre-test of MT and MAI was completed by the experimental and control group a day before the start of the intervention. To avoid confusion, the teacher read out the instrument to the students before having them fill out the form. The students were also encouraged to ask questions for any items they were not clear about. On the same day, following the tests, an introductory session with the experimental group was conducted to brief the participants about the nature of the activities to be carried out.

The control and experimental groups participated in eight 50-minute long sessions spread over a period of 5 weeks. This was originally planned for a two-month session but with the holiday approaching and the busy school schedule around December, this was cut to six weeks and so, during the last week, three sessions were delivered consecutively and the post-test followed the next day. The experimental group participated in activities that used tablet devices while the control group participated in activities of a similar nature but without the aid of mobile technologies (refer to Table 6-2 for a summarised list of activities and the section that covers the learning activities for a detailed discussion). Students worked in pairs throughout the intervention and where possible with the same partner (unless their assigned partner was not present for the day). They participated in collaborative learning activities carried out within the classroom and the shared work area just outside the classroom. There were three topics covered (symmetry, angles, area and perimeter) with two sessions each. The last two sessions covered a combination of the previous topics. Both control and experimental group completed an End Activity Evaluation questionnaire at the end of every topic.

Four students from the experimental group were assigned by the teacher to wear a wearable camera for all the sessions except the first. The teacher selected the four students to wear the camera with the criterion being their performance in maths. As such, one very good student, two average students and a more challenged student were selected. The activities of these four students were recorded throughout the sessions. At the end of the programme, both groups took the MT and MAI post-test. An interview with the teacher and student participants of the experimental group was also carried out at the end to get feedback on the intervention.

## Data analysis

**Micro-evaluation.** For the experimental group, each of the scores in the adjective pairs were grouped into tablet and activity ratings resulting in nine adjective pairs per category. For the control group, the nine adjective pairs were all grouped under activity ratings. The scores for each of the items in the group were averaged to obtain the usability score for the activity and the tablet (experimental group only), giving a score ranging between 0-5. The higher the score, the better the usability and vice versa. The activity usability ratings were compared between the experimental and control group using an independent t-test. Gender and level differences in the tablet and activity ratings within the experimental group were also compared using an independent t-test.

**Meso-evaluation.** Two areas cover the meso-level evaluation for this Study. The first area covers student interviews and is similar to that carried out in Study 2 (please refer to Study 2 for details). The second area of analysis is the video recordings of the paired activities. Of the four pairs of students, only two pairs of student worked consistently with the same partner so only the videos from this pair were used. The class discussions that came before and after the activity were not analysed as the focus was on the nature of interaction that happened during an activity supported by mobile devices. The videos of hands-on activity with the mobile devices were coded at 10 second intervals, which meant 10 seconds of the video was played then coded into the categories provided, giving a total of 1520 10-second segments from 14 different videos from sessions 2 to 8. The video recordings were later analysed into percentages to show how much the students were on-task and off-task within the session and the nature of communication that went on. The observations made were compared to the student and teacher feedback in the student interviews.

**Macro-evaluation.** An analysis of covariance (ANCOVA) was conducted to test the difference in performance of the experimental group and control group at MT post-test with MT pre-test as covariate. The adjustment for pre-test score in ANCOVA ensures that the differences at post-test are not leftover differences between the groups and to account for variation around the post-test means that comes from the variation in where the participants started at pre-test (Grace-Martin, 2013). For the MAI scores, data was grouped into experimental and control groups then tested using a paired t-test for each of the MAI subscales to see what significance there was in differences in pre and post-test MAI scores. Data were further grouped by level and gender to check for significant changes in students' attitudes to maths.

## Results

### Micro-evaluation

**End activity evaluations by group.** Table 6-4 shows the descriptive statistics for the student evaluation carried out at the end of each lesson. Evaluation for the angles session was not conducted because of the students' busy schedule on that day. Of the total 1957 item responses from the three sets of end activity evaluations in the experimental group, 62% agreed with the positive adjective, 17% were in agreement with the negative adjective and the other 20% were neutral ratings.

A t-test of the ratings at item-level (refer to Table 6-4) showed significant difference in the items *not useful vs useful*, *boring vs fun*, *gets in the way vs helpful* and *frustrating vs enjoyable* on the topic Symmetry. On these items, students in the control group rated the activity higher than the experimental group. For the topic area and perimeter and the sessions that combine the topics at the end, there is a significant difference in the item *old-fashioned vs innovative* with the experimental group scoring significantly higher than the control group. In terms of effectiveness, there is a significant difference in the groups' ratings on the topic area and perimeter, in favour of the control group,  $t(60) = -2.06$ ,  $p=.044$ ,  $d=.53$ . No other significant differences were found.

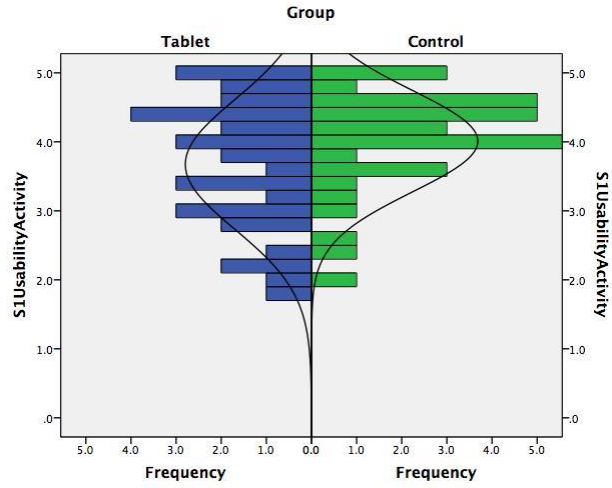
The total usability score was obtained by averaging the scores of the adjective pairs for each session. Given that the adjective pairs were relevant twice (for tablet and activity), this resulted into two scales: overall usability rating for the activity and an overall usability rating for tablet use. A histogram of the usability ratings for the activity is shown in Figure 6-11. The distribution of the usability ratings of the activity for all three iterations are skewed to the left but with the scores of the experimental group having a wider spread than that of the control group. The usability ratings were also compared between groups (see Table 6-5) but no significant difference was found at scale level for sessions on symmetry,  $t(61)=-1.630$ ,  $p=.108$ ,  $d=.40$ ; area and perimeter,  $t(60)=-1.056$ ,  $p=.295$ ,  $d=.27$ ; and the last two sessions,  $t(63)=.897$ ,  $p=.373$ ,  $d=.22$ .

Table 6-4

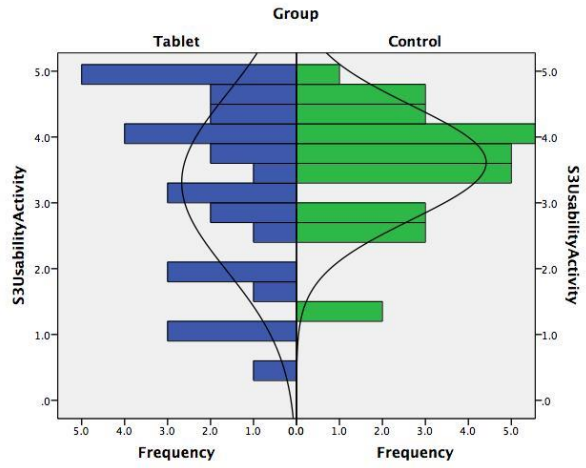
*Descriptive statistics of end activity evaluation (EG = experimental group; CG = control group).*

	Symmetry			Area and Perimeter			Combined Topics		
	EG	CG	<i>p-value, ES</i>	EG	CG	<i>p-value, ES</i>	EG	CG	<i>p-value, ES</i>
Not useful vs Useful	3.38 (1.45)	4.12 (1.12)	.021, d=.58*	3.24 (1.70)	3.68 (1.40)	0.282, d=.28	3.51 (1.57)	3.37 (1.28)	0.708, d=.09
Confusing vs Clear	4.18 (0.96)	4.16 (1.31)	0.952, d=.01	3.61 (1.36)	4.06 (1.24)	0.183, d=.34	3.98 (1.49)	4.01 (1.16)	0.926, d=.02
Distracting vs Thought-provoking	3.20 (1.04)	3.51 (1.55)	0.340, d=.23	2.88 (1.74)	3.10 (1.23)	0.564, d=.15	3.40 (1.48)	2.96 (1.57)	0.250, d=.29
Old-fashioned vs Innovative	3.84 (0.98)	3.39 (1.64)	0.181, d=.33	3.84 (1.25)	2.8 (1.67)*	0.007, d=.71	4.12 (1.16)	3.25 (1.47)	0.011, d=.65*
Boring vs Fun	3.28 (1.71)	4.26 (1.13)	0.008, d=.67*	2.82 (1.97)	3.53 (1.52)	0.120, d=.40	3.78 (1.64)	3.39 (1.37)	0.309, d=.25
Gets in the way vs Helpful	3.59 (1.33)	4.28 (0.95)	0.017, d=.60*	3.30 (1.73)	3.75 (1.35)	0.258, d=.29	3.48 (1.59)	3.42 (1.43)	0.860, d=.04

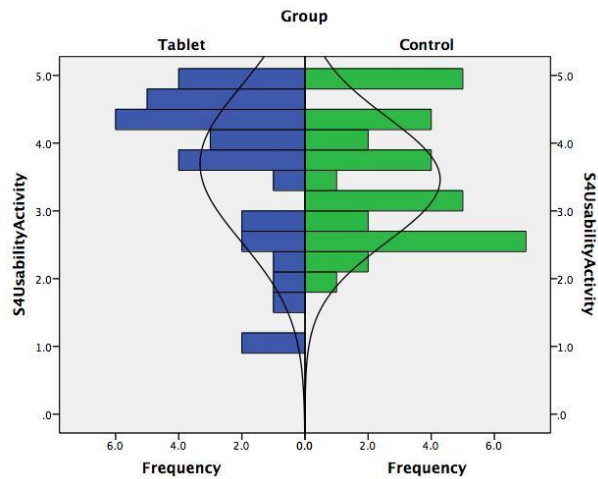
	Symmetry			Area and Perimeter			Combined Topics		
	EG	CG	<i>p-value, ES</i>	EG	CG	<i>p-value, ES</i>	EG	CG	<i>p-value, ES</i>
Ineffective vs Effective	3.61 (1.34)	3.64 (1.55)	0.935, d=.02	2.77 (2.08)	3.71 (1.46)	0.044, d=.53*	3.31 (1.68)	3.38 (1.34)	0.861, d=.04
Difficult to understand vs Easy to understand	4.16 (1.40)	4.31 (1.3)	0.656, d=.11	3.76 (1.38)	4.01 (1.32)	0.481, d=.18	3.94 (1.45)	3.76 (1.40)	0.612, d=.13
Frustrating vs Enjoyable	3.82 (1.41)	4.41 (0.89)	0.041, d=.51*	3.57 (1.52)	3.88 (1.19)	0.376, d=.23	3.75 (1.51)	3.63 (1.17)	0.730, d=.09
Overall, I am satisfied with the ease of completing the tasks in this activity. Strongly disagree (SD) vs Strongly Agree (SA)	3.56 (1.76)	4.19 (1.14)	.088,, d=.43	3.28 (1.52)	3.7 (1.46)	0.272, d=.28	3.23 (1.63)	3.59 (1.41)	0.340, d=.24
Overall, I am satisfied with the amount of time it took to complete the tasks in this activity. (SD vs SA)	3.61 (1.31)	3.95 (1.27)	0.285, d=.26	3.15 (1.69)	3.57 (1.57)	0.314, d=.26	3.18 (1.67)	3.53 (1.49)	0.383, d=.22



(a) Usability rating for symmetry



(b) Usability for area and perimeter sessions



(c) Usability rating for combined topics (session 7 and 8)

Figure 6-11. Histogram of usability ratings divided into topics

Table 6-5  
Usability scores of experimental and control group

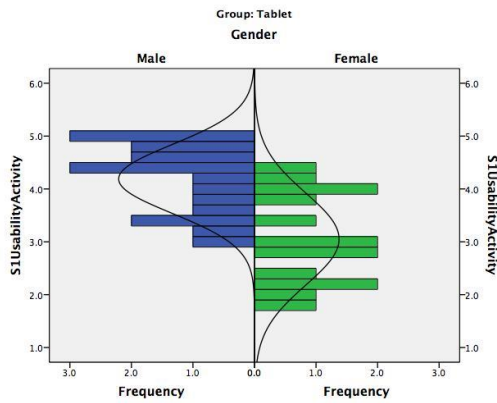
	Group	N	Mean	Std. Deviation	p-value	Effect size d
Symmetry Usability (Activity)	EG	33	3.67	0.94	.108	.40
	CG	34	4.01	0.74		
Area and Perimeter (Activity)	EG	30	3.31	1.35	.295	.27
	CG	32	3.61	0.87		
Combined Topics (Activity)	EG	32	3.70	1.15	.373	.22
	CG	33	3.46	0.92		

**Gender differences in experimental groups' evaluation.** Table 6-6 lists the descriptive statistics for the three end activity evaluations. An independent t-test of the ratings by gender showed that there was a significant difference between the boys' usability ratings of the tablet and the activities in comparison to the girls' ratings. In all instances, the boys rated the activities higher than the girls, which means that the boys had more positive perceptions of the activity than the girls. These gender differences were not significantly different with the control group in all three iterations of the evaluation: symmetry,  $t(32)=-.782$ ,  $p=.415$ ,  $d=.29$ ; area and perimeter,  $t(30)=-.875$ ,  $p=.388$ ,  $d=.31$ ; all topics,  $t(31)=1.850$ ,  $p=.074$ ,  $d=.65$ .

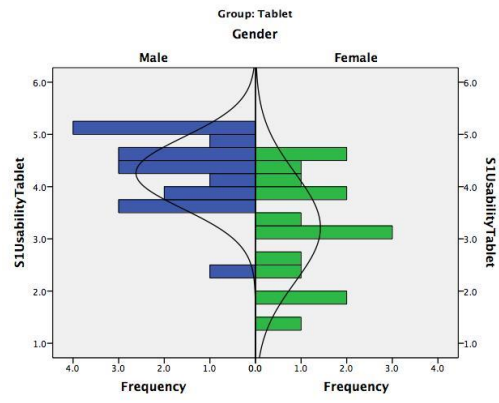
Table 6-6  
Gender differences in the experimental group's evaluation.

	Group	N	Mean	Std. Deviation	p-value	Effect size d
Symmetry Usability Rating (Activity)	Male	18	4.19	0.65	.000	1.51
	Female	15	3.05	0.87		
Symmetry Usability Rating (Tablet)	Male	18	4.26	0.68	.002	1.20
	Female	15	3.22	1.05		
Area and Perimeter Usability Rating (Activity)	Male	16	3.77	1.14	.045	.77
	Female	14	2.79	1.40		
Area and Perimeter Usability Rating (Tablet)	Male	16	3.77	1.18	.004	1.14
	Female	14	2.35	1.31		
All Topics Usability Rating (Activity)	Male	17	4.29	0.61	.002	1.29
	Female	15	3.03	1.27		
All Topics Usability Rating (Tablet)	Male	17	4.26	0.59	.004	1.22
	Female	15	3.09	1.26		

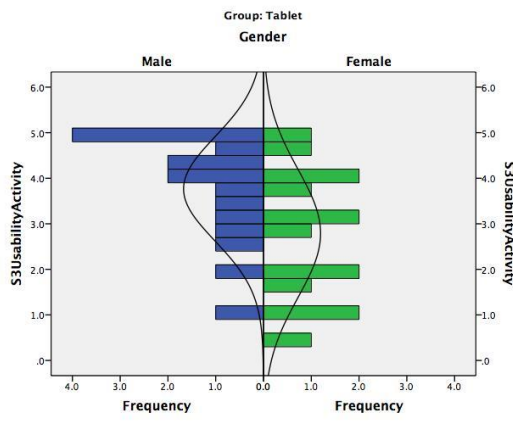
A graph of the distribution of the usability ratings is shown in Figures 6-12. From these figures, it can be observed that the usability ratings from the boys were mostly skewed to the left and mostly concentrated on the higher end of the scale while the girls' rating for all iteration were spread over the scale, showing differences in opinion between the gender groups.



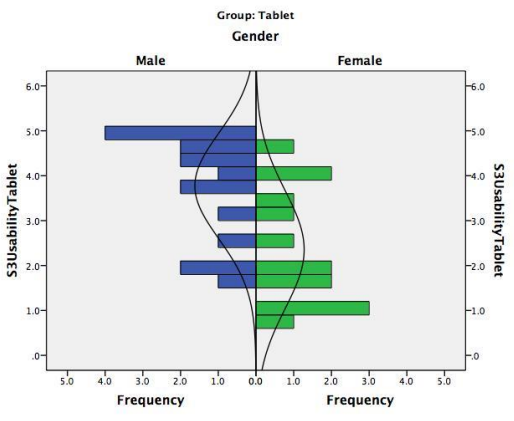
Usability rating (activity) for symmetry



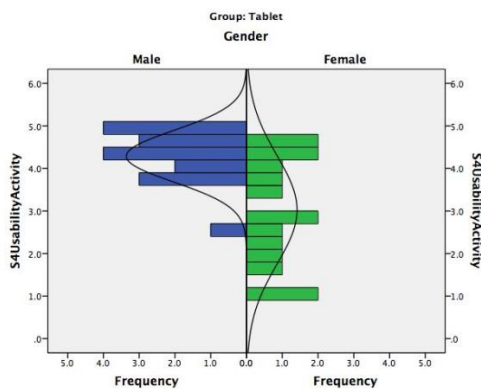
Usability rating (tablet) for symmetry



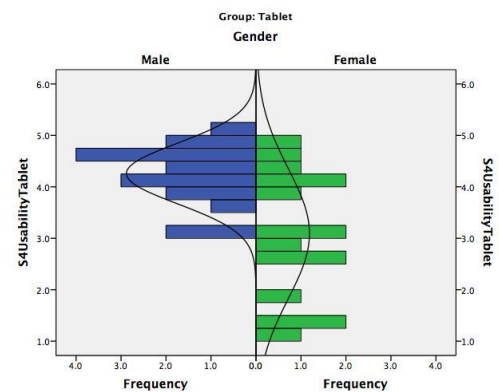
Usability rating (activity) for area and perimeter



Usability rating (tablet) for area and perimeter



Usability rating (activity) combined topics



Usability rating (tablet) combined topics

Figure 6-12. Histogram of usability ratings split by gender.



**Differences on end activity evaluations by grade level.** An independent t-test of the ratings by grade level showed that there was a significant difference between the Primary 6 students' usability ratings in comparison to the Primary 7 ratings but only for the session area and perimeter for the activity usability scale,  $t(26)=2.733$ ,  $p=.011$ ,  $d=.89$ . Table 6-7 lists the descriptive statistics for the three sessions. Again, these differences by grade level were not significant with the control group in all three iterations of the evaluation: symmetry,  $t(32)=1.981$ ,  $p=.056$ ,  $d=.68$ ; area and perimeter,  $t(30)=.488$ ,  $p=.658$ ,  $d=.16$ ; all topics,  $t(31)=1.163$ ,  $p=.254$ ,  $d=.41$ , showing that student evaluation of the activity did not statistically vary by grade level.

Table 6-7

*Descriptive statistics in the experimental group's evaluation grouped by grade level*

	Group	N	Mean	Std. Deviation	p-value	Effect size d
Symmetry Usability Rating (Activity)	P6	15	3.74	0.92	.705	.13
	P7	18	3.61	0.98		
Symmetry Usability Rating (Tablet)	P6	15	3.92	0.85	.477	.25
	P7	18	3.67	1.13		
Area and Perimeter Usability Rating (Activity)	P6	12	3.98	0.70	.011	.89
	P7	18	2.87	1.50		
Area and Perimeter Usability Rating (Tablet)	P6	12	3.55	1.27	.168	.52
	P7	18	2.82	1.47		
All Topics Usability Rating (Activity)	P6	14	3.83	0.89	.574	.21
	P7	18	3.59	1.34		
All Topics Usability Rating (Tablet)	P6	14	3.86	0.93	.527	.23
	P7	18	3.60	1.25		

### Meso-evaluation

**Student perception of the tablet activities.** Thirty-one out of the thirty-five students in the experimental group participated in the student interviews. Of the four students who didn't participate, one elected to not be interviewed while the three other students were not available on the day the interviews were carried out.

Twenty-four out of the 31 (71%) students gave positive feedback about the intervention while the other nine (29%) students felt negative about it. Students found

the activities fun (n=14), interesting (n=4), easier (n=2) and preferable to their usual maths (n=2). The activities were overall good (n=4), challenging (n=2), helpful (n=1) and novel (n=1). For some, however, they felt that the traditional way of doing maths is better (n=3). These students explained that they really didn't get a lot from the intervention as it didn't teach them anything new (n=2), and did not present enough challenges (n=1). They explained that it was boring (n=2) and at times even more confusing (n=2).

An analysis of the feedback above by level and gender showed some differences in student views. Of the 19 male students interviewed, three students felt negative about the use of tablets while the rest were more positive about the intervention. For the female students, feedback was split evenly with 6 out of the 12 students (50%) not liking the intervention and the other half being more positive about it. In terms of differences of the feedback by level, only one of the 14 students in Primary 6 felt negative about the intervention. She found the intervention *“quite confusing because it's a lot of games and I find it hard because I don't really know a lot about technology.”* For the Primary 7 sample, 8 out of 17 (47%) felt negative about the intervention while the remaining 53% (n=9) were more positive about it. A closer look at the Primary 7 sample showed that students who felt negatively about the intervention were all from the Primary 7 only class. Those from the composite class of Primary 6/7, apart from one student, were mostly positive with the programme. Possible explanations for this include teacher effect and the general classroom condition in the experimental group. The class was oversubscribed and some students sat on the floor while others sat very near the door. However, the effect of the classroom condition and the teacher effect were not investigated further in the interview so these are just assumptions.

Students discussed their most preferred activity (see Table 6-8). The most preferred topic was the lesson on angles (n=21, 64%) which comprised several activities: a walkabout activity using QR Codes that made them look for angles in their environment, followed by using another application to help investigate and measure the angles they have taken, and a game-based activity at the end to help practice estimation of angles. For the boys, they preferred the more active walkabout activity of finding the angles in the environment (n=6) while the girls preferred the in-classroom activity on estimating angles (n=10). This pattern was also seen in the last session that covered all the topics and followed a scavenger hunt theme; five boys preferred the activity but only one of the girls mentioned that they preferred it. One of the girls explained that they

preferred the game-based in-class activity on angles “*because it doesn't feel that something has been added in just for the sake of it*”. The boys, on the other hand, preferred the activity that looked for angles in the environment because it was more active (n=3).

*Table 6-8  
Breakdown of preferred activities by gender and level*

Topic	Gender		Level	
	M	F	Primary 6	Primary 7
Symmetry	2	0	1	1
Angles	9	12	11	10
Area and Perimeter	3	0	1	2
All three topics	5	1	2	4

\*N = 32, One student provided two answers

The least preferred activity was on the topic area and perimeter (n=6). Students explained that they found the topic confusing (n=4). The next on the list of least preferred session was the angle activity (n=4) and the symmetry session (n=4). One of the girls explained that she didn't like the walkabout activity on angles “*because my partner, he kept on taking the tablet and he didn't let me use it.*” As for the session on symmetry, one of the boys from Primary 7 explained that “*it was something that we have done before so I never got that much enjoyment out of it.*” Still, a third of the students (n=11) mentioned that they liked all the activities so it was not possible to pick one that they disliked.

#### **Perceived advantages/disadvantages of doing mobile-supported activities.**

One of the frequently mentioned advantages of doing the tablet-based activities was that it makes learning fun (n=8) and consequently making them want to do it more. Another student explained that because it was fun, it made her understand the topic a bit more. Some students think that it was easier (n=5) to do maths with the tablets. Unfortunately, this answer was not explored during the interviews so it was not possible to know what made it easier in comparison to their usual maths. There were, however, frequent mention of jotter works and writing things down so this concept of being easier might be related to the process of traditional classroom maths which is about drill and practice exercises. One student who discussed the activities with a student in the control group explained that the process of using the tablets in the walkabout activities made the activity a lot easier.

*“When I went next door (control group) what they were doing was so hard and I think what we did was easier and they were saying we did it but the tablets make it easier coz they were doing it on paper[in reference to the control group’s activity where students have to draw objects that fit certain geometric properties].”*

The other advantage of using the tablets with maths was because of the opportunity to use technology (n=6) but again, this was more on the line of using technology over jotter works. One student explained that an advantage to using technology with maths was because he is used to using technology and this confidence to use technology consequently made him more confident with maths. Some students appear to have a negative attitude towards jotter works and having to write things down (n=5) so the use of the tablets was a break from that usual activity. Students explained that the mobile supported activities were a lot more active (n=2) than their normal maths lesson. A student explained, *“it’s a lot more active and it makes you think a lot more than just sitting down and writing down on a piece of paper.”* A couple of students, however, do not see an advantage of using mobile technologies (n=2), noting their preference for jotter works and learning with a teacher.

As for the disadvantages of using technology, some students think that it can be a distraction (n=5) during maths class, referring to other students who prefer not to listen because they were fiddling with the tablets. Students who were not positive about the use of the tablets (n=3) explained that the use of technology was a step back from learning as it requires knowing technology first before doing maths.

*“I just think it’s a massive step back for your learning... So you’ve got the app, you need to learn how to control the tablet, you need to learn how to control the app and that.”*

Other students felt that disadvantage of using tablets is related to the technical issues that one can encounter (n=6). The instability of the applications used, for example, would make them lose some of their work and start all over.

**Working in pairs.** The breakdown of feedback on doing the collaborative activities on the mobile devices is shown in Table 6-9. Most of the students have negative views about working in pairs (n=12; 7 girls and 5 boys) noting how it was difficult to work on just one tablet especially when they were in disagreement with their partner. Boys (n=8) see working in pairs more positively than the girls (n=2). The

majority of the boys enjoyed working in pairs whereas the majority of the girls had more negative feedback about it. One of the boys from Primary 7 commented, *“I find it easier. They could help you and you could help them... I made a friend like that.”* Some students note, however, that working with someone they don’t really know has been difficult (n=4). One of the girls explained, *“I like working in pairs, working with new people but I just think I work better alone or with my friends.”*

Table 6-9

*Tally of positive and negative feedback on tablet use by gender and grade level*

	Male		Female		Total
	P6	P7	P6	P7	
Positive	3	6	2	0	11
Negative	2	4	3	4	12
Mixed	3	2	3	3	6

To students who viewed working in pairs positively, they saw how working in pairs simplified some of the tasks. A student explained:

*“I don't mind working with a partner because I struggle a bit with my work so it helps me to have someone who knows when I've made a mistake or not.”*

This point of view is shared by other students who scored low (score of less than 50%) in the initial maths test score (n=6). The other students who scored low in the MT claimed that they liked working in pairs (n=4) but didn’t explain their reasons for being so.

The idea of shared work, however, did not suit half of the students who scored low in the maths test (n=8). They explained that they didn’t like having to work in pairs because they felt that they didn’t have a lot of chance to use the tablets because their partner was *“hogging the tablet coz she knew what everything was.”* Students who scored high in the maths test also have difficulty working in pairs (n=5) as they too experienced having to disagree with their partner and find the sharing of the tablet difficult.

*“My partner could say the same thing about me (hogging the tablet) but the thing is we were at two different levels of maths and so it was*

*quite like hard to not take the tablet just for yourself but also share it with your partner.”*

One issue that students found about working in pairs is the pairing itself. Some students were paired with the opposite sex and a student explains that this pairing has been difficult.

*“Seeing someone as a boy and a girl together, I don't think they would work unless they like each other it wouldn't be as good for them. So if boys work together and girls work together then you're good.”*

Other students were paired with a partner who was from a different grade level and this also caused some conflicts.

*“Me and my pair we're very very different... we're of different years. I have done everything that you taught us whereas he hadn't. So, when we went on a disagreement, I sometimes try to explain to him.”*

Even students who were paired with students from their own class had issues with the pairing because they were of different skill level.

**Challenges encountered.** As discussed in the previous section, the paired work was an issue for most students as some students had difficulty working with their partners. A few of the students mentioned some technical difficulties like unresponsiveness of the tablet (n=2), the stability of the application (n=7), network connectivity (n=2) and an occasion of battery issue. None of these technical issues, however, caused a breakdown to the point that students were not able to participate. In most cases, the problems were resolved by exiting the application and logging back in. One student also mentioned that the difficulty lies with the maths content and another student explained that the difficulty was more to do with knowing the technology.

*“A lot of the technical difficulties were knowing what you're doing coz it's easier to just give you a pen and paper and write it all down but with the tablets you need to at least use one before you can get into it and start using them.”*

Some students specifically mentioned that they did not encounter any difficulties (n=4) while the rest of the students interviewed did not answer the question.

**Teacher interview.** A semi-structured interview was carried out at the end of the study. The teacher found the mobile learning activities good and interesting. She added that she'd "love to use them again; it really captured the children and made them engaged." She noted that the use of the tablets could complement the students' written work, adding that the children need a combination of both.

For the teacher, it was the walkabout activity (session 8) at the end that worked very well as it allowed her to "*see all their learning at the end.*" She added that she also thought the angles activity worked well because it allowed the students to "*visually see one in front of them rather than a representation on the white board.*" As for the one that didn't work very well, it was the symmetry session.

*"I thought it was great but I think it just had an effect because some of my children have done symmetry before so I think it was maybe too easy for some of mine and I don't know if they became disengaged because of it."*

Advantages of using the tablet were improved student engagement and visualisation of maths concept. The teacher observed that it's particularly good for students who are less inclined to engage during normal maths period.

*"I noticed the difference in attitudes towards their learning. They normally really don't like maths, disengaged, don't want to do it. You normally have to push them to do it. Whereas [with the tablet-based activities] they actually got on really well, really enjoyed it. They were saying to me that they were looking forward to tablet maths."*

The teacher also observed that the tablets would be good to help students visualise maths. For example, in the angle activity, the application used allowed the students to see angles rather than a representation of it.

When asked about the disadvantages of using the tablets, the teacher said that the disadvantage of using the tablets would be more for herself rather than the children. "*They were able to work the tablets better than me, know how to access the tasks and things.*" This was something she found a bit daunting.

*"I tried to open something and the children have already got it open and I don't even know how to do it. I think with that, that kinda made them a bit bored to begin with as well coz they were waiting for me to*

*do something and it's not working right for me. However, they know exactly how to do it and they were able to go on."*

She added that while the guidance given to her before the intervention has been great, it was the newness of the setup, "*connecting them to the whiteboard, setting it up on the computer*" that has held her back a bit.

As for carrying things forward, she said that the next time she runs a session with the tablets, she thinks of doing it in small groups and "*to get some of those more able children with the tablet to even help the others open the apps and kind of teach them.*" She also added that while differentiation is something that will be quite hard to implement with the tablets, it's something that needs to be added.

**Video observation of paired activity.** Four pairs of students wore wearable video cameras throughout the sessions. However, only 2 of these pairs consistently worked with the same partner throughout so the data presented here is only of these two student pairs. The first pair is a girl-boy pairing with both students in Primary 6. In terms of maths ability as measured by the maths test at the start of the program, the boy's pre-test score was ranked high while the girl's score was ranked low. The second pair is a boy-boy pairing with one Primary 6 and one Primary 7 student. Both students' scores in the maths test belonged to the upper half of their respective class. Table 6-10 shows a snapshot of the change in the students' scores in the maths attitude inventory and maths test.

Table 6-10  
*Changes in student scores for MAI and MT.*

Participant		Maths Test	EN	SC	VM	CT	VMT
Pair 1	P6 Boy	+9	-3.8	-1.0	+0.7	-0.8	+1.1
	P6 Girl	+4	-5.2	-2.6	-5.5	-6.5	+0.2
Pair 2	P6 Boy	+1	+2	+0.7	-1.3	+3.9	+1.9
	P7 Boy	+8	3.7	+0.5	+1.0	+0.1	+4.9

The distribution between on-task and off-task activities for Pair 1 and 2 are shown in Figure 6-13. From the graph, it can be observed the both student pairs have at least one student involved in the activity 86% of the time. The proportion where students are both on-task in comparison to the other categories ranged between 34% to 86% across



all the sessions. There were several cases where one student was on task and their partner was off camera (between 6% and 63% for both pairs). Being off-camera means that the partner is outside the viewfinder and their audio cannot be heard. There are many potential reasons for this. Some that were observed in the video recordings were:

- The wearable camera became dislodged and was not capturing a good view of the student activities.
- Student pairs split the task between them so one student was working on one part of the activity and the other student was supposed to be doing a different task (but this became difficult to ascertain as the partner was not on camera).
- The partner was seated at the side of the person wearing the camera and may or may not have been working with their partner.
- The partner’s audio was drowned by the voices of other students in the table as was the case for Pair 2.

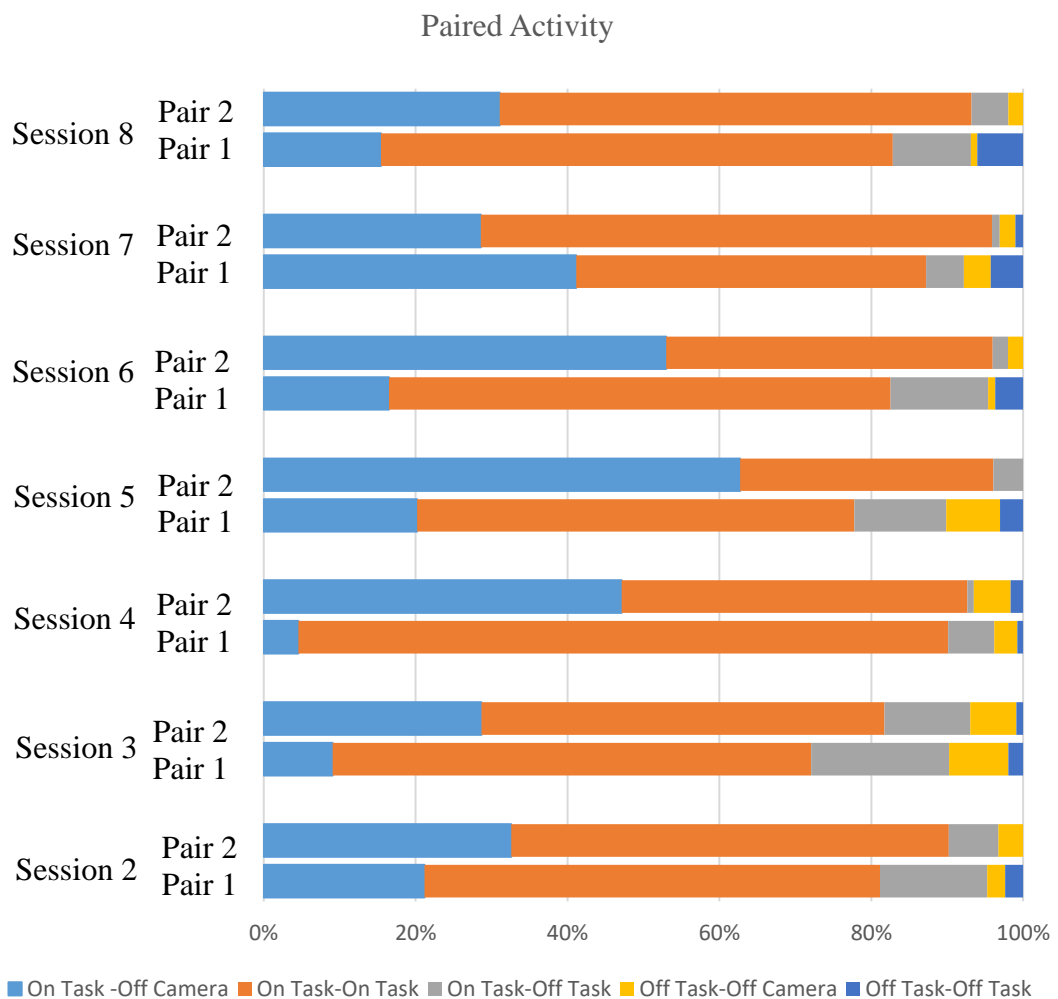


Figure 6-13. Graph of paired activity

These were some of the limitations of the wearable camera but it has nevertheless provided information on the kind of interaction the two pairs were having. Pair 1 in comparison to Pair 2 had fewer situations where the partner was off-camera. This might mean that Pair 1 had more vocal discussions than Pair 2 because the only way that this will be marked as off-camera is when no audio can be heard at all.

Pair 1 also had more cases where one student was on-task and the partner was off-task. This usually happened when one of the pair was working on the tablet and not letting the other person have a go. This was also the case when the pair decided to take turns in working rather than working together. In contrast, arguments on whose turn it was were not so evident with the second pair apart from one occasion. Usually, the Primary 7 student would assign a task to the Primary 6 student. Most of the time, the decision on whose turn it was rested with the Primary 7 student. The older student also tended to delegate the task on the tablet to the younger one when he was already quite familiar with the topic, allowing the other student to explore the application further. For example, in the activity on area and perimeters where the application used was augmented realities to help visualise area and perimeter, the older student realised that the application was only a visual aid and saw how things could progress without the application. He then left the control of the tablet to the younger student but constantly checked on the work of his partner. Cases where both students were off-task were also higher for Pair 1 as opposed to the other pair, but the percentage of both students being off task was only between 0-6% across all sessions.

Figure 6-14 shows the nature of conversations that occurred in percentage form. As a reference, there was a total of 553 counts of conversations for Pair 1 and 380 counts of conversation for Pair 2 across the sessions. There were far more on-task conversations than off-task discussions for both pairs. Off-task conversation was between 4%-21%. Expressing, explaining and evaluating ideas was the most common type of conversation particularly towards the latter half of the programme.

## Conversations

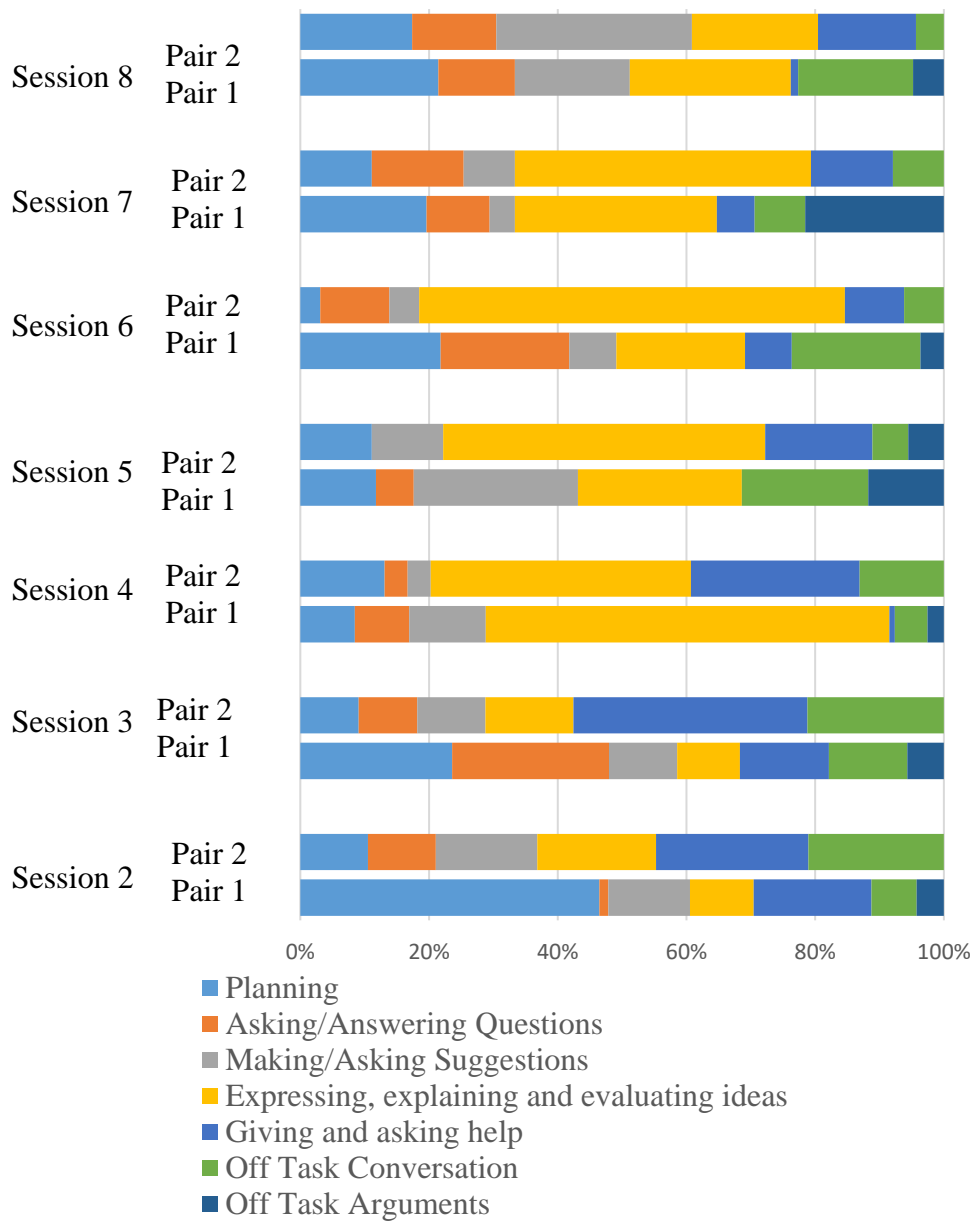


Figure 6-14. Nature of conversation

There were relatively more discussions on how to do the activity with the first pair in comparison to the other. This is because the students in Pair 1 tended to discuss more about who should be using the tablet for a particular task, whereas in Pair 2 discussions on whose turn it was to work on the tablet was very limited. The graph also shows that discussions that involved planning occurred at the highest level during Session 2 for the first pair. Off-task arguments were also higher for Pair 1 and occurred only once for Pair 2. These arguments usually resulted when the students were not in agreement about whose turn it was or when one student was taking more time on the tablet. There were

also more cases of giving help in Pair 2 as opposed to Pair 1 and usually it was the older student who provided some assistance to the younger Primary 6 student. This was in the form of questioning the other student (for example, in the symmetry activity, he would ask his partner where the line of symmetry was), correcting the other student in a constructive way (e.g., when he commented that the other's suggestion was a good idea but explained how it did not meet the geometric properties asked for) and giving directions (for example, the Primary 7 student would assign a task to his partner but check the task afterward).

It is worth looking at how the pairs fared in their attitudes and maths test scores. Pair 1 who had planned more and discussed things more had gained in their MT scores but both students' enjoyment scores had gone down. Pair 2 where there was a lot of help-giving had increased their enjoyment scores, but gains in the maths test were only marginal for the less vocal student but up eight points for the student giving help.

### **Macro-evaluation**

**Mathematics Attitude Inventory (MAI).** A paired t-test for each of the MAI subscales was conducted to check if there was a significant change in pre-post-test MAI scores. Table 6-11 lists the descriptive statistics as well as the p-value for each of the subscales. There was a significant difference in the experimental group value of mobile technology (VMT) scores, with their pre-test scores ( $M = 13.77$ ,  $SD=3.66$ ) higher than their post-test scores ( $M=11.85$ ,  $SD=5.53$ ),  $t(34)=2.256$ ,  $p=.031$ ,  $d=.38$ . For the control group, there was a significant change in students' enjoyment (EN) scores. Their post-test scores ( $M=16.37$ ,  $SD=3.99$ ) were higher than their pre-test ( $M=14.29$ ,  $SD=4.47$ ) scores,  $t(38)=-3.337$ ,  $p=.002$ ,  $d=.53$ . No other significant differences in pre-test and post-test scores in the MAI scale were found.

Table 6-11  
*MAI scores of experimental and control group*

	Experimental Group					Control Group				
	Pre-test M (SD)	Post-test M (SD)	Gain Score M (SD)	p-value	Effect size, d	Pre-test M (SD)	Post-test M (SD)	Gain Score M (SD)	p-value	Effect size, d
Enjoyment (EN)	17.39 (5.52)	18.04 (5.25)	.65 (4.71)	.418	.14	14.29 (4.47)	16.37 (3.99)	2.08 (3.90)	.002*	.53
Self-confidence (SC)	19.98 (5.28)	20.43 (4.64)	.45 (3.67)	.474	.12	18.77 (6.32)	19.08 (6.54)	.31 (5.66)	.732	.06
Value of Maths (VM)	21.49 (2.63)	21.85 (2.77)	.36 (3.60)	.561	.10	20.29 (4.05)	20.3 (4.31)	.01 (2.83)	.987	.00
Confidence with technology (CT)	13.26 (4.2)	13.52 (4.42)	.26 (2.84)	.587	.09	14.11 (3.87)	13.88 (4.46)	-.24 (4.03)	.717	.06
Value of mobile technology (VMT)	13.77 (3.66)	11.85 (5.53)	-1.92 (5.04)	.031*	.38	12.81 (5.16)	11.58 (5.23)	-1.23 (4.06)	.067	.30

\* p < .05

**Gender differences (experimental group).** A comparison of the MAI pre-test and post-test scores grouped by gender showed a significant difference in the pre and post-test scores of male students in the subscale CT and for female students in the subscale VMT. Male students in the experimental group had a significant positive change in confidence to use technology,  $t(19) = .030$ ,  $d=.53$ . Ratings on the subscale value of mobile technology decreased for female students  $t(14) = p = .015$ ,  $d=.74$ . There was also a small effect ( $d=.22$ ) in male students' EN scores but this change was not statistically significant. There were no other significant findings in pre and post-test pairings (refer to Table 6-12).

Table 6-12

*Descriptive statistics of MAI subscale scores grouped by gender (experimental group)*

Subscale	Boys (n=20)				Girls (n=15)			
	Pre M (SD)	Post M (SD)	p-value	ES	Pre M (SD)	Post M (SD)	p-value	ES
EN	18.02 (4.37)	18.96 (3.8)	.345	.22	16.55 (6.84)	16.81 (6.67)	.850	.05
SC	20.21 (3.95)	20.91 (4.02)	.413	.19	19.66 (6.8)	19.78 (5.44)	.905	.03
VM	21.8 (2.61)	22.21 (2.72)	.615	.11	21.08 (2.7)	21.37 (2.85)	.770	.08
CT	14.36 (4.43)	15.33 (3.73)	.030	.53	11.79 (3.47)	11.11 (4.2)	.486	.19
VMT	14.34 (3.56)	13.72 (4.11)	.565	.13	13.01 (3.78)	9.35 (6.29)	.015	.74

**Differences by grade level (experimental group).** There was a significant difference in the Primary 7 students' pre ( $M=13.27$ ,  $SD=3.52$ ) and post-test ( $M=10.29$ ,  $SD=5.54$ ) scores on the scale value of mobile technologies,  $t(19)=2.443$ ,  $p=.025$ ,  $d=.56$ . No other significant pairings were found in either Primary 6 and Primary 7 participants as shown in Table 6-13.

Table 6-13  
*Descriptive statistics of MAI subscale scores grouped by level (experimental group)*

Subscale	Primary 6 (n=15)				Primary 7 (n=20)			
	Pre	Post	p-value	ES	Pre	Post	p-value	ES
	M (SD)	M (SD)			M (SD)	M (SD)		
<b>EN</b>	17.83 (6.21)	19.14 (3.05)	.376	.24	17.06 (5.08)	17.22 (6.38)	.858	.04
<b>SC</b>	18.94 (5.44)	20.4 (3.43)	.097	.48	20.76 (5.15)	20.45 (5.46)	.724	.08
<b>VM</b>	20.88 (3.36)	21.92 (2.79)	.348	.26	21.95 (1.89)	21.8 (2.83)	.831	.05
<b>CT</b>	12.58 (4.18)	13.47 (3.82)	.284	.30	13.77 (4.25)	13.56 (4.92)	.721	.08
<b>VMT</b>	14.43 (3.86)	13.92 (4.96)	.644	.13	13.27 (3.52)	10.29 (5.54)	.025*	.56

*Usability scores and technology related scales.* A correlation matrix of the usability scores with the MAI scales (CT and VMT) is shown in Table 6-14. There was a significant positive moderate correlation between students' perceived ease of use of the tablets and their CT scores at post-test. The same is true for the usability scores and post-test VMT scores. There was also a moderate correlation between confidence to use technology and how the students perceived the value of mobile technology.

Table 6-14  
*Correlation matrix of usability scores and MAI technology related scales*

	1	2	3	4	5
1 Ease of use	-				
2 Usefulness	.661**	-			
3 User satisfaction	.638**	.854**	-		
4 CT (post-test)	.704**	.414**	.465**	-	
5 VMT (post-test)	.622**	.723*	.637**	.513**	-

**Mathematics Test.** An analysis of covariance was conducted to test for the differences between the experimental group and control group with pre-test as covariate. Prior to running the test, a test of the assumptions for conducting ANCOVA was completed as follows:

- There was a linear relationship between pre- and post-intervention MT scores for each intervention type, as assessed by visual inspection of a scatterplot
- There was homogeneity of regression slopes as the interaction term was not statistically significant,  $F(1, 70) = .409, p = .524$ .
- Standardized residuals for the interventions were normally distributed, as assessed by Shapiro-Wilk's test ( $p > .05$ ).
- Standardized residuals for the overall model were normally distributed, as assessed by Shapiro-Wilk's test ( $p > .05$ ).
- There was homoscedasticity, as assessed by visual inspection of the standardized residuals plotted against the predicted values.
- There was homogeneity of variances, as assessed by Levene's test of homogeneity of variance ( $p = .353$ ).
- There was one outlier in the data, assessed by looking at the standardized residuals. This outlier was a student in the control group who performed lower than the other students. This data was kept in the analysis of covariance.

The adjusted and unadjusted means are presented in Table 6-15. After adjustment for pre-test scores, there was no statistically significant difference in post-test MT scores between the experimental and control group,  $F(1, 71) = 1.000, p = .321$ , partial  $\eta^2 = .014$ . To double check the results, a separate test was conducted without the outlier and this also resulted in no significant difference between the groups.

Table 6-15  
Adjusted vs Unadjusted pre-test scores

N	Unadjusted		Adjusted	
	M	SD	M	SE
Experimental	20.57	6.30	20.57	.64
Control	19.72	5.69	19.62	.68

Some items in the maths test aimed to measure student performance relating to common misconceptions (items 11 and 12 for symmetry, items 19-22 for angles, 25 and



26 for area and perimeter). Table 6-16 lists the mean scores at item level which can also be interpreted as the percentage of students who got the correct answer at pre and post-test. The results of the paired t-test to check if there was a significant change in student performance at item level is also shown. There was a significant improvement in the experimental group's performance for items relating to misconception on angles (items 20, 21, and 22). For the control group, there was a significant improvement in student performance for one of the items relating to angles (item 20) and for an item relating to perimeter (item 25).

An independent t-test of the gain scores showed a significant difference in the gains of students who scored low at pretest ( $M=7.50$ ,  $SD=5.12$ ) and those who scored high ( $M=3.0$ ,  $SD=3.48$ ),  $t(30)=2.905$ ,  $p=.007$ . The control group had no significant difference between the lower ( $M=8.55$ ,  $SD=3.52$ ) and higher half ( $M=6.39$ ,  $SD=3.52$ ),  $t(34)=2.037$ ,  $p=.073$ .

An ANCOVA of the post-test MT score grouped by gender and with pre-test as covariate showed no significant difference,  $F(1, 32)=1.33$ ,  $p=.257$ . The same was true for grade level,  $F(1,32)=1.169$ ,  $p=.288$ .

Table 6-16  
*Item level statistics.*

	Experimental Group		Paired t-test p-value	Control Group		Paired t-test p-value
	Pre-test	Post-test		Pre-test	Post-test	
Item 11	.66	.78	.161	.83	.89	.324
Item 12	.59	.75	.057	.58	.75	.083
Item 19	.63	.56	.536	.39	.50	.210
Item 20	.59	.84	.003	.39	.58	.033
Item 21	.75	.94	.012	.61	.64	.744
Item 22	.63	.91	.002	.56	.69	.134
Item 23	.78	.88	.325	.72	.78	.535
Item 24	.66	.53	.255	.56	.56	1.0
Item 25	.13	.16	.712	.03	.31	.003
Item 26	.22	.13	.263	.08	.25	.057

**Triangulation of student feedback on tablet use.** Several of the instruments used in the study were self-reporting instruments and so, to validate the student responses, their feedback on end activity evaluation, student interviews and mathematics attitude inventory are compared. Student feedback about the intervention are compared with their valuation of mobile technology (VMT) post-test score and students who scored 60% and above the maximum VMT score had positive feedback about the intervention and those who scored below 60% had overall negative feedback except for three cases. These students had VMT scores of 40%, 49% and 55% the maximum score but provided positive feedback during the interviews about the usefulness of the intervention for their maths. The rest of the students had consistent interview results and VMT scores.

A comparison of the VMT scores with the usability of the tablet scores were all statistically significantly correlated with correlation coefficients of .60, .66 and .70 for symmetry sessions, area and perimeter sessions and the sessions on combined topics respectively. Majority of the students who scored 11 points out of the total 20 (55%) on the VMT scale rated the usefulness of the tablets between 3.5 to 5.0 with a mean of 4.4 and mode of 5.0. Students who scored 10 and below on the VMT had end activity evaluations ranging between .8 and 5.0 with mode of 3.1 and mean of 2.7. Figure 6-15 shows the scatterplot of the VMT score with the end activity evaluations. These numbers show that students who found the use of mobile technology useful (as measured by the VMT scale) had positive evaluations of the tablet use during the individual activities. Students who were below the midpoint score of 10 had varying end activity evaluations for the different sessions, sometimes rating the activity high and sometimes low.

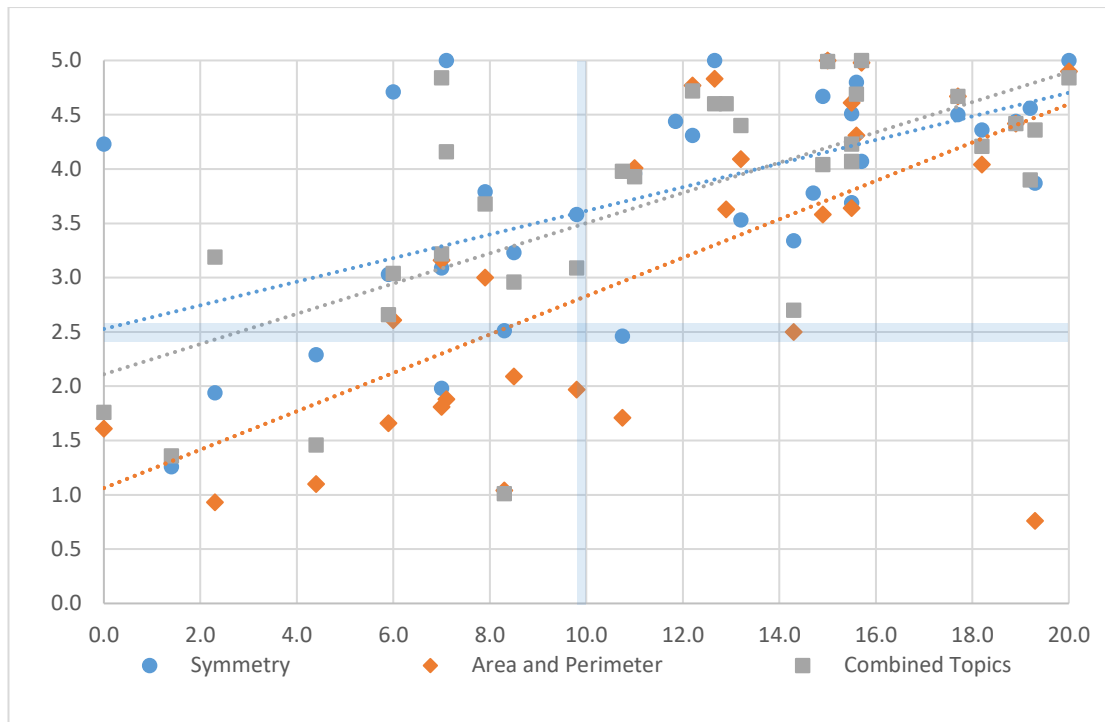


Figure 6-15. Scatterplot diagram showing VMT score vs End Activity Evaluation

### Discussion

This section covers a short discussion of the results. It draws the findings from the micro, meso, and macro evaluations and covers (a) evaluations of mobile technology use (b) attitudes to mathematics (c) attitudes to technology and (d) mathematics achievement. Limitations of the current study are also discussed. As with the previous studies, the discussion will be limited to an interpretation of the results. Discussion of the results in relation to the mobile learning literature and technology supported mathematics learning is covered in the next chapter.

### Student Evaluations of Mobile Technology Use

For most of the items, the ratings of the control and experimental group were not statistically different across the three end activity evaluations (refer to Table 6-4) and most responses agreed with the positive adjective. The interpretation is that both the experimental and control group had mostly positive perceptions about their respective activities. Students in the experimental group consistently rated the activities as innovative over being old-fashioned throughout the three end activity evaluations carried out. The activities with the control group, despite being similar in nature, led to them rating the innovativeness of the activity on a declining score. This finding can be an indication of how the presence of technology changes student perception about the novelty of an activity.

While the usability ratings of the two groups were not significantly different for most items, in the symmetry and the area and perimeter sessions, the control group scored a little higher than the experimental group. For the session on combined topics, this pattern was broken with the experimental group getting slightly higher scores than the control group for most of the items. These two topics (symmetry and area and perimeter) where the control group rated the activities higher than the experimental group are the least preferred activities mentioned during the student interviews with the tablet group. Reasons cited for not liking the activities were related to the difficulty of the topic. Some students didn't like the sessions on area and perimeter because they found them confusing and some students didn't like the session on symmetry because it was something they had already covered before. The control group, despite having covered the same topic on symmetry did not seem to have an issue with the repetition. Their activity ratings did not also raise issues relating to confusion on the topic area and perimeter.

A possible explanation for the differences in rating might be related to the interplay of novelty and topic difficulty. In the symmetry session, while the students in the experimental group viewed the use of mobile technology as innovative, the topic it was implemented on was too easy for the students, making the sessions seem more supplementary than a truly novel learning experience. In the area and perimeter sessions, while the use of mobile technology was novel, some students did not see the benefit of using mobile devices for the activity. Lessons on area and perimeter were deemed difficult anyway and the effect of the technology was merely to add an extra layer of difficulty. The two sessions to cover exploration of the relationship between area and perimeter using virtual manipulatives on the tablet might not have been enough and might have caused confusion to some students rather than clarifying. The last session, however, was different as the use of the mobile device was as instrumental in doing the activities. In this example, the mobile device facilitated the gathering of artefacts that represent geometric properties. These gathered artefacts became discussion points in the classroom as students presented their findings to the rest of the class.

Another possible factor that may have affected how the students evaluated the activity was the class size. The recommended class size for maths in Scotland is 33 for Primary 4 to Primary 7 and 25 for composite classes (Scottish Government, 2014). The experimental group with a mix of Primary 6 and 7 students had 35 students, 40% more

than the prescribed number. Being over the prescribed maximum class size might have affected the learning condition as some students were sat on the floor and others were crowded at a small table. The students made no mention of this, but during the interviews some of the students who were at the right-hand side of the classroom (the area that was a bit crowded as some students were sitting on the floor) had the more negative responses about the activity. While it is not certain whether the class size affected student perceptions about the activity or not, what is clear is that the class size affected the level of support provided to the students. There were several occasions that students had to queue for a minute or so to get technical support and this lack of immediate support may have affected how the students engaged with the activity.

**Gender differences.** There was an observed gender difference in the tablet group as evidenced by the end activity evaluation and the student interviews. Male students consistently rated the activities higher than the girls. In the student interviews, female students provided less positive responses about the intervention than male students. One possible reason for this is the nature of the paired work. Some girls that were paired with boys did not manage to work particularly well with their partner as the boys tended to take control of the tablet. This hesitation to work with the opposite sex was mentioned several times in the interviews. The end activity evaluation of female students did not statistically differ in relation to their partners' gender. For male students, however, those who were paired with female students had lower usability scores for the last session in comparison to those who were working with another male partner. This shows that gender has some role in how students perceived some of the activities. Another possible reason for the gender difference is the technology and the familiarity of using it. Although the students all mentioned that they had used tablets before, there were students who struggled to use technology. For example, two female students specifically mentioned that they were not too familiar with using technology and this was a hurdle they had to go through to be able to do the maths.

**Differences by grade level.** As for differences in the student evaluation by grade level, the Primary 6 students in the tablet group consistently rated the sessions higher than Primary 7 students in the group, although this difference was only statistically significant for the session on area and perimeter. Of the four students who specifically mentioned they didn't like the area and perimeter sessions because they found it confusing, three of those students were at Primary 7 and one at Primary 6. A possible explanation for this confusion is the difference in the continuity of what had been

already taught to Primary 7 students on the topic area and perimeter and what was explored in the mobile learning activities. The Primary 7 students discussed that they already knew how to solve for area and perimeter and this is evidenced by around two-thirds of the class getting a correct answer on the MT item, where the straightforward formula of *length x width* for area and perimeter applies. With the focus of the mobile learning activity on the concept of area and perimeter and not the process of solving for area and perimeter, it is possible that the older students might have been confused as they were already operating on the Van Hiele level of abstraction, whereas the activity focus was on the Van Hiele levels of visualisation and analysis. The Primary 6 students did not appear to have this issue as they were just starting out on the topic. What is important to point out in this section is that the grade level differences in students' rating can possibly be caused by the mismatch of the content with what the students have previously covered.

### **Student Attitudes to Mathematics**

The majority of students in the tablet group reported that they found the activities fun, but this improvement was not reflected in the MAI enjoyment (EN) scores, regardless of looking at the paired t-test at group level (by gender or by grade level). The paired t-test results were all not statistically significant but there were small effects computed for male students ( $ES=.22$ ) and for Primary 6 students ( $ES=.24$ ). Students who specifically mentioned that they found the activities fun and enjoyable had their EN pre and post-test scores examined. Of these 14 students, 8 had gains in EN score and 6 had lower EN scores at post-test. Students who viewed the use of the tablets negatively ( $n=6$ ), for example boring or frustrating, included three students with increased EN scores and three students with decreased EN score. These shifts in responses can be interpreted in several ways. For some students, the change in EN scores can be interpreted as a validation of their positive or negative views about the use of the tablets. It is also possible that students had shifted their views about their regular maths sessions differently. For example, a student with an EN score of 23.4 (94% of the full mark) at pre-test and 19.6 at post-test added "*if we have the chance, I'd say we should do maths like that normally.*" Another student who started with an EN score of 20 and scored 24.1 at post-test but did not view the use of tablets positively added "*I think that the traditional [way] is more effective.*" There is also the possibility of interpreting the results as a response-shift bias. Response shift bias is when the

participants' internal frame of reference changes between pre-test and post-test due to the influence of the programme (Drennan and Hyde, 2008). There is also the chance of social desirability bias at pre-test. More than half of the students had initial scores above the third quartile and yet, the teacher had described the group as students who were not very enthusiastic with maths. While the students were told that they should answer as close to how they genuinely felt about maths, it is possible that some students rated their attitudes to maths quite highly at the start of the programme, either for lack of a standard for rating or for wanting to appear in a better light. Over time, and as they get more accustomed to doing self-ratings, these biases might have lessened.

Self-confidence in mathematics was not a subject explored in the student interviews and the MAI paired t-test for this scale showed no significant differences. There was, however, a medium effect ( $ES=.48$ ) for the Primary 6 students. The teacher in the tablet group, who also happened to be the class teacher of the Primary 6 students, observed that the use of the tablets was good for those students who were less inclined to participate during regular maths class, as she observed these students to have actively participated during the intervention.

There was no change in how the students valued mathematics, but the students' initial scores for this item was already high to begin with. There were marginal positive shifts in scores for both girls and boys and those in Primary 6, but none that resulted in a significant difference.

### **Student Attitudes to Technology Use**

There was a small positive change in the experimental group's confidence in using technology and a small positive decline in the control group, but none of these changes were statistically significant. The experimental groups' data showed that this gain in confidence to use technology was significant for the male students with a medium effect. The scores of the female students, on the other hand, hardly saw any shifts. This shows how the use of technology as part of the learning experience can improve some students' confidence to use technology, although in this instance, it worked better for the male students than for girls. Gender difference in technology and mathematics is a well-researched area. This difference will be discussed again in the next chapter in relation to the wider literature.

As for the value of using mobile technology for maths (VMT), the experimental group had a significant decrease in their VMT scores at post-test in comparison to their

pre-test score. This significant change was affected by gender and by grade level. The VMT scores of female students went down significantly and so did the VMT scores of Primary 7 students. These findings echo the results of the student interviews, where girls and Primary 7 students had some reservations about tablet use. This is not to say that these students now have negative views about mobile technology use, as their post-VMT scores were still at the midpoint of the scale. What it can be interpreted as is a shift in expectation of the value of mobile technology to math. The male students and those in Primary 6 had no significant changes in their pre-and post VMT scores (both around the 75% maximum score). This means that the perceived value of mobile technology was the same before they used the tablets and after they were involved in the mobile learning activities. As the programme is only six weeks long, it would be interesting to find out how their evaluation about mobile technology use changed over time as they became more confident to use the technology and as the technology became more integrated into their lessons.

Students confidence to use technology and the value they put on the use of mobile technologies were correlated to how they evaluated the activities. It is possible that their perception about the tablets' usability has affected their own perception about their ability to use technology. For example, if they found the tablet useful, it means that they have successfully operated the tablet and this consequently affected their self-views about their capacity to use it as well as its relevance to learning maths. In the same way, if they found the use of the tablets troublesome, then their confidence to use technology might have been affected adversely. In some cases, where students had issues using the technology, then it is also likely that they did not see it as valuable to learning maths. This finding can be interpreted in terms of the wider literature of the technology acceptance model which will be covered in the next chapter.

### **Student Engagement**

The findings from the video observation of paired work showed that students were highly engaged in the activities. This finding supports the teacher observation that the activities has captured the students interests and made them engaged. There were a few instances of off-task behaviour and these usually occurred when students were not collaborating well, particularly when one of the students took ownership of the tablet rather than share it with their partner. Students have mentioned in the interviews that they had issues with the paired work for various reasons, two of which were: their



partner was not letting them use the tablet and was not willing to collaborate. This was the case observed in the video recordings of the paired activity. In addition to one partner ending up being off-task, student pairs who had not been working well together spent more time planning what to do. In contrast, a good pairing resulted in more opportunities to work together. This means that just as important as the activity design, assigning students with a partner they can work with is equally important.

### **Student Achievement**

Both control and experimental groups had significant changes in their pre and post-test scores indicating that student performance had improved under their respective treatments. A comparison of the treatment effect, however, showed no significant difference between the two groups. This means that the experimental group performed just as well as the control group. Given that the nature of the activities was the same both groups, this result is not very surprising. In principle, the set of learning activities for both groups followed the same teaching strategy of active experiential learning. In the SAMR (Puentadura, 2006) spectrum model mentioned in the literature review, this would classify the use of technology in most of the activities either under the augmentation or the modification spectrum rather than an the higher spectrum of re-definition

Some sessions can be classified under the modification spectrum of the SAMR model and these were sessions where mobile technology proved more useful than the paper and pencil counterpart. For example, in the angles sessions, students observed angles in their environment, captured evidence of these then explored the properties of the angles they had captured. These learning activities showed a seamless process of exploration and investigation of maths concepts facilitated by the mobile technology. Using the mobile device, students captured representations of angles in their environment. They then went on to investigate these angles further by annotating the images taken and manipulating the images (for example, the process of pinching and zooming to compare angle measurement of a zoomed in picture vs. a zoomed out image). They were then given an opportunity by the teacher to share these artefacts with the rest of the class. The control group, on the other hand was limited in the further investigation that they were able to do, as their output was limited to a description or a drawing of an object. While both groups followed a constructivist learning activity, the mobile device facilitated investigation across contexts as students did the artefact

gathering outside the classroom and reflected on these artefacts through further investigations and formed mathematical conclusions from it. Thus, both the experimental and control did constructivist activities, but the activities of the experimental group were **more** constructivist. Within this topic, there was a small treatment effect, with students in the experimental group performing better than the control group. The group also performed better on items relating to misconception on angles. This can be interpreted as a sign that the mobile supported learning activities on the topic angles was effective.

For the topic area and perimeter, the statistical test showed a significant difference in the gain scores of the groups in favour of the control group, an indication that the control group had higher gains than experimental group. This result cannot be taken at face value when combined with the other statistics. For example, the average score on this scale is less than 35% of the maximum score for both groups. There was also little indication that it addressed the common misconceptions, either in the control or experimental group, aside from the one item where the control group showed an improvement. This is because that one item, despite seeing a significant increase in the number of students who got it right, meant that it was a shift from one student getting it right to 12 students getting it correct. It was significant but still less than a third of the class answered correctly. Even so, this finding about the control group performing better on those items cannot be ignored. However, because it was not known in detail what occurred in the control group's activities beyond the worksheets and test sheets that was used in the study, it is not possible to explain what accounted for the control group's gain on area and perimeter.

Perhaps a more apt interpretation of the result above is that the sessions had not been enough to clarify for everyone the concepts of area and perimeter. It is possible that the two sessions on area and perimeter had not been enough to provide a foundation on the topic for Primary 6 students (as evidenced by the low number of Primary 6 students who scored correctly on the test, both for control and experimental groups). It's also possible that mismatch of the content with what the Primary 7 students already knew may have confused the students (as evidenced by the shifts in the Primary 7 test scores and by student interviews).

### **Limitations of this Study**

Several limitations are present in this study: the instruments used, programme fidelity and the overall research design. As this study used the same instruments in Study 1 and 2, there is again the problem with the self-reporting nature of the instruments used. The use of the wearable camera also presented some issues as it did not capture the full interaction between pairs. Sometimes, the audio background would give a clue but there were instances where it was difficult to ascertain what the students were doing. First, the wearable camera followed the view of the person wearing the camera. As such, it was not always possible to know what the other student in the pair was doing. Second, the position of the camera tended to move as students worked on the activities, which sometimes caused both student pairs to be out of the camera view. Another shortcoming was that the person wearing the camera was never seen, which meant facial expressions and some non-verbal cues were not captured on screen (for example, it was not possible to check if the person wearing the camera was actively listening to their partner). Nevertheless, this manner of video recording was able to capture student engagement in a mobile learning environment.

There was also the issue with programme fidelity. During the last session, it was found that control group was split into two groups between the two teachers. This meant that the class size of the experimental group was twice as much as the control group. This was not the agreed setup. Initially, the setup was to split the Primary 6 and 7 students into two groups and the control group would be co-taught by two teachers and the experimental group would be co-taught by another teacher and a teaching assistant. While the change in setup did not change the teacher to student ratio, the classroom condition was different. This is a confounding variable of the study.

There were also limitations with the research design. The sample size although bigger than the sample in Study 2 was still relatively small and only consisted of two classes. Again, this was addressed to some extent by reporting effect sizes to give the magnitude of difference between the groups. While this study had a control group that closely followed the same activities as the experimental group, data gathered from the control group was limited to the activity evaluation, their attitudes to maths and their performance in a maths test. This would have been improved had they been interviewed or observed as well to allow a finer contrast between the two groups.

Another limitation of the study is the duration of the programme. Study 1 and Study 2 had almost three months' difference between pre-test and post-test. This study

had 6 weeks between pre- and post-test, with one of the weeks having three consecutive mobile learning sessions. It is possible that the six weeks, more intensive programme might have affected the results, as it lacked opportunities to become more accustomed to the technology, as was the case in Study 2. This leads on to the next limitation about the timing of the study and the reason why the programme had to be cut short. The study started in the last week of October, close to the Christmas holidays. Schools are typically busy with extracurricular activities around December, as was the case with this study. So, it is possible that students might have been less focused with the mobile learning activities as they also had other projects to work on, which in turn might have affected the results.

The amount of time put into the sessions was also a shortcoming. The previous iterations were more flexible with class time, allowing students to finish the activity before ending the session. The same flexibility was not possible for this iteration because students were originally part of different classes. It was also not possible to excuse the students, just so they could continue working on the activities, because of the other projects that they had to finish before the Christmas break. Aside from not being able to extend the class time, there were also occasions where the sessions lasted less than the 50 minutes specified because the class had to participate in another activity either before or after the maths class. Again, these small changes might have had an impact on the overall effectiveness of the study.

### **Summary and Next Directions**

This study set out to investigate the effectiveness of using mobile technologies in a randomized controlled trial where the control group participated in activities similar in nature to the experimental group. Student evaluations of the activities were positive for both groups, but there were gender and grade level differences in student perceptions about tablet use. Gender and grade level differences was also found in students' confidence to use technology and their perceived valuing of mobile technology use in maths. The intervention also saw significant improvement in performance for both groups, but there was no difference observed in the groups' performance at post-test, indicating that there was no significant treatment effect.

This study concludes the data collection stage. Several limitations have been raised which in an ideal setup could be addressed by having a longer study, bigger sample size and stricter programme fidelity. It might also be useful to compare across

three groups: a no-treatment control group, a control group with similar activities and an experimental group working on the tablet based activities. It might also be worthwhile to bring back the outdoor based activities carried out in the previous studies, weather allowing. In addition, it might also be beneficial to put some focus on how the use of mobile technology supported student development of maths knowledge. These are all considerations for future research. The discussion in the next chapter will be limited to the similarities and differences of the three studies and their relationships to the wider mobile learning literature.

## CHAPTER 7 DISCUSSION

### Overall Summary of the Results

Three studies have been conducted as part of an investigation into the effects of using mobile technologies for primary school mathematics. In these three studies, the following recurring research questions have been raised:

- RQ1. What are the students' views on the use of mobile technology for learning mathematics?
- RQ2. Is there a change in attitudes towards technology when mobile technology is used for learning mathematics?
- RQ3. Is there a change in attitude towards mathematics when mobile technology is used for learning maths?
- RQ4. How has the use of mobile technologies affected student engagement?
- RQ5. Is there an improvement in mathematics achievement when using mobile-supported maths learning activities?

The three studies followed an iterative design process where the design of the succeeding study was a response to the limitations raised in the previous study. All three studies were mixed-method designs but differed in the design of the experiment. Study 1 was a single group pre-test, post-test design. Study 2 was a quasi-experimental design while Study 3 was a randomised controlled trial. A summary of these findings follows.

#### Study 1

Student views about mobile technology use have been positive overall although the technical difficulties encountered affected some of the students' views about mobile technologies. Student enjoyment of the activities did not translate to a change in attitudes towards mathematics but the technical issues they experienced is reflected in their lower confidence to use technology and lower value placed in mobile technology use for mathematics. On the other hand, their performance in the maths test score has seen a significant improvement.

A critical incident analysis found several technology and activity breakdowns and breakthroughs. Among the technical issues encountered were instability of the application used, network connectivity issues, responsiveness of the mobile device and accuracy of the measurements on the device. Activity design issues included insufficient time to complete the activity and non-clarity of tasks while social issues relate to student roles in group activities. A full list of these issues is given in Table 4-6. As for

breakthroughs, the following advantages of using the mobile device were found: encouraged reflection; allowed abstract maths concepts to be paired with concrete representations in their environment; facilitated collaboration and also promoted active learning.

## **Study 2**

The design issues identified in the critical incident analysis were incorporated in the design of Study 2. Among the changes incorporated were the sequencing of tasks, more orientation time, nature of student pairings, tablet allocation and the inclusion of a no-treatment control group.

The majority of students gave positive feedback on the mobile learning sessions. Students found the mobile learning activities fun, engaging and useful. They explained that the active learning activities had allowed them to move about and engage with mathematics in their environment and that the use of technology was a good opportunity while learning maths. Likewise, the teacher felt positive about the intervention and observed that the students had been engaged throughout. There was no significant difference in the students' MAI scores for all five subscales both in the experimental and control group, except for the control groups' significant decline in their enjoyment scores. Students in the experimental group also had significantly higher gain scores in comparison to the control group.

## **Study 3**

Study 3 made changes to the study design following recommendations from Study 2 but also considering the constraints of Study 3. This included topic coverage, a limit to carry out indoor-based only activities, shorter time frame, as well as inclusion of a control group that followed similar activities without the use of mobile devices. The usability ratings of the mobile learning activities had been positive but this was also the case for the control group. There were gender and grade level differences observed in the usability ratings in the experimental group. Boys tended to rate the activities higher than girls across all activities. Grade level difference existed only for the topic area and perimeter. These differences were also observed in the student interviews.

The teacher observed that the students had been engaged positively during the activities and this observation is supported by students' narratives on how they found the mobile learning fun and easier compared to their usual maths. The video case studies of two pairs of students also showed that students have been highly engaged in

the mobile learning activities with little occurrences of off-task behaviours. However, the paired nature of the activities was not always well received. Half of the interviewed students felt negatively about it. The video case studies have also shown how opportunities were missed by students when their partner took charge of the tablet and declined to work together. Other issues raised included problems working with the opposite sex, issues with mixed ability pairing and personal differences between partners.

Students attitudes to mathematics did not show a significant change either for the control group or the experimental group, except for the experimental groups' changes in their VMT score. Students in both experimental and control groups had lower scores on their valuation of mobile technology at post-test in comparison to their pre-test score, particularly for the Primary 7 students. As for their maths test scores, both groups had significantly improved from pre-test to post-test, but when pre-test score was taken as covariate, there was no significant treatment effect. Nevertheless, the experimental group fared better on topics that covered misconception on angles as opposed to their counterparts.

What follows is a discussion of the results. It is divided into the themes raised by the research questions in the three studies and its relation to current literature.

## **Discussion**

### **Student Attitudes**

The three studies covered different aspects of student attitudes—student perceptions of the mobile learning activities, the effect of the mobile learning activities on their attitudes towards technology and the effect of the mobile learning activities on their attitudes to math.

**Student perceptions of the mobile learning activities (RQ1).** Overall, the three studies found positive student attitudes towards the learning activities based on the end activity evaluations and student interviews. The majority of students across the three studies perceived the mobile learning activities to be enjoyable. Pollara and Broussard's (2011) systematic review of student perception of mobile learning across different disciplines also had the same findings. One of the reasons for enjoyment was the incorporation of technology into their usual maths activities. Students explained that the mobile learning sessions were a good opportunity to learn maths while using technology. This sentiment is echoed in several mobile learning studies on mathematics



(Franklin & Peng, 2008; Kim, 2011). The other reason for enjoyment is the active nature of the activities, particularly the outdoor learning sessions in Studies 1 and 2. The outdoor element was not present in Study 3 but the sessions still required moving about the shared workspace area within the building. Previous mobile learning studies carried out in outdoor settings also had positive student reception (Kurti et al., 2008; Rehm, 2015; Bray and Tangney, 2015). For the current study, it is possible that in addition to the outdoor setting, it was the active nature of the activities that students appreciated. This was discussed in the student interviews, and students explained that the activities were better as opposed to “*just taking it all in*” or “*just writing it on a jotter*”.

The mobile learning sessions were also perceived to be useful tools for visualising mathematics. The use of technology to aid in visualisation of maths concepts is embedded in mathematics education literature (Lagrange et al., 2003). Boaler, Chen, Williams, & Cordero (2016) posit that “when students learn through visual approaches, mathematics changes for them, and they are given access to deep and new understandings” (p.1). Some of the student narratives discussed how the process of being able to see angles as opposed to having the teacher explain/describe it was helpful. This was quite different from the findings of an earlier mobile learning study (Learning2Go, 2007) which found mobile technologies offered “limited effectiveness for visualisation” (p.26), but that study utilised the smaller form PDAs and the nature of mobile technology use was also different, as the previous study tended to use the mobile device for game-based learning activities and for off-loading computational tasks. Studies that tried to facilitate a link between real-world and abstract maths yielded similar positive feedback (Baya’a & Daher, 2009; Sommerauer & Müller, 2014) to the current study.

Some students felt that mobile learning activities helped them understand the topics better. As above, the activities were perceived to be useful tools to help visualise mathematics. There were also students who explained that the technology medium removed some of the barriers they had with learning mathematics and that their confidence to use the tools has translated to a confidence in math. This perception is also present in other maths and mobile learning studies (Burden et al., 2012; Perry & Steck, 2015). Several students who struggled with maths because of their additional support needs found the use of technology useful in overcoming that barrier. Similar studies on specific learner groups have also found the use of technology resulted in

improved engagement (Burton, Anderson, Prater, & Dyches, 2013; O'Malley, Jenkins, Wesley, Donehower, Rabuck & Lewis, 2013).

Novelty was also a common theme among the studies. It wasn't investigated how much of the results could be attributed to novelty effect, but there were indications of this from the student responses in the interviews and end activity evaluation. For example, in Study 1, the first session had higher student evaluations than the other sessions, even though in the student interviews this session was not actually a favourite among the students. Student perceptions of the mobile learning activities was also more reflective of the whole learning activity during the interviews carried out at the end of the study in contrast to the mid-intervention data. For Study 2 and 3, there were the comparisons of the mobile learning sessions to their usual maths which indicated that the current intervention was different from their day to day maths activities. Other mobile learning studies have also acknowledged novelty effect (Baya'a and Daher, 2009; Riconscente, 2013; Rehm, 2015), but this is an issue that is difficult to avoid given the relatively newness of mobile technologies in comparison to more established technologies being used in schools.

There were a few negative perceptions about tablet use. In the end activity evaluations, there were a few ratings that favoured the negative adjective, particularly for Study 1 and Study 3 (18% for Study 1, 5% for Study 2, 16% for Study 3 out of the total item responses). Some of the negative student perceptions are related to the topic being studied. When students found the topic boring or difficult, this was reflected in the end evaluation. When they encountered technical difficulties, they also rated the activities lower. The socio-cultural perspective of learning suggests that "learning is affected and modified by the tools used for learning" (Kearney et al., 2012, p. 1) and in the case of technical difficulties, students' learning is also likely to be affected.

In the student interviews, students from Study 1 discussed that while the activities were fun, the technical issues made the experience less enjoyable. In Study 3, some students, particularly the older female students, did not see the benefit of using the tablets given that they have already covered some of the content in the previous year. Negative perceptions about tablet use are not common in current mobile learning literature. Liu's (2007) study started out with positive student perceptions but these declined over the 12-week intervention period as the novelty of the project wore off. Over time, students felt that the activities with the devices became monotonous and they felt even less in control of their own learning. Robert and Vanska's (2011) study also

had a set of students from more affluent schools who reported that the mobile learning programme was “boring and not appealing enough, while those in poorer contexts had no such complaints” (p. 256). In both cases, the activities failed to engage students and were one of the factors that consequently resulted in negative perceptions. The issues with Study 1 and 3 was also related to engagement. In Study 1, the technology breakdowns caused some of the students to become disengaged with the activity as they waited for technical support, or in some cases became frustrated with it as it meant having to start all over. In Study 3, some students found the activities boring because the content was something they had already covered and the addition of the technology was not enough to engage them fully.

Overall, the mobile learning activities were perceived by most of the students to have made learning more active, fun, engaging and easier in comparison to their usual maths offerings. The activities afforded them opportunities to use technology while learning maths as well as connect abstract maths concepts with their environment. These reasons can be categorised into a hierarchical level of: (1) satisfaction due to the use of technology, (2) satisfaction due to the changed pedagogy enabled by the technology, and (3) student satisfaction with their own performance. It can be argued that it is satisfaction with technology that is likely to be the soonest to wear off, as was the case in Liu (2007) and in Study 1. Previous studies like Afari et al. (2013) suggest that enjoyment was greater for classrooms with more teacher support, cooperation and personal relevance. So, it is not enough to just use technology for technology sake, but more importantly to integrate technology use in a way that facilitates student understanding.

**Student attitudes to technology (RQ2).** Student attitudes in relation to their confidence in using technology and their views on the value of mobile technology varied across the studies. Study 1 showed a significant negative change in their confidence with technology and value of mobile technology; Study 2 had a non-significant but small positive effect for both variables; while Study 3 did not have a significant change in confidence scores but a significant decrease in their valuation of mobile technology. It is worth noting that participants in Study 1 started out with high scores – 20% more than Study 2 and 38% higher than Study 3.

None of the studies in the systematic review carried out in Chapter 2 have explored how the use of mobile technologies affected change in students’ attitudes towards technology. Instead, literature has tended to include end-report evaluations of

mobile technology use in mathematics (for example, Huang et al., 2012). A more recent study by Bray and Tangney (2016) considered this change and found no significant difference in students' confidence with technology, but found a significant improvement in attitudes towards technology. The timings and implementation, however, were different in Bray and Tangney's three interventions (one with two hours a day over a week, another with six hours over two days and the third a two-hour afternoon session), which may explain why the same gains were not shown in this study. A similar pattern of decrease in attitudes toward technology has been found in a computer-based implementation (Yushau, 2006). Yushau explained that possible reason for this decline may be that the system used as part of the intervention was more rigorous and at a higher standard than what students were used to. Applying this line of reasoning, it could be that the use of mobile technologies in this study was different from what students might normally use in their own mobile technologies. So, while the findings of the study have pointed to a decrease in students' attitudes towards technology, this finding is not entirely negative. While their confidence scores might have gone down, the design of the activities has let them explore other ways to use technology, an observation noted by the teachers across all three studies.

There were gender differences found in Study 2 and 3 (gender difference was not investigated in Study 1). A significant amount of literature suggests gender differences in attitudes towards technology use (Rabah, 2016). There is the belief that male students are better with technology than their female counterparts. As such, male students tend to have higher perceptions about the value of technology in comparison to female students (Barkatsas et al., 2009; Reed, Drijvers & Kirschner, 2010), and this was the case at the start of Study 2 and 3. Boys initially had higher perceptions about the usefulness of mobile technology (VMT). For Study 2, throughout the end activity evaluations and the VMT test at the end, no gender difference was found. This result suggests that male and female students' perceptions of mobile technology use did not vary. This finding is consistent with other mobile learning studies in mathematics (Tsuei, Chou and Chen 2013; Deater-Deckard, Mallah, Chang, Evans and Norton 2014) where gender was not a contributing factor to students' evaluation of mobile learning activities.

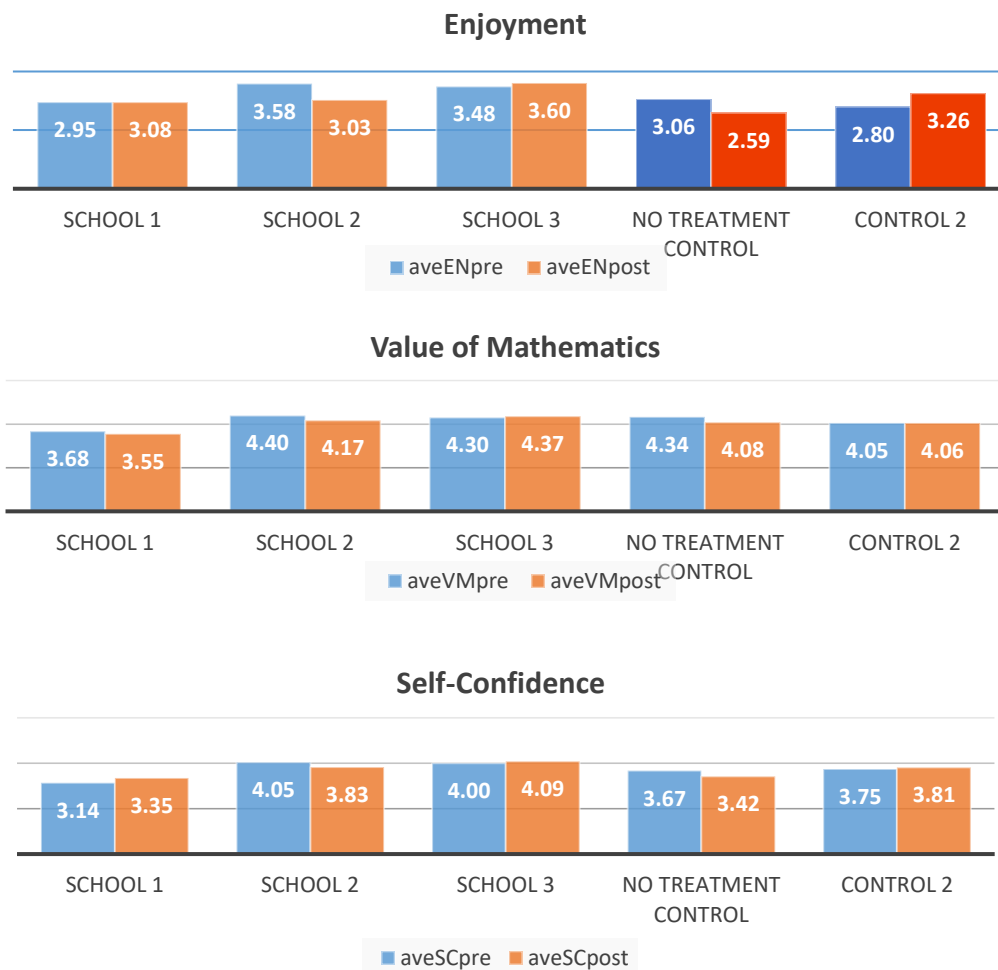
For Study 3, the differences in gender were apparent in the interview responses and end activity evaluations. In all instances, the boys' usability ratings for the tablet were higher than the girls and the magnitude of the difference was high (refer to Table 6-6). The standard deviations of the girls' ratings were also relatively higher than the

male students, showing that the female ratings were spread more widely. Female students also had a significant decrease in their VMT scores whereas their male counterparts had none. In contrast, male students had a significant increase in their confidence to use technology, but the female students scores remained the same. This finding is similar to some of the mobile learning literature (Yen, Wang, & Chen, 2011; Yorganci, 2017). Obviously, this is in contrast with the findings of Study 2, but rather than a clear-cut difference in gender because of technology use, it is possible that there are other factors at play which could have affected students' own perception of their confidence to use technology and the value they placed on the use of mobile technologies. This could have been affected by the student pairings, the short duration of study 3, or the class size of the experimental group in study 3. There were some clues about these factors in the video data for student engagement, but these are just speculations to possibly help explain why an almost similar programme ended up with different results.

**Student attitudes to mathematics (RQ3).** Across the three studies, there was no significant change found in students' attitudes to maths except for the two control groups' change in enjoyment scores. A graph of the MAI scores is shown in Figure 7-1. The graph is not to compare the three studies, as they are, after all, conducted in different conditions. This is just a quick way to illustrate pre and post intervention scores. The lack of statistically significant change can be assumed to be connected to the program frequency and duration. It might be that the once a week exposure to the tablets was possibly not enough to yield a change. In the case of Study 3, the six weeks programme was possibly just too short. Positive attitude changes tended to be associated with short term interventions (Afari et al., 2013; Wu et al., 2006) and are possibly explained by novelty affect. The current study did not find an attitude change and this, in a way, is a positive finding as it illustrates that the other findings of the current study are not just novelty effects. Some maths and mobile learning studies that were longer than Study 1-3 (between 18 weeks to one year) also did not find a change in students' attitude (Jaciw et al., 2012; Perry & Steck, 2015; Singer, 2015). Hilton's (2016) two-year longitudinal study also did not find a difference in students' attitude at the end of the first year, but after two years of using the iPads, a positive change in students attitude to maths was achieved.

The other possible explanation of the non-significant results relates to the sample size of the studies and consequently effect sizes as a measure of the magnitude of the

difference between the pre and post intervention data might be more pertinent. The three studies had varying results in relation to student attitudes to math. In Study 1, there was a small positive effect in students' self-confidence (ES=.20). This is comparable to Riconscente's (2013) small effect in attitudes (ES=.30), although in Riconscente's case, the effect was measured after only a week. This result, although not significant, is interesting considering that the study suffered some technical breakdowns and although the groups' confidence in working with technology declined, this did not affect self-confidence scores for maths. The other point is that the teacher characterised the class as *"more than half of the class have issues with themselves and their abilities"* and so an increase in self-confidence scores in maths (even a small one) is a positive change. The students explained that they were normally stressed with their regular maths, but with the sessions with the activities on the tablet, they were surer about what they should do.



Note: No treatment is part of Study 2, Control 2 is part of Study 3. The different colour code represents a significant paired t-test result.

Figure 7-1. MAI scores across three studies.

In Study 2, there was a small negative effect in the experimental groups' enjoyment ( $ES=-0.41$ ) as well as a significant medium negative effect in the control groups' enjoyment ( $ES=-0.54$ ). In the systematic review conducted, there was one study that reported a decline in students' enjoyment over the course of the intervention (Liu, 2007), but the case of that study is different from Study 2. Students from Liu's study felt that the activities were more restrictive than their usual maths, whereas the experimental group in Study 2 felt positive about the intervention as discussed in the teacher and student interviews. A possible explanation for this decline might be their attitudes to the increasing difficulty of what they were studying, considering that the study was taking place when the end of the school year was already approaching. Research has shown that students find mathematics less valuable when they approach middle school and that their self-concept and effort in school tend to decline as they grow up (Pajares & Graham, 1999; Yeung, 2011). This assumption is supported by the decline in the control group, as it shows that it was not just the experimental group that had a decline in attitude scores.

The other possible explanation is that the decline in attitude is a result of the positive reception of the mobile learning activities, such that the normal activities that they had with maths which the students were initially happy with had now become boring for them. Glimpses of negative attitudes towards mathematics were noted in the interviews, as students repeatedly compared the tablet activities with their usual maths class, often quoting their usual maths session as boring and the tablets better. It could be that while students found the once a week activity with the tablet interesting, this did not outweigh their daily experience with maths. This assumption, however, is difficult to support given the limited literature on maths attitudes and mobile learning and none of the previous studies has suggested this possibility.

In Study 3, there was a significant medium positive effect in the control groups' enjoyment ( $ES=.53$ ) but none of the experimental group's MAI changes met the small effect threshold. It is possible that the smaller class size of the control group is a factor in the change in scores. Research has shown that teacher to student ratio affects student satisfaction (McDonald, 2013), which may have been the case for this study but due to the focus of the study on the experimental group, there was no data to support this.

A systematic review of the effect of using technology on maths anxiety found that technology was a useful tool for reducing mathematics anxiety (Sun & Virginia,

2009). Taking maths anxiety as the opposite of the self-confidence scale used in this study, then the use of mobile technologies should have resulted in improved self-confidence. This was not the case at group level for the experimental groups as was the case for the three mobile learning studies identified in the review section (Jaciw et al., Miller and Roberson, 2010, 2011). An examination of students' attitude by gender and grade level showed a different result.

Within the experimental group, the MAI findings of Study 3 split by gender showed a small positive effect on male students' enjoyment and self-confidence but the female students score did not change. This finding has similarities to Kahveci's (2010) study, who found that males students had higher gains in attitude than the female students. The TIMMS study (Else-Quest et al., 2010) also found the same gender gap. A possible reason for the gender difference is the context of the activities. The OECD (2015) reports that girls are less confident than boys on applied mathematics, in contrast to abstract maths. The current study was applied mathematics in a sense; the lessons mostly covered linking abstract maths to the environment and as such, might have contributed to the small difference between groups.

There was also a small positive effect for the Primary 6 students' enjoyment ( $ES=.24$ ), self-confidence ( $ES=.48$ ) and value of mathematics ( $ES=.26$ ), but none of the Primary 7 scores reached the small effect threshold of  $.20$ . Savelsbergh et al. (2016) suggest that attitude of older children towards innovative learning interventions is more resistant, which may have been the case in this instance. It is also possible that the teacher factor might have affected the results for Primary 7 students. The teacher for the experimental group was the students' teacher the previous year. It is possible that some students might have felt that this was a step back, but this is only a possible explanation and not confirmed by data. Another possibility is that some Primary 7 students were not enthused about working with the younger students. This issue was raised in the student interviews and an examination of the MAI results by class found that there was a small to medium effect in the MAI scores for the Primary 6 only class and the composite P6/P7 class but none for the Primary 7 only class. Students in multi-grade classes are said to have a higher level of independence, confidence, social skills and positive attitudes towards school (Cornish, 2009), so this may possibly explain why the single-grade Primary 7 students' attitude differed from those in the composite classes. Attitude to mathematics is affected by several factors such as teacher and peer support, student competence and the learning environment (Mata, Monteiro, & Peixoto, 2012; Yilmaz,



Altun, & Olkun, 2010). These conditions varied across Study 1 – 3 and so it might have affected the directions of change for each of the studies.

**Technology acceptance model.** TAM is a theoretical model that shows the relationship between the two usability factors, perceived ease of use (PEOU) and perceived usefulness (PU), to attitudes towards technology. In the three studies, this relationship was tested via relationship between the usability evaluation and the MAI subscale value of mobile technology (VMT). Students' usability evaluation in the three studies has been mostly positive but there were variations observed depending on the activity and student characteristics. These differences fit the Unified Theory of Acceptance and Use of Technology (UTAUT) model (Venkatesh et al., 2003) where gender, age and experience are factors that affect technology acceptance.

There was a moderate to strong correlation (Cohen, 1988) between students' PEOU and students' attitudes towards mobile technology use in mathematics (refer to Table 7-1). This means that students with higher scores in PEOU also have higher scores in their attitudes towards mobile technology use for maths and vice versa. These findings are consistent with other TAM models for mobile learning (Chang, Yan, & Tseng, 2012; Huang et al., 2007; Hwang et al., 2015). The relationship between the ease of using the system and students' attitudes towards mobile technology was also evidenced in the student narratives about mobile use. For example, a student who found the use of mobile technology cumbersome particularly when it failed as they have to re-do the activity found paper-based maths activities preferable. Another student who was not familiar with technology also preferred traditional activities over the mobile supported ones as she explained that it takes one more step in the learning process by having to learn the technology first before being able to do the maths. On the other hand, students who found the use of the tablets easy also had more positive views about using mobile technology, saying it was better than their normal maths as well as more fun and engaging.

Table 7-1  
*Correlation coefficients mapped into the technology acceptance model*

	Study 1 (P7)	Study 2 (mostly P6)	Study 3 (P6 and P7)
PEOU → VMT	.485**	.401*	.622**
PEOU → PU	.794**	.455*	.661**
PU → VMT	.297	.473*	.723**
US → VMT	.557**	.493*	.637**

\*significant at the .05 level (1-tailed); \*\*significant at .01 level (1-tailed)  
 PEOU = perceived ease of use; VMT = value of mobile technology; PU = Perceived usefulness; US = User Satisfaction

The TAM framework suggests that PEOU affects how the user perceive the usefulness of the system. This means that users are likely to consider a system useful if they think that the system is easy to use. For Study 1-3, this relationship was observed and is consistent with findings from other mobile learning studies (Chang et al., 2012; Nikou & Economides, 2017; Park, Nam, & Cha, 2012) and other technology integration models in the classroom (Padilla-Meléndez, del Aguila-Obra, & Garrido-Moreno, 2013).

There was a significant relationship found between usefulness and attitudes to mobile technology except for Study 1. Study 2 and 3's findings are the same with other mobile learning studies (Cheon, Lee, Crooks, & Song, 2012; Park et al., 2012) while Study 1 validates Ha, Yoon and Choi's (2007) findings. A possible reason for the difference is the technical difficulties encountered by the participants in Study 1. UTAUT model suggest that experience is a moderating factor in user acceptance model. The technical difficulties encountered in Study 1 may have led the students to rating the usefulness of the mobile device in the activities lower but their overall attitudes to using mobile technology have remained positive. And so, in this particular case, perceived usefulness is not a predictor of students attitudes to using mobile technologies.

For all three studies, user satisfaction with the activities were significantly correlated to student attitudes towards using mobile technology. The user satisfaction scale contained items relating to students' enjoyment of the activities. TAM studies suggest that enjoyment has a positive effect to attitudes (Ha et al., 2007; Merikivi, Tuunainen, & Nguyen, 2017) and this was the case for Study 1 – 3. Students' satisfaction with the activities not only affected their attitudes to using mobile

technologies for maths but also affected how they view the usefulness of the mobile device (Padilla-Meléndez et al., 2013). Huang et al. (2007) notes that “enjoyable experiences result to positive attitudes” and this was likely case for the three studies. Students who were inundated with technical problems had negative views about the use of mobile technology and those who had less technical issues were more positive about it.

Mobile learning activities that were perceived to be useful, easy to use and fun are likely to result into more positive perceptions about mobile learning. The relationship between these three variables to attitudes to mobile learning can serve as a design guideline for mobile learning sessions. If an application is useful but awkward to use, then users might not take to it very well. In the same way, if an application is useful and easy to use but the activities end up boring the students, then this would likely not be received very well by the students.

#### **Student Engagement (RQ4)**

Student engagement has been partly covered in the section on student perceptions. This section focuses on how the learning activities engaged the students, the breakdown of the activities and the nature of collaboration in mobile learning

Teachers who taught the experimental groups all confirmed that students were engaged in the activities, but the effect was greater for students who were ordinarily reluctant to engage with maths. This observation was supported by the video observations in Study 1 and Study 3 and by the student narratives of Study 2. Most of the maths and mobile learning literature also had the same positive observation (Deater-Deckard et al., 2014; Kiger et al., 2012; Project Tomorrow, 2010; Rehm et al., 2015). Novelty was a common reason why the teachers thought the activities had engaged the students, which is a theme typical when implementing new strategies (Savelsbergh et al., 2016). The teacher from Study 2 also added that the learning activities engaged the students at a personal level. Personalised learning environments are one of the features of mobile learning (Kearney et al., 2012). In the current study, students gathered artefacts “in the wild” and reflected on these gathered artefacts back in the classroom. This gathered artefacts gave the students ownership of some sense as they did not just get something from a textbook but rather have gone out to investigate and capture visual representations of geometric objects, which they have then presented to the rest of the class.

An investigation into the nature of engagement carried out in Study 3 found that there was a high level of engagement during the activities. This engagement was mostly in the form of tablet use and communicating with their partner. Sometimes, the students were engaged in the activities but were not using the tablets, like when the students went looking for objects that had specific geometric properties, but mostly engagement involved using the tablet. This finding is a direct contrast to Heflin, Shewmaker & Nguyen (2017) and Perry and Steck (2015), who both found that students were mostly disengaged when they were using the tablets. Both studies, however, were with older students and mostly desk-based activities, which possibly explains the difference in results. In other mobile learning studies that used video observations, the incorporation of novel use of technology facilitated improved student engagement (Deater-Deckard et al., 2014; Lonsdale, 2011; Roschelle et al., 2010). This shows that more than the technology, it is the learning tasks that drive the interaction with technology.

There were however instances of student disengagement. In Study 1, there were cases where students finished ahead of the class and so had to wait for the rest before continuing with the lesson. Differentiated instruction is an approach that allows for students to follow different paths with regards to student backgrounds and preferences (Scalise, 2007) and this was an element that was not explored in Study 1 and Study 3. Each of the student pairs was doing the same task and naturally, some students finished earlier and some students found the tasks less challenging than the others. This again, points to a design guideline for mobile learning activities: allow for differentiated instruction. Other instances of student disengagement were because of problems working in pairs, but mostly disengagement occurred during breakdowns while students waited for support. The next sections cover these breakdowns and discussion on student engagement.

**Breakdowns of mobile learning.** A critical incident analysis was conducted in Study 1 and identified technical, social and activity design issues in the mobile learning activities (see Table 4-6). The technical difficulties of the mobile learning sessions included issues with the battery, stability of the application, accuracy of the measures given by application, and network connectivity. The activity design issues included problems with the content and student background knowledge. The social issues included problems with collaboration and students' adaptability. These problems are not new and has been covered by previous maths and mobile learning literature (Goldman et al., 2004; Lai et al., 2012; Wijers et al., 2010).

The effects of the technical problems in the activity varied. For example, the battery issues normally came up at the start of the session, so this only caused a minor delay as the students used a different tablet. When only a portion of the activity was lost due to the unresponsiveness of the application, students quickly recovered from the problem. When it happened towards the end, with the majority of work being lost, this left some students frustrated. Students tolerated the technical issues up to a point. In the earlier section, it was mentioned that students who had encountered several technical issues had mixed views about the use of mobile technologies and these views had also affected their behavioural engagement. Some students persisted while there were those who became disengaged from the activity. This links back to the technology acceptance model that suggests that there should be a balance of usability and utility (Davis, 1989).

The non-technical issues related to the activity were more difficult to troubleshoot because these were mostly issues related to students' skills and the design of the activities. For example, when students did not have a good grasp of the topic, this meant that the teacher had to quickly go over the maths lesson with the whole class. In this case, it occupied some of the time for the activity. The other option was for the teacher to support the struggling student, and in that case, the teacher became temporarily unavailable to support the rest of the class. Whichever the case, both situations called for a re-think of the design of the learning activity.

The problem was partly caused by bringing in the technology without fully considering the learners and partly by not having fully considered the different scenarios that could go wrong in the classroom. The lesson plans were linear, restrictive and time-bound and did not allow much flexibility in terms of carrying out the lesson. Other mobile learning studies, particularly those carried out outside the classroom environment identified the need for careful planning of scenarios and flow of activities (Eliasson et al, 2010; Spikol and Eliasson, 2007). This then leads to the concept of classroom orchestration, "the methods and strategies empowered by a technology equipped classroom that an educator may adopt carefully to engage students in activities conducive to learning" (Chan, 2013, p. 515). This highlights the important role of the teacher, their flexibility and adaptability to carry out novel use of technology. More careful planning and more teacher training might have avoided the problems related to activity design.

**Collaboration in mobile learning environment.** All activities in Study 1-3 were carried out at least in pairs and in some activities in Study 1 and 2 in groups of four, but

social interaction was not limited to the paired work. In the observation of student activities, there were a lot of cases where students acted as mediators and experts. These students provided help to their peers not just with technical support but also with the topic being investigated. When students found a quick way to use the mobile device, they were quick to share it with the other groups. When a student solved a difficult problem (e.g. looking for an object with three lines of symmetry), that student would then share the answer with the other members of the class.

Students had mixed views about the nature of the paired work. Some students appreciated working with a partner and saw it as a helpful process in getting the activity completed. However, there were those who felt negatively about it because they felt that they weren't able to work well with their partners. There were several instances of students arguing over control of the tablet. In Kim et al.'s (2012) study, frustration was felt by some of the students who had to wait for their turn to use the tablet, which in some instances contributed to disengagement. This feeling of frustration was echoed by some of the students in the present research and in some instances caused disengagement. This reaction is typical in group/paired activities where students who are not working in a more active role tend to tune out (Goldman et al., 2004). However, in cases where students have become disengaged, it can be argued that they were not exactly collaborating but rather taking turns or at best sharing the device between them.

Some of the reasons why the paired setup of the activities was not appreciated were either due to a mismatch in skill, unfamiliarity with their partner or sometimes because of a personality mismatch. At times, it was due to the nature of the activity. Kucirkova, Messer, Sheehy & Panadero (2014) suggests that the app features influences student engagement and collaboration. In Study 3, it was observed that some activities facilitated collaboration while some activities had collaboration reduced to turn-taking. For example, one of the symmetry activities in Study 3 required designing a symmetrical logo using a pixel-art application. As the activity involves design, it is likely that each of the students in the pair would have his/her own idea that they would like to try, so rather than having a joint design, the children instead took turns. In contrast, the walkabout activity, where students had to look for certain objects with specific geometric properties, showed students working together to finish the activity within the time constraint.

Most of the time, students were working together to complete the activity but when they did not, this sometimes resulted in temporary disengagement in at least one

of the students. Previous studies suggest that there are at least two types of students—the highly engaged and the variably engaged (Deater-Deckard et al., 2014). During the paired work, these two types become apparent when the students were not working together. For instance, when students decided to take turns rather than work together, the person using the tablet was highly engaged, but the person waiting for his/her turn was not, but would engage again when his/her turn came. The challenge is the design of mobile learning activities that facilitate interaction between the students to maintain a high level of engagement.

### **Student achievement (RQ5)**

The post-test scores of the experimental groups in Study 1-3 showed a significant improvement in their pre-test scores. Students across studies shared that they found the activities fun and easier and it is possible that this positive attitude might have contributed to their increased scores in the maths test. This idea of positive attitudes leading to improved student performance is supported by new and old maths literature (Ma and Kishor, 1997; Shih et al., 2012; Zan et al., 2006).

Some students from Study 2 and 3 explained that the activities made them recall the topics better and helped them visualise the concepts being learned, as was the case in other mobile learning studies (Baya'a and Daher 2009; Chang, Wu, Lai & Sung, 2014). Videos, animations and maths manipulatives are typical mediums that are used to help visualise maths concepts, both in mobile learning environments and computer-based environments. However, with mobile devices, an additional medium for visualisation is the learners' environment, facilitating a connection between abstract maths concepts and the real world. Some students felt that this new way of doing maths had helped them grasp abstract maths concepts and as a result helped them remember better. These narratives were supported by a significant improvement in MT scores and further supported by the significantly higher gains of the experimental group in Study 2 in comparison to the control group.

Students were able to operate at different levels of the Van Hiele Model. Literature suggests that students in middle school are typically between level 1 and 2 (Mason, 1997; Ma, Lee, Lin and Wu, 2015). It was clear that the students were able to operate at Level 1 (Visualisation) as most had the ability to identify the geometric figures based on their appearance. In the video data, there were indications of Level 2 (Analysis) when the students constructed objects to meet the properties requested when

they had difficulty looking for it in their environment. There were even cases showing Level 3 (Abstraction) like when students realised the connection between the acute angle and reflex, or when they were investigating the relationship between area and perimeter. Admittedly, these are just snapshots and not representative of the class results. The Study 3 data on the experimental groups' better performance on topics that fall under common misconceptions shows that some students had progressed to higher levels of the Van Hiele model, but again, this is just to illustrate rather than generalise. Maths and mobile learning studies that cover the process of students' conceptual development are limited but as this is not the focus of the current study, this will have to be left for future research.

For Study 2 and 3, students who initially scored low had higher gains than those who scored high at pre-test. This difference in performance was not observed in the control groups. These reports suggest that the mobile learning intervention might be more effective in supporting lower-performing students, as indicated by previous maths mobile learning studies (Ketamo, 2003; Shin et al., 2006).

The gains in the experimental groups have shown that the intervention can have a positive effect on student achievement, but it should be noted that the control groups also had positive gains. While the gains of the experimental group in Study 2 were better than the gains of the control group who followed the traditional model (although covering the same curricular ground), that result was unsurprising. The result of Study 3 was the opposite. Students in the control group who followed very similar activities had higher gains. The Study 3 finding contrasts with the findings of mobile learning studies that utilised the same control group (Wu et al., 2006; Shih et al., 2012). However, both studies are far shorter in duration, which might explain the difference in findings. It is difficult to ascertain the factors that have led to such differences as there was not enough data on the control group. It is also worth noting that the control group of Study 3 ended up as two smaller classes shared between the two teachers assigned for the control group, rather than the assumed setup of two teachers co-teaching one big class. Literature suggests that reduced class size has a positive effect to student achievement (McDonald, 2013), so it is possible that this affected the difference in results. It is also possible that the gains in the control group were in part due to the design of the activities. Wu et al. (2006) who used two control groups for comparison found that the control group that followed similar activities to the experimental group outperformed those taught using traditional methods. This factor, in addition to the class size of the



control group might be some of the possible reasons why control group performed better than the experimental group.

In the earlier section, gender difference was found in student engagement and attitudes, but in terms of their gains scores in the maths test, no gender difference was found for Study 1 - 3. This suggests that the intervention was effective for both boys and girls, but so was the non-mobile learning activities of the Study 3 control group. Older literature suggests that there are gender gaps in mathematics in favour of male students (Else-quest et al., 2010), but the present findings suggest otherwise, which is more in keeping with a recent meta-analysis (Voyer and Voyer 2014). The difference in the performance of female students of the experimental group with the female students of the control group in Study 2 suggests that for that study, the intervention had a greater effect on the female students. A possible explanation is the difference in the nature of the activity. Hossain, Mendick and Adler (2013) suggests that female students perform better in collaborative activities, which is clearly not the case for the control group of Study 2. This trend in gain scores is consistent with other mobile learning studies on maths (Schacter and Jo, 2016; Shin et al.'s, 2006), but this finding is limited by the small sample of Study 2 and 3 and thus this result can only be viewed as suggestive.

Context is a key concept in mobile learning research. Mobile learning studies on maths that attempted to link classroom mathematics to real world maths had positive results in student achievement (Shih et al., 2012; Wu et al., 2006), as was the case in the current study as evidenced by significant change in pre and post maths test scores of Study 1-3. The literature of maths and technology maintains that context is an important factor in adopting technology in the mathematics classroom (Li and Ma, 2010). In fact, the change in attitude and improvement in student performance comes from not only embedding technology but also on the “embedded method of teaching developed from the pedagogical reform (ibid, p. 219).” For this study, it is difficult to ascertain how the incorporation of the outdoor space, the collaborative nature of the activity or the students’ perception of the activities contributed to the difference in the gains between the experimental and control group, but it is also worth noting that these enshrine the potential of mobile technologies: to facilitate learning across context and provide personal and collaborative learning environments (Cochrane, 2010b).

### Critical success factors

This section considers how the study has met the elements deemed necessary for a mobile learning project to succeed. A consolidation of three success factors (Naismith and Corlett, 2006; Cochrane, 2010a; Alrasheedi and Capretz, 2015) in the literature review section resulted in five success factors as listed in Table 7-2. From Table 7-2, it can be observed that not all success factors have been fully met by the three studies. A discussion of how these success factors were met follows.

Table 7-2

Checklist of critical success factors across Study 1 – 3

Components	Study1	Study 2	Study 3
Appropriate choice of mobile devices and software (including user friendliness of design)	P	✓	✓
Level of pedagogical integration of the technology into the course	P	✓	P
Level of lecturer modelling of the pedagogical use of the tool (including development of technical competence of students)	P	✓	P
Technological and pedagogical support (including learner community)	P	✓	P
Allowing time for developing an ontological shift, both for the lecturers and the students.	P	✓	P

\*P means partially met

**Appropriate choice of mobile devices and software and user friendliness of design.** The end activity evaluation surveys that measured three elements of usability (ease of use, usefulness and satisfaction) mostly have above average scores (refer to Figure 4-12, Figure 5-3, Table 6-3) implying that for most students, the applications used were fit for purpose. However, for Study 1, despite the high activity ratings, there were breakdowns identified in the critical incident analysis, and as such, this criterion was only partially met. As Kukulska-Hulme (2007) discussed, technical difficulties affect the overall experience but users will tolerate it to an extent. Study 1 findings has shown that technical difficulties affect the learning experience but often these technical difficulties were minor enough to discourage students in participating in mobile learning activities.

**Level of pedagogical integration of technology into the course.** All activities carried out in Study 1 – 3 were mapped according to the *Curriculum for Excellence (CFE): Numeracy and Mathematics* standards and this partially validated the fitness of the activities with the participants' curriculum. The teachers were also provided the

topics before the start of the project to assure that the content matches the curriculum. The collaborative nature of the activities and the element of real-world in the mobile learning activities also supported this measure. Despite the lesson's supposed fitness with the curriculum, this criterion was only partially met by Study 1 and Study 3. For Study 1, some of the activities proved to be difficult for the students as identified in the critical incident analysis (see Table 4-6). For Study 3, one of topics provided little challenge to the Primary 7 participants of the experimental group. It was only for Study 2 where there is some evidence that this criterion was fully met. Differentiation of the activities was offered to some extent in Study 2, with the teacher adding extra tasks for more able learners. Studies 1 and 3 were not able to provide this. This means that goodness of fit should also account for the individual characteristics of the learners. None of the systematic review studies explicitly discussed differentiation but majority still reported positive results, and so, while differentiation may not be a key issue, taking it into account is likely to improve the learning experiences of the more able students and those who require extra help.

**Level of lecturer modelling and development of technical competence of students.** All three studies included a short tutorial on how to use the applications before the mobile learning activities. Perry & Steck (2015) suggested that scaffolding and modelling tends to maximize the potential of mobile technologies. Initially, the modelling process was at the start of the lesson but this process was identified as the source of a breakdown for sessions that used two different applications (refer to critical incident analysis of Study 1, Table 4-6). This format was modified for both Study 2 and Study 3, and modelling was shifted to just before they used the application. This resulted in students being clearer with what they must do on lessons that involved a series of activities and mobile applications. This finding reiterates the need for student training on the use of mobile technologies and despite studies reporting that some students required little user training (Kerrigan et al., 2013; Wagner, 2005), such is not always the case, particularly when the nature of use of the mobile device is different from what students normally use it for.

**Technological and pedagogical support (including learner community).** In all three studies, technical support was provided during all learning activities. Students were also seen helping other groups when they encountered technical issues. Some technical issues, however, were not foreseen, particularly for Study 1 as some technologies worked differently during actual use and testing stage. These technical

glitches were addressed in Study 2, and as such, the implementation required little technical support. Study 3, however, had an issue with the class size being 48% oversubscribed than the recommended 25 students in a composite class. This resulted in more wait times to troubleshoot minor technical issues and resulted in some students being temporarily unengaged in the task as they waited for the technical support that they needed. This shows the importance of on-going technical support when implementing novel learning environments and when this isn't possible, then it is important to have provision to train students who can act as technology leaders to help other members of the class.

**Allowing time for ontological shifts.** Admittedly, this criterion is difficult to measure against the studies as the research was conducted only once per school. There were traces of evidence in the teacher interviews as they discussed how they intended to take mobile learning forward. They have suggested ways to change the intervention to better fit their classes and have considered alternative ways to implement the activities. For example, the teacher in Study 1 thought it would be better not to have the entire class on the mobile learning activity to facilitate better classroom management. The issue, however, is the lack of technology to carry out future plans particularly for Study 1 and Study 3. Study 2 already has a provision for mobile learning so it is only with this sample that this criterion can be met. For this sample, this process of ontological shift, can be argued to have started even before the mobile learning research. The teacher was already using iPads and computers for group activities and the paired lessons in the mobile learning intervention was an addition to that repertoire. Since the completion of the study, the teacher narrated that the students have already shared with the Primary 1 and 2 students how to use some of the applications that they've learned in the intervention.

This subsection has considered how the studies met the critical success factors in implementing a mobile learning environment. As illustrated in Table 7-2, some of the factors were not fully met in Study 1 and 3. It was only for Study 2 where each of the success factors were met and having done so, it was evident in the student performance, student narratives and teacher testimony that the intervention has worked well for the class. The usability issues experienced in Study 1 had an effect in the overall student experience. After all, it is not possible to carry out the learning activities with devices that are erratic and unstable. There is also the case of appropriate level of integration which is probably an issue for intervention studies from external researchers. Training

and support are also factors that affect the success of the project but these two elements are not always easy to meet as this involves allowing time for an ontological shift in the participants of the study. This wasn't the case for Study 2, mainly because there was already an established culture of technology use for that specific class. Were it a different case, it's possible that the results would have turned out differently. Even so, this points out the need for the success factors to be considered when implementing mobile learning scenarios. Having considered how the three studies relate to the critical success factors of mobile learning, the next section covers a discussion of the advantages of adopting mobile learning activities.

### **Advantages of Mobile Learning**

One of the advantages of using mobile devices is the range of activities they are able to support in a single device. Using Sawaya and Putnam (2015) as a mapping framework to analyse the different activities, the learning goals for the activities used in this study varied from solving problems, forming connections and using representations. The activities involved practicing maths skills, creating content, investigating and applying maths concepts. The mobile devices in this study have supported constructivist learning activities through a process of learning by doing in a collaborative environment. While the control group of Study 3 was also able to conduct constructivist learning activities, the experimental groups of Study 1 – 3 could be considered to be **more** constructivist. The mobile device facilitated the constructivist and collaborative activities carried out as students gathered artefacts that contained geometric representations from their environment. Students then moved to a more formal learning context and carried out further reflection and investigation on the artefacts they had gathered. These artefacts and creations became discussion points enabling the covering of topics from the standard maths curriculum. This process illustrates Crompton's (2013) definition of mobile learning which is "learning across context, through social and content interaction, using personal electronic devices (p. 4)."

The critical incident analysis carried out in Study 1 identified the following advantages adopted from JISC's (2011) list of tangible benefits of mobile learning:

- encouraged reflection in close proximity to the learning event
- allowed for abstract and concrete information to be presented side by side
- promoted active learning.

These observed breakthroughs tally with the students' perceived advantages of mobile learning for math: facilitate visualisation of abstract maths concepts as well as engagement in fun and active learning activities that use technology. There was also the benefit of allowing personalisation, ownership of learning and improved student engagement, as the teacher suggested. These tangible benefits map well into Cochrane's (2010b) potential benefits of mobile learning introduced in the first chapter: facilitating learning across contexts, facilitating contextual learning, and providing personalisation in both personal and collaborative environments.

The mobility offered by the technology facilitated learning as students moved in and out of different learning spaces, investigating maths properties within their environment. The multimodality, portability and multi-functionality of the mobile device facilitated a variety of learning goals, from more active and situated learning activities to more reflective classroom based activities. The networked devices facilitated sharing of students' works wirelessly between devices or tethered to the class's bigger screen. Admittedly, it didn't always work but on times that it didn't the portable nature of the devices allowed sharing students work simply by passing it on to another group. The process of finding concrete representations of abstract maths within the environment facilitated a personal learning environment as the students worked on their own devices. These learning scenarios map to Carpenter and Lehrer's (1999) five activities that promote mathematical understanding: constructing relationships, extending and applying mathematical knowledge, reflecting about experiences, articulating what one knows, and making mathematical knowledge one's own.

### **Limitations**

Limitations of the individual studies were covered in their respective chapters. These included research design issues, programme fidelity, sample size and instruments used. As these were already covered in the individual studies, only some of these will be discussed here. There were adjustments in the study to provide a more robust research design (for example, from the SGPP design in Study 1 to the RCT design of Study 3). Despite the reasonable adjustments, there were still issues in the design that limit the generalisability of the results.

The first relates to the small sample sizes of the three studies. Statistical significance is mainly affected by the size of the sample so unless the effect is very big, then statistical significance is less likely to be obtained with small samples (Coe, 2002).

Some findings were significant and some were not, but effect sizes were provided. Even so, the significant findings remain suggestive and require further research. After all, the studies did not always validate each other's result.

The use of adapted instruments in the studies is yet another limitation. In addition to the self-reporting nature of the instruments, the computed reliability scores were also low. The self-reporting nature of the instruments meant that some students may have misunderstood the questions. This was moderated by explaining the full instrument to the students in the beginning, then again explaining the items likely to confuse them just before they completed the form. The low reliability scores for the end activity evaluation was a possible issue, as it may mean that some students interpreted the items differently from the others. However, the instrument was a usability evaluation and as such, likely to result in different answers anyway.

There is also the effect of researcher in the classroom. The presence of the researcher in the classroom may have affected students' behaviour. This is not known, but if it has, it is assumed that this effect diminished over the course of the intervention. What is known is that the presence of the researcher in the classroom meant the availability of technical support. In real classroom situations, troubleshooting technical issues and responses to break downs would be left to the teacher and the more technically-able students, so the scenario in this case can be considered as a best-case scenario. How the classes would have fared on their own is not known.

There was also a lot of focus on the experimental group, but limited information was obtained from the control group. This would have been useful particularly for Study 3, as the control groups were following similar activities. The modified end activity evaluation provided some insight, but if the study were done again, it would probably be better to include interviews as well.

Novelty possibly had an effect on the results but to what extent is not known. This was moderated by having a slightly longer intervention in comparison to some existing mobile learning literature, but even so it was still difficult to isolate the results from a novelty effect. As discussed, this is an issue that is difficult to avoid given the relatively newness of mobile technologies in comparison to more established technologies being used in schools. Perhaps only longer interventions and increased used of the mobile device would remove the novelty effect altogether.

Sometimes, the data does not always tell the same story. For example, in Study 3 there was a positive evaluation of the mobile learning activities, but some students felt

negatively about it. The M3-level evaluation framework has proven particularly useful for triangulating responses and has allowed the showing of differences where these were initially obscured. It also provided support to data where there were questions of validity and reliability.

### **Contribution to Knowledge**

Outlined below are some of the contributions to knowledge that this study was able to provide, but this is by no means an exhaustive list.

The systematic review carried out in Chapter 2 was, to the author's knowledge, the first systematic review carried out in maths and mobile learning that investigated the effects of mobile technology on students' attitude, engagement and achievement. It was also one of few meta-analyses that exist in this field. In addition, the systematic review was able to show the variety of ways by which mobile devices can be integrated in the classroom, and by doing so, illustrated the unique affordances of mobiles devices in facilitating connection between abstract maths and the real world.

The design of the studies also provides a methodological contribution to the field of mobile learning for mathematics. Judging from the systematic review, the critical incident analysis used in Study 1 and The M3-level evaluation framework (Vavoula and Sharples, 2009) used in the three studies, this was probably the first joint adoption in the field of maths and mobile learning. The use of a wearable camera (Google Glass and clip-on cameras) was also novel and allowed data collection as students moved about in and out of different learning spaces.

The critical incident analysis in Study 1 facilitated the identification of breakdowns and breakthroughs of mobile learning. What was found was that breakdowns can be classified into technical issues, activity design and social factors. Recommendations on how to avoid these issues are brought forward.

The M3-level evaluation framework used for all three studies provided an integrated approach to evaluating mobile learning for mathematics. This framework, together with the mixed method design, facilitated the investigation of effects of mobile learning on three aspects: usability, learning experience and impact of technology use. There is a call for more comparative studies on mobile learning within the wider mobile learning field (Crompton, Burke & Gregory, 2017; Sharples, 2013) and Study 2 and 3 were able to provide that. Previous studies on maths and mobile learning that carried out investigation outside the classroom environment tended to be short with small sample



sizes and be qualitative by design. The current study involved the whole class and provided both quantitative and qualitative data, showing the different pushes and pulls of technology use with different users.

The use of the wearable camera was novel and video data from these technologies provided insights into student engagement - in particular, identifying forms of engagement and disengagement when using mobile devices for maths. The study found that students were highly engaged in the mobile learning activities, but become disengaged when breakdowns occurred. This points back to the role of orchestration, differentiation and the need for teacher flexibility in addressing breakdowns when they occur.

## CHAPTER 8 CONCLUSION

This study set out to investigate the effects of using tablet devices for mathematics learning in indoor and outdoor environments in terms of student attitudes, perceptions, engagement and achievement. A systematic review and three mixed method studies were conducted as part of this research, with each iteration addressing the limitations of the previous study. The design of the activities featured mobile technologies being used for active, collaborative learning activities as students moved in and about their learning environment. The M3-Level evaluation framework was used to evaluate the mobile learning intervention, utilising different instruments to analyse usability, learning experience and impact of technology use. At micro level, it examined the usability and student perceptions about the activities through individual end activity evaluations. At meso-level, it examined the learning experience through a critical incident analysis of breakdowns and breakthroughs while using the mobile device and through student interviews. At macro level, it examined the effect of the intervention on students' performance and attitudes through an attitudes inventory and a maths test aligned with the topics covered in the intervention. This approach enabled triangulation and provided different levels of granularity in the investigation of effects of using mobile technologies in the classroom.

Through the systematic review of mobile learning studies, the possibilities and potential of mobile technology use for maths were identified, leading to connected and comprehensive evidence for mobile learning for mathematics. The review showed the unique affordances of mobile devices in comparison to traditional computing and their potential to connect mathematics learning to the real-world, a challenge that has always been present in mathematics education literature. There was promising evidence in this regard, but evidence of effectivity in the form of measurable outcomes and comparative evaluations have been few. This study filled that gap through a mixed method research design that evaluated mobile technology use in activities that facilitated visualisation and linked maths to the environment.

The findings from Studies 1 – 3 suggested that the use of mobile technologies elicit positive responses from students. Most of the students found the activities enjoyable, engaging and useful in facilitating visualisation of abstract maths concepts. However, technical and social issues could be disruptive and affect students' overall views. Drawing on the theory of the Technology Acceptance Model (Davis, 1989), the

three aspects of usability, ease of use, usefulness and satisfaction affected overall student perception about the mobile learning activities. When students found the activity enjoyable, their engagement was also higher. If they saw the benefit of doing the activity, then they were also likely to engage. However, when they become inundated with difficulties, be it technical, social or with the topic itself, then their overall views about the usefulness of mobile technology changed. This highlights the role of careful orchestration of the learning activity and the responsibility this places on the teacher.

Students' attitudes to mathematics is a well-researched area but the effect of using technology with maths on students' attitudes to maths is patchy and limited. With mobile technologies, this is even less. The systematic review conducted identified this gap and it was one that this study tried to fill. There were indications of effect on students' self-confidence in Study 1, but the changed direction of effect for Study 2 and the unaltered attitudes in Study 3 contradicted Study 1 findings. What this suggests, however, is that attitudes are affected by several factors like teacher and peer support, gender and learner characteristics, as well as the learning environment. Attitudes are formed over time, and perhaps, so are attitude changes. Longer intervention studies, like a more integrated use of mobile technologies for an academic year, are promising research designs that would be better equipped to answer this question.

The mobile learning activities resulted in high student engagement, evidenced by student and teacher narratives and researcher observation. Novelty, technology use, and the nature of the activities are some of the factors likely to have affected engagement. A detailed analysis of engagement in Study 3 found that engagement was usually in the form of tablet use and communicating with peers, depending on the nature of the task. This suggests that interaction with technology is driven by the learning tasks, rather than technology driving the learning activity. Disengagement is likely to occur when there is a problem with the design of the learning activity, for example, pairing a student with the wrong partner or assigning the same task to the class without regard for individual students' characteristics. Disengagement is also likely to occur when students are not able to perform the task, for example, because of failure in technology or a gap in students' understanding of what is being asked. This shows the onus that teachers have in driving successful mobile learning interventions and moreover, the need for continued teacher training, support and time to develop the confidence and the skill in using novel learning technologies.

The systematic reviews carried out before and after the current study showed that using mobile technologies resulted in a modest difference in students' achievement. The findings of the present three studies also suggest an improvement in student scores in the experimental group, although the magnitude of effect for each was different, with Study 2 having the largest effect and Study 1 having the smallest of the three. It can thus be suggested that the mobile learning interventions promote student achievement. A comparison with the control group, however, pointed to two opposing findings. The experimental group in Study 2 performed better than the control group. Study 3, whose control group followed very similar activities without the tablets, performed better than the experimental group. This hints that the context-based learning activities promote improved student performance but there are also other classroom conditions that affect this.

Study 3 also found a significant improvement for the experimental groups' performance on questions relating to common misconceptions. This can be interpreted as students' progression on the Van Hiele Model. It is possible that the visualisation offered by the mobile learning activities helped students to operate at higher levels of the Van Hiele Model after the intervention. However, this is just a speculation. Further research with instruments that specifically measure students' progression on the Van Hiele Model is needed.

Several advantages of mobile learning for mathematics were identified through the critical incident analysis conducted in Study 1 and through the interviews. The activities were found to have facilitated visualisation by linking abstract and concrete representations, encouraging reflection, promoting active learning as well as allowing personalisation and ownership of learning. These confirm the potential of mobile learning set out in the first chapter. The mobility of tablet devices supported students in carrying out constructivist activities as they moved across different learning spaces—from the investigations and artefact collection outside the classroom environment to the more formal context of the classroom to reflect and discuss the artefacts gathered. The flexible functionality of tablets facilitated a variety of learning activities including creating content and applying maths concepts. The multimodality, portability and multifunctionality of the mobile devices facilitated the activities as students moved in and out of the different learning spaces, from gathering artefacts “in the wild”, analysing and discussing these artefacts in the classroom, creating new content and sharing these new artefacts with other members of the class.

While there are advantages in adopting these technologies in the classroom, it is worth emphasising how the design of the activities, the technical breakdowns and learner characteristics can make a difference in results. Similarly, it is important to consider the functionalities of the device and how it can be used to integrate into the existing curriculum, while it is also important to consider how the design of the activities fit with learner characteristics.

### **Recommendations for practice**

Students have positive perceptions about the use of mobile technologies for mathematics. This much was known at the start, through the systematic review (e.g., Baya'a & Daher, 2009; Pollara and Broussard, 2011). The present study confirmed this but also characterised reasons for student satisfaction into three categories: technology, pedagogy, and self. Satisfaction due to technology use wears off as novelty effects decrease, whereas the sense of satisfaction and confidence that the students acquire as a result of the learning activity tends to have longer effects. However, the latter is also the more difficult to achieve. What this means is that, in practice, students may initially be excited about the prospect of using novel technology, but if the technology does not add much value to the learning experience, then students are likely to lose interest eventually. This goes back to the design of learning activities suggested by the SAMR model (Puentadura, 2006), in which the goal of technology use should go beyond substitution and augmentation but rather move towards transformation.

In investigating the issues associated with mobile technology use, the present study was able to identify three categories of breakdowns: technical issues, activity design and the social layer. Some of these issues could have been avoided through a more careful orchestration of the learning activity. Again, this points back to the important role that teachers play in designing and carrying out novel technology use. For the author, as an outsider, this was difficult to do without a better understanding of the learner, but a co-design approach to research may have avoided some of the issues, especially those relating to the social layer and activity design.

The mobile learning experiences facilitated active learning activities in math, facilitating investigation and forming connections between abstract maths and concrete representations in the environment. In these activities, there was a shift in the teacher's role and responsibility, from the person guiding and stimulating discussion to that of a "curator—a collector, organiser and guarantor of educational opportunities" (Traxler

and Crompton, 2015, p.230). As such, it would be worthwhile addressing how teachers are being trained to target those issues as well as being trained to use new technologies.

It was shown that success in using mobile technologies in the classroom is dependent on various factors as identified by Cochrane (2010b): appropriate choice of the mobile device, level of pedagogical integration, level of teacher modelling, technological and pedagogical support and allowing time for developing an ontological shift for teachers and students. The findings also show that this last factor is difficult to meet, particularly for short term interventions, as ontological shift is something that happens over continued practice. Change doesn't happen overnight but ongoing support in a community of practice may be more likely to achieve such change.

### **Recommendations for researchers**

A criticism of mobile learning literature is that it is mostly in the form of attitude surveys, interviews or observations, with only a few attempts to carry out comparative evaluations (Sharples, 2013; Crompton, Burke, Gregory, 2017). One of the contributions of this research is that it provides empirical data on the effects of mobile learning on students' attitude, engagement and achievement in mathematics. Previous mobile learning studies on maths have covered student perceptions, engagement and achievement, but have done so separately. Using the M3-level evaluation framework proposed by Vavoula & Sharples (2009), this study was able to provide an integrated evaluation of usability, learning experience and impact of technology use, and thus fills some of the gaps identified earlier on. However, some of the gaps are still not filled. Due to practical constraints, the present study is limited by small sample sizes, relatively short duration of the experiment and the use of adapted instruments. It is recommended that future research focuses on longer interventions that follow a more integrated approach in embedding technology use. This can be achieved through close working practice with teachers when designing the learning activities.

The findings of Study 3 in relation to student attitudes and achievement were not expected and as such, require further investigation. Very few mobile learning studies in maths adopted a control group that followed similar activities to the experimental group. Previous studies were far shorter than the current intervention, so it is not known how their students would have fared over time. A research design with a control group that follows the traditional method and a control group that follows similar activities with the experimental group might provide more clarity in relation to the results of Study 3.

The systematic review points out that few studies discussed students' cognitive development. In the current study, the Van Hiele model was mentioned in the discussion and there were signs in the student responses that showed higher levels of the Van Hiele model. However, such findings require further research, using instruments that particularly measure student progression across the model.

Lastly, there were several allusions to the teacher's role in the discussion chapter and in the recommendations for practice. This study has partly given the teachers a voice through an interview, but a more in-depth study on their role, the changes, stresses and challenges that they undergo in adopting new technologies would provide a more informed view.

## REFERENCES

- Afari, E., Aldridge, J. M., Fraser, B. J., & Khine, M. S. (2013). Students' perceptions of the learning environment and attitudes in game-based mathematics classrooms. *Learning Environments Research*, 16(1), 131–150. doi.org/10.1007/s10984-012-9122-6
- Aiken, L. R. (1970). Attitudes toward Mathematics. *Review of Educational Research*, 40(4), 551–596. doi.org/10.3102/00346543040004551
- Al-Mashaqbeh, I. F. I. F. (2016). iPad in elementary school math learning setting. *International Journal of Emerging Technologies in Learning*, 11(2), 48–52. doi.org/10.3991/ijet.v11i02.5053
- Alrasheedi, M., & Capretz, L. F. (2015). Determination of Critical Success Factors Affecting Mobile Learning : A Meta-Analysis Approach, 14(2), 41–51.
- Amiratashani, Z. (2010). M-learning in high school: the impact of using SMS in mathematics education-an Iranian experience. In *Fourth International Conference on Distance Learning and Education, Proceedings* (pp. 152–154). San Juan, Puerto Rico: IEEE. doi.org/10.1109/ICDLE.2010.5606018
- Barkatsas, A.T, Kasimatis, K., & Gialamas, V. (2009). Learning secondary mathematics with technology: Exploring the complex interrelationship between students' attitudes, engagement, gender and achievement. *Computers and Education*, 52(3), 562–570. doi.org/10.1016/j.compedu.2008.11.001
- Baviskar, S., Hartle, R. T., & Whitney, T. (2009). Essential criteria to characterize constructivist teaching: derived from a review of the literature and applied to five constructivist-teaching method articles. *International Journal of Science Education*, 31(4), 541–550. doi.org/10.1080/09500690701731121
- Baya'a, N., & Daher, W. (2009). Learning mathematics in an authentic mobile environment: the perceptions of students. *International Journal of Interactive Mobile Technologies (iJIM)*, 3, 6–14. doi.org/10.3991/ijim.v3s1.813
- Baya'a, N., & Daher, W. (2010). Middle school students' learning of mathematics using mobile phones : conditions and consequences. *Journal of Interactive Learning Research*, 21(2), 165–185.

- Benedek, J. & Miner, T. (2002). Measuring desirability: New methods for evaluating desirability in a usability lab setting. *Proceedings of Usability Professionals Association*.
- Boaler, J., Chen, L., Williams, C., & Cordero, M. (2016). Seeing as understanding: the importance of visual mathematics for our brain and learning. *Journal of Applied & Computational Mathematics*, 5(5), 1–17. doi.org/10.4172/2168-9679.1000325
- Borenstein, M., Hedges, L.V., Higgins, J.P.T., & Rothstein, H.R. (2009). *Introduction to Meta-Analysis*. Chichester, UK: John Wiley & Sons, Ltd. doi.org/10.1002/9780470743386
- Boticki, I., Looi, C., & Wong, L. (2010). Doing collaboration and learning fractions with mobile devices. In *Proceedings of 14th global chinese conference on computers in education* (pp. 9–15). Singapore.
- Braun, V., & Clarke, V. (2008). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3, 37–41. doi.org/http://dx.doi.org/10.1191/1478088706qp063oa
- Bray, A., Oldham, E., & Tangney, B. (2013). Technology-Mediated Realistic Mathematics Education and the Bridge21 Model : A Teaching Experiment. In *Proceedings of the Ninth Congress of the European Society for Research in Mathematics Education* (pp. 2487-2493). Prague.
- Bray, A., & Tangney, B. (2016). Enhancing student engagement through the affordances of mobile technology: a 21st century learning perspective on Realistic Mathematics Education. *Mathematics Education Research Journal*. doi.org/10.1007/s13394-015-0158-7
- Bryman, A. (2006). Integrating quantitative and qualitative research: how is it done? *Qualitative Research* 6(1), 97-113. doi.org/10.1177/1468794106058877
- Burden, K., Hopkins, P., Male, T., Martin, S., & Trala, C. (2012). *iPad Scotland Evaluation*. University of Hull. doi.org/10.3402/rlt.v20i0/14406
- Burton, C. E., Anderson, D. H., Prater, M. A., & Dyches, T. T. (2013). Video self-modeling on an iPad to teach functional math skills to adolescents with autism and intellectual disability. *Focus on Autism and Other Developmental Disabilities*, 28(2), 67-77. doi.org/10.1177/1088357613478829
- Caliskan, H. (2012). Inquiry learning. In N. Seel (Ed.), *Encyclopedia of the Sciences of Learning* (pp. 1571–1573). Boston, MA: Springer US. doi.org/10.1007/978-1-4419-1428-6\_51
- Carpenter, T.P. & Lehrer, R. (1999). Teaching and learning mathematics with understanding. In E. Fennema & T. Romberg (Eds.) *Mathematics classrooms that promote understanding*, 19-32. New Jersey: Routledge.
- Carr, J. M. (2012). Does math schievement h'APP'en when iPads and game-based learning are incorporated into fifth-grade mathematics instruction? *Journal of Information Technology Education*, 11, 269–286.
- Chan, K. K., & Leung, S. W. (2014). Dynamic geometry software improves mathematical achievement: systematic review and meta-analysis. *Journal of Educational Computing Research*, 51(3), 311–325. doi.org/10.2190/EC.51.3.c
- Chan, T. (2013). Sharing sentiment and wearing a pair of 'field spectacles' to view classroom orchestration. *Computers & Education*, 69(November), 514-516.
- Chang, C., Yan, C.-F., & Tseng, J.-S. (2012). Perceived convenience in an extended technology acceptance model : Mobile technology and English learning for college students. *Australasian Journal of Educational Technology*, 28(5), 809–826.



- Chang, K. Wu, L., Lai, S. Sung, Y. Using mobile devices to enhance the interactive learning for spatial geometry. *Interactive Learning Environments*. doi.org/10.1080/10494820.2014.948458
- Chauhan, S. (2016). A meta-analysis of the impact of technology on learning effectiveness of elementary students. *Computers & Education*, *105*, 14–30. doi.org/10.1016/j.compedu.2016.11.005
- Chen, Z. H., Liao, C. C. Y., Cheng, H. N. H., Yeh, C. Y. C., & Chan, T. W. (2012). Influence of game quests on pupils' enjoyment and goal-pursuing in math learning. *Educational Technology and Society*, *15*(2), 317–327.
- Cheon, J., Lee, S., Crooks, S. M., & Song, J. (2012). An investigation of mobile learning readiness in higher education based on the theory of planned behavior. *Computers and Education*, *59*(3), 1054–1064. doi.org/10.1016/j.compedu.2012.04.015
- Cheung, A. C. K., & Slavin, R. E. (2013). The effectiveness of educational technology applications for enhancing mathematics achievement in K-12 classrooms: A meta-analysis. *Educational Research Review*, *9*, 88–113. doi.org/10.1016/j.edurev.2013.01.001
- Cochrane, T. (2010a). An mlearning Journey: Mobile Web 2.0 Critical Success Factors. *MLearn 2010: The 9th International Conference on Mobile Learning*, (pp. 167–174). Malta.
- Cochrane, T. (2010b). Exploring mobile learning success factors. *Research in Learning Technology*, *18*(2), 133–148. doi.org/10.3402/rlt.v18i2.10758
- Cochrane, T. (2014). Critical success factors for transforming pedagogy with mobile Web 2.0. *British Journal of Educational Technology*, *45*(1), 65–82. doi.org/10.1111/j.1467-8535.2012.01384.x
- Coe, R. (2002). It's the effect size, stupid. What effect size is and why it is important. Paper presented at *Annual Conference of the British Educational Research Association*, Exeter, England. Retrieved 13 January 2015 from <https://www.leeds.ac.uk/educol/documents/00002182.htm>.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*, 2<sup>nd</sup> ed. Hillsdale, NJ: Erlbaum Associates Inc.
- Confrey, J., & Kazak, S. (2006). A thirty year reflection on constructivism in mathematics education in PME. In A. Gutierrez & P. Boero (Eds.), *Handbook of Research on the Psychology of Mathematics Education: Past, Present and Future* (pp. 305–345). Taipei: Sense Publishers.
- Cornish, L. (2009). Teaching the world's children: theory and practice in mixed-grade classes. In G. Lyons, Terry, Choi, Joon, McPhan (Ed.), *Improving Equity in Rural Education* (pp. 117–126). New England, Australia.
- Crompton, H. (2013). A historical overview of mobile learning: Toward learner-centered education. In Z. L. Berge & L. Y. Muilenburg (Eds.), *Handbook of Mobile Learning* (pp. 3–14). Florence, KY: Routledge.
- Crompton, H. (2015). Understanding angle and angle measure: a design-based research study using context aware ubiquitous computing. *International Journal of Technology in Mathematics Education*, *22*(1), 19–30.
- Crompton, H., & Burke, D. (2015). Research trends in the use of mobile learning in mathematics. *International Journal of Mobile and Blended Learning*, *7*(4), 1–15. doi.org/10.4018/IJMBL.2015100101
- Crompton, H. Burke, D. & Gregory, K. (2017). The use of mobile learning in PK-12 education: a systematic review. *Computers & Education*, *110*(July), 51-63. doi.org/10.1016/j.compedu.2017.03.013

- Crompton, H., & Traxler, J. (2015). *Mobile Learning and Mathematics*. New York: Routledge.
- Crowley, M. (1987). The van Hiele model of the development of geometric thought. In M. Lindquist (Ed.), *Learning and Teaching Geometry, K-12*, (pp 1–16). Reston, VA: National Council of Teachers of Mathematics.
- Davies, D., Jindal-Snape, D., Collier, C., Digby, R., Hay, P., & Howe, A. (2013). Creative learning environments in education—A systematic literature review. *Thinking Skills and Creativity*, 8, 80–91. doi.org/10.1016/j.tsc.2012.07.004
- Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), 319–340.
- Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: a comparison of two theoretical models. *Management Science*, 35(8), 982–1003. doi.org/http://dx.doi.org/10.1287/mnsc.35.8.982
- Deater-Deckard, K., El Mallah, S., Chang, M., Evans, M. A., & Norton, A. (2014). Student behavioral engagement during mathematics educational video game instruction with 11–14 year olds. *International Journal of Child-Computer Interaction*, 2(3), 101–108. doi.org/10.1016/j.ijcci.2014.08.001
- Di Martino, P., & Zan, R. (2010). “Me and maths”: Towards a definition of attitude grounded on students’ narratives. *Journal of Mathematics Teacher Education*, 13(1), 27–48. doi.org/10.1007/s10857-009-9134-z
- Di Martino, P. & Zan, R. (2015). The Construct of Attitude in Mathematics Education. In B. Pepin & B. Roesken-Winter (Eds.), *From beliefs to dynamic affect systems in mathematics education* (pp. 95-117). Cham: Springer International Publishing. doi.org/10.1007/978-3-319-06808-4
- Dickinson, P., & Hough, S. (2012). *Using Realistic Mathematics Education in UK classrooms*. Retrieved from [http://mei.org.uk/files/pdf/rme\\_impact\\_booklet.pdf](http://mei.org.uk/files/pdf/rme_impact_booklet.pdf)
- Drennan, J. & Hyde, A. (2008) Controlling response shift bias: the use of the retrospective pre-test design in the evaluation of a master's programme. *Assessment and Evaluation in Higher Education*, 33(6), 699-709.
- 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). Cham: Springer International Publishing. doi.org/10.1007/978-3-319-17187-6\_8
- Drijvers, P., Kieran, C., Mariotti, M.-A., Ainley, J., Andresen, M., Chan, Y. C., ... Meagher, M. (2009). Integrating technology into mathematics education: theoretical perspectives. In C. Hoyles & J. Lagrange (Eds.), *Mathematics Education and Technology-Rethinking the Terrain* (pp. 89–132). New York: Springer. doi.org/10.1007/978-1-4419-0146-0\_7
- Education Scotland (n.d.). *Curriculum for excellence: numeracy and mathematics experiences and outcomes*. Retrieved from <https://education.gov.scot/Documents/numeracy-maths-eo.pdf>.
- Eliasson, J., Nouri, J., Ramberg, R., & Pargman, T. C. (2010). Design heuristics for balancing visual focus on devices in formal mobile learning activities. *The 9th International Conference on Mobile Learning*. Malta.
- Else-Quest, N. M., Hyde, J. S., & Linn, M. C. (2010). Cross-national patterns of gender differences in mathematics: A meta-analysis. *Psychological Bulletin*, 136(1), 103–127. doi.org/10.1037/a0018053
- Engel, G., & Green, T. (2011). Cell phones in the classroom: Are we dialing up disaster? *TechTrends*, 55(2), 39–45. doi.org/10.1007/s11528-011-0482-z
- Engestrom, Y., Miettinen, R., & Punamaki, R. (1999). *Perspectives on Activity Theory*.

- Cambridge: Cambridge University Press.
- Ernest, P. (2010). Reflections on Theories of Learning. In B. Sriraman & L. English (Eds.) *Theories of Mathematics Education* (pp. 39–47). Berlin, Heidelberg: Springer Berlin Heidelberg. doi.org/10.1007/978-3-642-00742-2\_4
- Evidence for Policy and Practice Information and Co-ordinating Centre. (2007). *EPPI-Centre methods for conducting systematic reviews*. Retrieved from <http://eppi.ioe.ac.uk/cms/>.
- Eynde, P.O., Corte, E., & Verschaffel, L. (2006). Accepting emotional complexity: A socio-constructivist perspective on the role of emotions in the mathematics classroom. *Educational Studies in Mathematics*, 63(2), 193–207. doi.org/10.1007/s10649-006-9034-4
- Fabian, K., & MacLean, D. (2014). Keep taking the tablets? Assessing the use of tablet devices in learning and teaching activities in the further education sector. *Research in Learning Technology*, 22. doi.org/10.3402/rlt.v22.22648
- Fabian, K. Topping, K.J, Barron, I.B. (2016). Mobile technology and mathematics: effects on students' attitudes, engagement and achievement. *Journal of Computers in Education* 3(1), 77-104. doi.org/10.1007/s40692-015-0048-8
- Fast, L. A., Lewis, J. L., Bryant, M. J., Bocian, K. A., Cardullo, R. A., Rettig, M., & Hammond, K. A. (2010). Does math self-efficacy mediate the effect of the perceived classroom environment on standardized math test performance? *Journal of Educational Psychology*, 102(3), 729–740. doi.org/10.1037/a0018863
- Franklin, T., & Peng, L.W. (2008). Mobile math: math educators and students engage in mobile learning. *Journal of Computing in Higher Education*, 20(2), 69–80. doi.org/10.1007/s12528-008-9005-0
- Frohberg, D., Göth, C., & Schwabe, G. (2009). Mobile learning projects - a critical analysis of the state of the art: Original article. *Journal of Computer Assisted Learning*, 25(4), 307–331. doi.org/10.1111/j.1365-2729.2009.00315.x
- Goldman, S., Pea, R., & Maldonado, H. (2004). Emerging social engineering in the wireless classroom. In *Proceedings of the 6th international conference on Learning sciences* (pp. 222–229). California, USA.
- Government Social Research Unit (n.d.) *GSR Professional Guidance: Ethical Assurance for Social Research in Government*. Retrieved 7 July 2014 from [https://gov.uk/government/uploads/system/uploads/attachment\\_data/file/515296/ethics\\_guidance\\_tcm6-5782.pdf](https://gov.uk/government/uploads/system/uploads/attachment_data/file/515296/ethics_guidance_tcm6-5782.pdf).
- Grace-Martin, K. (2013) *Analyzing Pre-Post Data with Repeated Measures or ANCOVA*. Retrived Feb 2, 2016 from [www.theanalysisfactor.com/pre-post-data-repeated-measures](http://www.theanalysisfactor.com/pre-post-data-repeated-measures).
- Green, S. (2011). Formative assessment. In S. Goldstein & J. Naglieri (Eds.), *Encyclopedia of Child Behavior and Development* (pp. 661–662). Boston, MA: Springer US. doi.org/10.1007/978-0-387-79061-9\_3141
- Ha, I., Yoon, Y., & Choi, M. (2007). Determinants of adoption of mobile games under mobile broadband wireless access environment. *Information and Management*, 44(3), 276–286. doi.org/10.1016/j.im.2007.01.001
- Hannula, M. S., Di Martino, P., Pantziara, M., Zhang, Q., Morselli, F., Heyd-Metzuyanım, E., ... Goldin, G. A. (2016). *Attitudes, Beliefs, Motivation, and Identity in Mathematics Education. Attitudes, Beliefs, Motivation and Identity in Mathematics Education: An Overview of the Field and Future Directions*. Switzerland: Springer Nature. doi.org/10.1007/978-3-319-32811-9\_1
- Hansen A. (2014). *Children's Error in Mathematics*. London: Sage.

- Harris, A. (2000). Symmetry. St. Martin's College. Retrieved 26 November 2013 from <http://ictedusrv.cumbria.ac.uk/maths/pgdl/unit9/SYMMETRY.PDF>.
- Heflin, H., Shewmaker, J., & Nguyen, J. (2017). Impact of mobile technology on student attitudes, engagement, and learning. *Computers & Education, 107*, 91–99. doi.org/10.1016/j.compedu.2017.01.006
- Herrington, J., & Oliver, R. (1995). Critical characteristics of situated learning : Implications for the instructional design of multimedia. In ASCILITE 1995 Conference, (pp. 253–262). Melbourne, Australia.
- Herrington, J., Reeves, T.C. & Oliver, R. (2009). *A practical guide to authentic e-learning*. New York: Routledge.
- Higgins, J. & Green, S. *Cochrane handbook for systematic reviews of interventions*. Chichester: John Wiley & Sons, 2011
- Hilton, A. (2016). Engaging primary school students in mathematics: can iPads make a difference? *International Journal of Science and Mathematics Education, 1–21*. doi.org/10.1007/s10763-016-9771-5
- Hirsh-Pasek, K., Zosh, J. M., Golinkoff, R. M., Gray, J. H., Robb, M. B., & Kaufman, J. (2015). Putting Education in “Educational” Apps. *Psychological Science in the Public Interest*. doi.org/10.1177/1529100615569721
- Hossain, S., Mendick, H., & Adler, J. (2013). Trouble "understanding mathematics in depth:" its roles in the identify work of student teachers in England. *Educational Studies in Mathematics, 84*(1), 35-48.
- Houghton Mifflin Harcourt (2012). *HMH Fuse Algebra I: Results of a yearlong algebra pilot in Riverside, CA*. Retrieved August, 24, 2013 from <http://www.stcolumbasspringwood.catholic.edu.au/SiteData/191/UserFiles/Resources/Results-of-a-yearlong-Algebra-pilot.pdf>
- Huang, J., Lin, Y., & Chuang, S. (2007). Elucidating user behavior of mobile learning. *The Electronic Library, 25*(5), 585–598. doi.org/10.1108/02640470710829569
- Huang, S., Wu, T.-T., Chen, H., Yang, P.-C., & Huang, Y.-M. (2012). Mathematics assisted instruction system of M/U-learning environment. In *2012 IEEE Seventh International Conference on Wireless, Mobile and Ubiquitous Technology in Education* (pp. 301–305). IEEE. doi.org/10.1109/WMUTE.2012.72
- Hwang, G., & Tsai, C. (2011). Research trends in mobile and ubiquitous learning: A review of publications in selected journals from 2001 to 2010. *British Journal of Educational Technology, 42*(4). doi.org/10.1111/j.1467-8535.2011.01183.x
- Hwang, G., & Wu, P. (2014). Applications, impacts and trends of mobile technology-enhanced learning: a review of 2008-2012 publications in selected SSCI journals. *International Journal of Mobile Learning and Organisation, 8*(2), 83. doi.org/10.1504/IJMLO.2014.062346
- Hwang, W.Y., Lin, L., Ochirbat, A., Shih, T. K., & Kumara, W. G. C. W. (2015). Ubiquitous Geometry. *Journal of Educational Computing Research, 52*(1), 26–49. doi.org/10.1177/0735633114568852
- Hyde, J. S., Fennema, E., Ryan, M., Frost, L. A., & Hopp, C. (1990). Gender comparisons of mathematics attitudes and affect: A meta-analysis. *Psychology of Women Quarterly, 14*(3), 299–324. doi.org/10.1111/j.1471-6402.1990.tb00022.x
- ICF Consulting Services Ltd. (2015). Literature review on the impact of digital technology on learning and teaching. *Social Research Series, 61*. Retrieved from <http://www.gov.scot/Resource/0048/00489224.pdf>
- Jaciw, A., Toby, M., & Ma, B. (2012). Conditions for the effectiveness of a tablet-based algebra program. In *Society for research on educational effectiveness*. Retrived from <https://eric.ed.gov/?id=ED535506>

- Johnson, R.B., Onwuegbuzie, A.J., Turner, L.A. (2007). Toward a definition of mixed methods research. *Journal of mixed methods research*, 1(2), 112-133.
- JISC (2011). *Mobile learning: A practical guide for educational organisations planning to implement a mobile learning initiative*. Retrieved 10 August 2013 from [http://jisc.ac.uk/guides/mobile learning](http://jisc.ac.uk/guides/mobile%20learning).
- Jonassen, D., & Hung, W. (2012). Problem-based learning. In N. Seel (Ed.), *Encyclopedia of the Sciences of Learning* (pp. 2687–2690). Boston, MA: Springer US. doi.org/10.1007/978-1-4419-1428-6\_210
- Kahveci, M. (2010). Students' perceptions to use technology for learning: Measurement integrity of the modified Fennema-Sherman attitudes scales. *Turkish Online Journal of Educational Technology*, 9(1), 185–201.
- Kaloo, V., & Mohan, P. (2011a). An investigation into mobile learning for high school mathematics. *International Journal of Mobile and Blended Learning*, 3(3), 59--76. doi:10.4018/jmbl.2011070105
- Kaloo, V., & Mohan, P. (2011b). Correlation between student performance and use of an mLearning Application for high school mathematics. In *2011 IEEE 11th International Conference on Advanced Learning Technologies* (pp. 174–178). Georgia, USA: IEEE. doi.org/10.1109/ICALT.2011.57
- Kearney, M., Schuck, S., Burden, K., & Aubusson, P. (2012). Viewing mobile learning from a pedagogical perspective. *Research in Learning Technology*, 20(1), 1–17. doi.org/10.3402/rlt.v20i0/14406
- Kebritchi, M., Hirumi, A., & Bai, H. (2010). The effects of modern mathematics computer games on mathematics achievement and class motivation. *Computers and Education*, 55(2), 427–443. doi.org/10.1016/j.compedu.2010.02.007
- Kerrigan, M., Blackburn, R., Force, S., Amin, Z., James, K., Yorke, J., ... Scott-Jones, E. (2013). *The student experience of using iPads to enhance undergraduate laboratory teaching. Mobile learning: how mobile technologies: good practice guide*. Retrieved from [http://www.ucisa.ac.uk/~media/Files/publications/case\\_studies/ASG\\_Effective\\_Use\\_Mobile Learning](http://www.ucisa.ac.uk/~media/Files/publications/case_studies/ASG_Effective_Use_Mobile_Learning)
- Keskin, N. O., & Metcalf, D. (2011). The current perspectives, theories and practices of mobile learning. *Turkish Online Journal of Educational Technology*, 10(2), 202-208.
- Ketamo, H. (2003). An adaptive geometry game for handheld devices. *Educational Technology and Society*, 6(1), 83–95.
- Kiger, D., Herro, D., & Prunty, D. (2012). Examining the influence of a mobile learning intervention on third grade math achievement. *Journal of Research on Technology in Education*, 45(1), 61–82.
- Kiili, K., Devlin, K., Perttula, A., & Tuomi, P. (2015). Using video games to combine learning and assessment in mathematics education. *International Journal of Serious Games*, 2(4), 37–55. doi.org/10.17083/ijsg.v%vi%i.98
- Kim, P. (2011). Stay out of the way! My kid is video blogging through a phone!: A lesson learned from math tutoring social media for children in underserved communities. *International Journal of Online Pedagogy and Course Design*, 1(1), 50–63.
- Kim, P., Buckner, E., Kim, H., Makany, T., Taleja, N., & Parikh, V. (2012). A comparative analysis of a game-based mobile learning model in low-socioeconomic communities of India. *International Journal of Educational Development*, 32(2), 329–340. doi.org/10.1016/j.ijedudev.2011.05.008

- Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist, 41*(2), 75–86.
- Knuchel, C. (2004). Teaching Symmetry in the Elementary Curriculum. *The Mathematics Enthusiast, 1*(1), 3–8.
- Knuth, R. A., & Cunningham, D. J. (1993). Tools for constructivism. In *Designing Environments for Constructive Learning* (pp. 163–188). Berlin, Heidelberg: Springer Berlin Heidelberg. doi.org/10.1007/978-3-642-78069-1\_9
- Kong, S. C. (2008). Collaborative learning in a mobile technology supported environment: A case study on analyzing the interactions. In *Fifth IEEE International Conference on Wireless, Mobile, and Ubiquitous Technology in Education* (pp. 167–169). China: IEEE. doi.org/10.1109/WMUTE.2008.39
- Kong, S. C. (2012). Using mobile devices for learning in school education. In *2012 IEEE Seventh International Conference on Wireless, Mobile and Ubiquitous Technology in Education* (pp. 172–176). Kagawa, Japan: IEEE. doi.org/10.1109/WMUTE.2012.39
- Kong, S. C., & Li, C. (2007). A study of using a cognitive tool in a mobile technology supported classroom. In *Proceedings of the 2007 conference on Supporting Learning Flow through Interactive Technologies*, (pp. 455–462). Netherlands: IOS Press Amsterdam.
- Kukulka-Hulme, A. (2007). Mobile usability in educational contexts: what have we learnt? *The International Review of Research in Open and Distributed Learning, 8*(2), 1–9. doi.org/10.19173/irrodl.v8i2.356
- Kucirkova, N., Messer, D. Sheehy, K & Panadero, C. (2014). Children's engagement with educational iPad apps: insights from a Spanish classroom. *Computers & Education 71*(February), 175-184.
- Kurti, A., Spikol, D., & Milrad, M. (2008). Bridging outdoors and indoors educational activities in schools with the support of mobile and positioning technologies. *International Journal of Mobile Learning and Organisation, 2*(2), 166-186. doi.org/10.1504/IJMLO.2008.019767
- Lagrange, J.-B., Artigue, M., Laborde, C., & Trouche, L. (2003). Technology and mathematics education: A multidimensional study of the evolution of research and innovation. In *Second International Handbook of Mathematics Education* (pp. 237–269). Dordrecht: Springer Netherlands. doi.org/10.1007/978-94-010-0273-8\_9
- Lai, A.F., Lai, H., Shen, V.R.L., Tsai, I.C., & Chou, A. (2012). The evaluation of two-stage mobile learning guidance of math in an elementary school. In *2012 IEEE Seventh International Conference on Wireless, Mobile and Ubiquitous Technology in Education* (pp. 282–286). Kagawa, Japan: IEEE. doi.org/10.1109/WMUTE.2012.68
- Lan, Y.J., Sung, Y.T., Tan, N., Lin, C.P., & Chang, K.E. (2010). Mobile-device-supported problem-based computational estimation instruction for elementary school students. *Educational Technology, 13*(3), 55–69.
- Larkin, K and Calder (2016). Mathematics education and mobile technologies. *Mathematics Education Research Journal, 28*(1), 1-7. doi.org/10.1007/s13394-015-0167-6.

- Larkin, K. and Jorgensen, R. (2016). I have maths: why do we need to do maths? Using iPad video diaries to investigate attitudes and emotions towards mathematics in Year 3 and Year 6 students. *International Journal of Science and Mathematics Education*, 14(5), 925-944.
- Laurillard, D. (2007). Pedagogical forms of mobile learning: framing research questions. *Mobile Learning: Towards a Research Agenda*, (2007), 153–175. Retrieved from [http://eprints.ioe.ac.uk/627/1/Mobile\\_C6\\_Laurillard.pdf](http://eprints.ioe.ac.uk/627/1/Mobile_C6_Laurillard.pdf)
- Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation Developmental Psychology*. Cambridge: Cambridge University Press.
- Learning2Go. (2007). *Learning2Go School Case Study Report 2006-2007*.
- Lee, J., Luchini, K., Michael, B., Norris, C., & Soloway, E. (2004). More than just fun and games: assessing the value of educational video games in the classroom. In *Conference on Human Factors in Computing Systems* (pp. 1375–1378). Vienna. doi.org/http://doi.acm.org/10.1145/985921.986068
- Lewis, J.R. (1995). IBM computer usability satisfaction questionnaires: psychometric evaluation and instructions for use. *International Journal of Human-Computer Interaction*, 7(1), 57-78.
- Leikin, R., Berman, A., & Zaslavsky, O. (2000). Learning Through Teaching : The Case of Symmetry. *Mathematics Education Research Journal Learning*, 12(1), 18–36.
- Li, Q., & Ma, X. (2010). A meta-analysis of the effects of computer technology on school students' mathematics learning. *Educational Psychology Review*, 22(3), 215–243. doi.org/10.1007/s10648-010-9125-8
- Linnenbrink, E. A., & Pintrich, P. R. (2003). The role of self-efficacy beliefs instudent engagement and learning inthe classroom. *Reading and Writing Quarterly*, 19(2), 119–137. doi.org/10.1080/10573560308223
- Liao, C.C.Y., Chen, Z.H., Cheng, H.N.H., Chen, F.C., & Chan, T.W. (2011). My-mini-pet: a handheld pet-nurturing game to engage students in arithmetic practices. *Journal of Computer Assisted Learning*, 27(1), 76–89. doi.org/10.1111/j.1365-2729.2010.00367.x
- Ligorio, B. (2008). Mobile phones to enhance reflection upon collaborative problem-solving. In *Beyond Knowledge: The Legacy of Competence: Meaningful Computer-based Learning Environments* (pp. 67–73). Dordrecht: Springer Netherlands. doi.org/10.1007/978-1-4020-8827-8\_10
- Lim, C. S., Tang, K. N., & Kor, L. K. (2012). Drill and practice in learning (and beyond). In N. Seel (Ed.), *Encyclopedia of the Sciences of Learning* (pp. 1040–1042). Boston, MA: Springer US. doi.org/10.1007/978-1-4419-1428-6\_706
- Lim, S.Y., & Chapman, E. (2013). Development of a short form of the attitudes towards mathematics inventory. *Educational Studies in Mathematics* 82(1), pp. 145-164.
- Lipsey, M. W., & Wilson, D. B. (1993). The efficacy of psychological, educational, and behavioral treatment: Confirmation from meta-analysis. *American Psychologist*, 48(12), 1181–1209. doi.org/10.1037/0003-066X.48.12.1181
- Liu, S.H., & Lee, G.G. (2013). Ipad infuse creativity in solid geometry teaching. *Turkish Online Journal of Educational Technology*, 12(2), 177–192.
- Liu, T. C. (2007). Teaching in a wireless learning environment : A case study. *Educational Technology & Society*, 10(1), 107–123.
- Lonsdale, P. (2011). *Design and evaluation of mobile games to support active and reflective learning outdoors*. Retrieved from <http://etheses.nottingham.ac.uk/2076/>
- Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of mixed methods research*, 1(2), 112-133.

- Ma, X. & Kishor, N. (1997). Assessing the relationship between attitude toward mathematics and achievement in mathematics: a meta-analysis. *Journal for Research in Mathematics Education*, 28(1), 26-47.
- Ma, H. Lee, D. Lin, S. Wu, D. (2015). A study of Van Hiele of geometric thinking among 1<sup>st</sup> through 6<sup>th</sup> graders. *Eurasia Journal of Mathematics, Science and Technology Education* 11(9), 1181-1196. doi.org/10.12973/eurasia.2015.1412a
- MacCallum, K., & Jeffrey, L. (2013). The influence of students' ICT skill and their adoption of mobile learning. *Australasian Journal of Educational Technology*, 29(3), 303–314. doi.org/10.1234/ajet.v29i3.298
- Mahamad, S., Ibrahim, M.N., Ab.Malek Foad, M. I., & Mohd Taib, S. (2008). Open source Implementation of M-Learning for Primary School in Malaysia. *International Journal of Human and Social Sciences*, 3(4), 309–313.
- Mahon, K. (2014). *Creating a content strategy for mobile devices in the classroom*. Center on Innovations in Learning, Temple University.
- Main, S., & O'Rourke, J. (2011). New directions for traditional lessons: Can handheld game consoles enhance mental mathematics skills? *Australian Journal of Teacher Education*, 36(2), 43–55.
- Mason, M. M. (1997). The van Hiele model of geometric understanding and mathematically talented students. *Journal for Education of the Gifted*, 21(1), 39–53.
- Mata, M., Monteiro, V., & Peixoto, F. (2012). Attitudes towards mathematics: effects of individual, motivational, and social support factors. *Child Development Research*, 2012, 1–10. doi.org/10.1155/2012/876028
- Mayes, T., & De Freitas, S. (2004). *Review of e-learning theories, frameworks and models*. London. Retrieved from <http://www.jisc.ac.uk/whatwedo/programmes/elearningpedagogy/outcomes.aspx>
- McCabe, M., & Tedesco, S. (2011). Building capacity for mathematics: Using m-learning to facilitate pedagogical practices among educational stakeholders. In *EdMedia: World Conference on Educational Media and Technology* (pp. 1579–1584). Montreal, Canada.
- McDonald, G. (2013). Does size matter? The impact of student–staff ratios. *Journal of Higher Education Policy and Management*, 35(6), 652–667. doi.org/10.1080/1360080X.2013.844668
- Meletiou-Mavrotheris, M., Mavrou, K., & Papanistodemou, E. (2015). *Integrating touch-enabled and mobile devices into contemporary mathematics education*. IGI Global. doi.org/10.4018/978-1-4666-8714-1
- Merikivi, J., Tuunainen, V., & Nguyen, D. (2017). What makes continued mobile gaming enjoyable? *Computers in Human Behavior*, 68, 411–421. doi.org/10.1016/j.chb.2016.11.070
- Miller, D.J., & Robertson, D.P. (2010). Using a games console in the primary classroom: Effects of “Brain Training” programme on computation and self-esteem. *British Journal of Educational Technology*, 41(2), 242–255. doi.org/10.1111/j.1467-8535.2008.00918.x
- Miller, D.J., & Robertson, D.P. (2011). Educational benefits of using game consoles in a primary classroom: A randomised controlled trial. *British Journal of Educational Technology*, 42(5), 850–864. doi.org/10.1111/j.1467-8535.2010.01114.x
- Molenaar, I., & Knoop van Campen, C. (2016). Learning analytics in practice The effects of adaptive educational technology Snappet on students' arithmetic skills. *Proceedings of the 6th International Conference on Learning Analytics & Knowledge - LAK '16*, 10–11. doi.org/10.1145/2883851.2883892



- Montrieux, H., Schellens, T., Van Landeghem, J., & Mouton, T. (2016). Introducing tablet devices during mathematics education: is it really a magical learning tool? *International Scientific Researches Journal*, 72(7), 393–410.
- Moore, M.G. (1997). Theory of transactional distance. *Theoretical Principles of Distance Education*, 22–38. doi.org/10.2307/3121685
- Moran, D., & Malott, R. (2004). *Evidence-based educational methods*. San Diego, CA: Elsevier Academic Press.
- Morris, M. G., & Dillon, A. (1997). How User Perceptions Influence Software Use. *IEEE Software*, 14(4), 58–65.
- Morris, S. (2008). Estimating effect sizes from pretest-posttest-control group designs. *Organizational Research Methods* 11(2), 364-386. doi:10.1177/1094428106291059
- Moyer-packenham, P. S., Salkind, G., & Bolyard, J. J. (2008). Virtual Manipulatives Used by K-8 Teachers for Mathematics Instruction : Considering Mathematical , Cognitive , and Pedagogical Fidelity Cognitive , and Pedagogical Fidelity. *Contemporary Issues in Technology and Teacher Education*, 8(3).
- Musti-Rao, S., & Plati, E. (2015). Comparing two classwide interventions: Implications of using technology for increasing multiplication fact fluency. *Journal of Behavioral Education*, 24(4), 418–437. doi.org/10.1007/s10864-015-9228-x
- Naismith, L., & Corlett, D. (2006). Reflections on success : A retrospective of the mLearn conference series 2002-2005. In *mLearn 2006: Across generations and cultures*. Banff, Canada.
- Naismith, L., Lonsdale, P., Vavoula, G., & Sharples, M. (2004). *Literature review in mobile technologies and learning*. Futurelab. Retrieved from <https://telearn.archives-ouvertes.fr/hal-00190143/document>.
- National Council of Teachers in Mathematics (2000). *Principles and Standards for School Mathematics*. Reston, VA: NCTM.
- Nielsen, J. (1994). *Usability Engineering*. London: Academic Press, Inc.
- Nerantzi, C., Wilson, J., Munro, N., Lace-Costigan, G., & Currie, N. (2013). Warning! modeling effective mobile learning is infectious. In *Mobile learning: how mobile technologies: good practice guide* (pp. 11–16). UCISA.
- Ng, O. L., & Sinclair, N. (2015). Young children reasoning about symmetry in a dynamic geometry environment. *ZDM*, 47, 421–434. doi.org/10.1007/s11858-014-0660-5
- Ng, W., & Nicholas, H. (2013). A framework for sustainable mobile learning in schools. *British Journal of Educational Technology*, 44(5), 695–715. doi.org/10.1111/j.1467-8535.2012.01359.x
- Nikou, S. A., & Economides, A. A. (2017). Mobile-based assessment: Investigating the factors that influence behavioral intention to use. *Computers & Education*, 109, 56–73. doi.org/10.1016/j.compedu.2017.02.005
- NO LIMIT (2002). *Math Classroom Observation Checklist*. Retrieved 13 December 2015 from [https://www.andrews.edu/sed/leadership\\_dept/webinars/presentationdocuments/math\\_classroom\\_observation\\_checklist.doc](https://www.andrews.edu/sed/leadership_dept/webinars/presentationdocuments/math_classroom_observation_checklist.doc)
- Nordin, N., Embi, M. A., & Yunus, M. M. (2010). Mobile learning framework for lifelong learning. *Procedia - Social and Behavioral Sciences*, 7(2), 130–138. doi.org/10.1016/j.sbspro.2010.10.019

- Ocuppaugh, J., Baker, R.S., Rodrigo, M.M.T (2015). *Baker Rodrigo Ocuppaugh Monitoring Protocol (BROMP) 2.0 Technical and Training Manual*. Technical Report. New York: NY: Teachers College, Columbia University. Retrieved 13 December 2015 from <http://www.upenn.edu/learninganalytics/ryanbaker/BROMP.pdf>
- O'Malley, C., Vavoula, G., Glew, J. P., Taylor, J., Sharples, M., Lonsdale, P., ... Sharples, M. (2005). *Guidelines for learning / teaching / tutoring in a mobile environment*. Retrieved from <https://hal.archives-ouvertes.fr/hal-00696244>
- O'Malley, P., Jenkins, S., M., Wesley, B., Donehower, Rabuck, D. & Lewis, E. (2013). Effectiveness of Using iPads to Build Math Fluency Effectiveness of Using iPads to Build Math Fluency. In *Council for Exceptional Children Annual Meeting*. San Antonio, Texas.
- OECD (2015). *The ABC of Gender Equality in Education*. OECD Publishing (Vol. PISA). doi.org/10.1787/9789264229945-en
- Olsen, A. K. (2016). The effects of technology on academic motivation and achievement in a middle school mathematics classroom. In *NERA Conference Proceedings*. Helsinki, Finland.
- Padilla-Meléndez, A., del Aguila-Obra, A.R., & Garrido-Moreno, A. (2013). Perceived playfulness, gender differences and technology acceptance model in a blended learning scenario. *Computers & Education*, 63, 306–317. doi.org/10.1016/j.compedu.2012.12.014
- Pajares, F., & Graham, L. (1999). Self-efficacy, motivation constructs, and mathematics performance of entering middle school students. *Contemporary Educational Psychology*, 24, 124–139. doi.org/10.1006/ceps.1998.0991
- Papadakis, S., Michail, K., Kalogiannakis, M., & Zaranis, N. (2016). Comparing tablets and PCs in teaching mathematics : An attempt to improve mathematics competence in early childhood education. *Preschool and Primary Education*, 4(2), 241–253.
- Papert, S. (1980). Computer-based microworlds as incubators for powerful ideas. In *The computer in the school: Tutor, tool, tutee* (pp. 203–210).
- Park, S. Y., Nam, M., & Cha, S. (2012). University students' behavioral intention to use mobile learning: Evaluating the technology acceptance model. *British Journal of Educational Technology*, 43(4), 592–605. doi.org/10.1111/j.1467-8535.2011.01229.x
- Park, Y. (2011). A pedagogical framework for mobile learning: Categorizing educational applications of mobile technologies into four types. *The International Review of Research in Open and Distributed Learning*, 12(2), 78–102.
- Patten, B., Sanchez, I. A., & Tangney, B. (2006). Designing collaborative, constructionist and contextual applications for handheld devices. *Computers and Education*, 46(3), 294–308. doi.org/10.1016/j.compedu.2005.11.011
- Pask, G. (1975). *Conversation, cognition and learning*. Amsterdam: Elsevier.
- Pekrun, R., Lichtenfel, H., Marsh, H., Murayama, K. & Goetz, T. (2017). Achievement emotions and academic performance: longitudinal models of reciprocal effects. *Child Development*. doi:10.1111/cdev.12704.
- Perry, D. R., & Steck, A. K. (2015). Increasing student engagement, self-efficacy, and meta-cognitive self-regulation in the high school geometry classroom: do iPads help? *Computers in the Schools*, 32(2), 122–143. doi.org/10.1080/07380569.2015.1036650
- Petticrew, M., & Roberts, H. (2008). *Systematic reviews in the social sciences*. Oxford, UK: Blackwell Publishing Ltd. doi.org/10.1002/9780470754887

- Pierce, R. Stacey, K. & Barkatsas, A. A scale for monitoring students' attitudes to learning mathematics with technology. *Computers & Education*, 48(2), 285-300.
- Pitchford, N. J., Savage, R. S., & Fletcher-flinn, C. M. (2015). Development of early mathematical skills with a tablet intervention : a randomized control trial in Malawi, 6(April), 1–12. doi.org/10.3389/fpsyg.2015.00485
- Pollara, P., & Broussard, K. K. (2011). Student Perceptions of Mobile Learning : A Review of Current Research. In *Proceedings of Society for Information Technology @ Teacher Education International Conference 2011* (pp. 1643–1650). Chesapeake, VA.
- Pope, H., & Mangram, C. (2015). Wuzzit trouble: the influence of a digital math game on student number sense. *International Journal of Serious Games*, 2(4). doi.org/10.17083/ijsg.v2i4.88
- Project Tomorrow. (2010). Students leverage the power of mobile devices through the Project K-Nect Mobile Learning Initiative in Onslow County. Retrieved from [http://www.tomorrow.org/docs/Project\\_k-Nect\\_Evaluationreport\\_Final\\_Jul7.pdf](http://www.tomorrow.org/docs/Project_k-Nect_Evaluationreport_Final_Jul7.pdf).
- Project Tomorrow. (2011). *Evaluation Report of the Impact of Project K-Nect on Teaching and Learning*. Retrieved from [http://www.tomorrow.org/docs/ProjectKNect\\_EvaluationReport\\_Mar2011.pdf](http://www.tomorrow.org/docs/ProjectKNect_EvaluationReport_Mar2011.pdf).
- Puentadura, R. (2006). Transformation, technology, and education?. Retrieved July 31, 2013, from <http://hippasus.com/resources/tte/>
- Quinn, C. (2000). mLearning: Mobile, Wireless, In-Your-Pocket Learning. Retrieved January 1, 2017, from <http://www.linezine.com/2.1/features/cqmmwiyp.htm>
- Rabah, J. (2016). *At the Intersection of gender & technology : A Meta-Analysis*. Concordia University.
- Reed, H. C., Drijvers, P., & Kirschner, P. A. (2010). Effects of attitudes and behaviours on learning mathematics with computer tools. *Computers and Education*, 55(1), 1–15. doi.org/10.1016/j.compedu.2009.11.012
- Rehm, M., Stan, C., Wøldike, N.P., & Vasilarou, D. (2015). Towards Smart City Learning: Contextualizing Geometry Learning with a Van Hiele Inspired Location-Aware Game. In K. Chorianopoulos, M. Divitini, J. Baalsrud Hauge, L. Jaccheri, & R. Malaka (Eds.), *Entertainment Computing - ICEC 2015* (pp. 399–406). Cham: Springer International Publishing. doi.org/10.1007/978-3-319-24589-8\_32
- Riconscente, M. M. (2013). Results From a Controlled Study of the iPad Fractions Game Motion Math. *Games and Culture*, 8(4), 186–214. doi.org/10.1177/1555412013496894
- Roberts, D.L., Leung, A.Y.L., & Lins, A.F. (2012). From the Slate to the Web: Technology in the Mathematics Curriculum. In M.A. Clements, A.J. Bishop, C. Keitel, J. Kilpatrick, & F. K. S. Leung (Eds.), *Third International Handbook of Mathematics Education* (pp. 525–547). New York, NY: Springer New York. doi.org/10.1007/978-1-4614-4684-2\_17
- Roberts, N., & Butcher, N. (2009). *Evaluation of the Imfundo yami / yethu Project : Executive Summary*. Johannesburg.
- Roberts, N., & Vänskä, R. (2011). Challenging assumptions: mobile learning for mathematics project in South Africa. *Distance Education*, 32(2), 243–259. doi.org/10.1080/01587919.2011.584850
- Rosas, R., Nussbaum, M., Cumsille, P., Marianov, V., & Lo, X. (2003). Beyond Nintendo: design and assessment of educational video games for first and second grade students. *Computers & Education*, 40, 71–94.

- Roschelle, J., Rafanan, K., Bhanot, R., Estrella, G., Penuel, B., Nussbaum, M., & Claro, S. (2010). Scaffolding group explanation and feedback with handheld technology: impact on students' mathematics learning. *Educational Technology Research and Development*, 58(4), 399–419. doi.org/10.1007/s11423-009-9142-9
- Rowe, K. (2006). Effective teaching practices for students with and without learning difficulties: Constructivism as a legitimate theory of learning and of teaching? *Student Learning Processes*, 1–24. doi.org/10.1080/19404150609546813
- Ryan, J., & Williams, J. (2007). *Children's Mathematics 4-15 : Learning From Errors and Misconceptions*. Maidenhead: McGraw-Hill Education.
- Sáinz, M., & Eccles, J. (2012). Self-concept of computer and math ability: Gender implications across time and within ICT studies. *Journal of Vocational Behavior*, 80(2), 486–499. doi.org/10.1016/j.jvb.2011.08.005
- Savelsbergh, E. R., Prins, G. T., Rietbergen, C., Fechner, S., Vaessen, B. E., Draijer, J. M., & Bakker, A. (2016). Effects of innovative science and mathematics teaching on student attitudes and achievement : A meta-analytic study. *Educational Research Review*, 19, 158–172. doi.org/10.1016/j.edurev.2016.07.003
- Sawaya, S.F. & Putnam, R.T. (2015). Using mobile devices to connect mathematics to out-of-school contexts. In J. Traxler & H. Crompton (Eds.) *Mobile Learning and Mathematics*, pp. 9-19. New York: Routledge.
- Scalise, K. (2007). Differentiated e-Learning: what it is and five approaches. *International Journal of Learning Technology*, 3(2), 169-182.
- Schacter, J. & Jo, B. (2016). Improving low-income preschoolers mathematics achievement with Math Shelf, a preschool tablet computer curriculum. *Computers in Human Behavior*, 55(February), 223-229. doi.org/10.016/j.chb.2015.09.013
- Scottish Government (2014). *Determining Primary School Capacity - Guidance*. Retrieved 16 February 2016 from [www.gov.scot/Publications/2014/10/6749/2](http://www.gov.scot/Publications/2014/10/6749/2)
- Scottish Government (2016). *Transforming Scotland into a maths positive nation: the final report of making maths count group*. Retrieved 02 December 2017 from <http://www.gov.scot/Resource/0050/00505348.pdf>
- Sharples, M. (2013). Mobile learning: research, practice and challenges. *Distance Education in China*, 3(5), 5–11.
- Sharples, M., Taylor, J., & Vavoula, G. (2007). A theory of learning for the mobile age. In C. Haythornthwaite, R. Andrews, J. Fransman, & E. Meyers (Eds.), *The Sage Handbook of Elearning Research*, (pp. 221–47). London: Sage Publications Ltd.
- Shih, S. C., Kuo, B. C., & Liu, Y. L. (2012). Adaptively ubiquitous learning in campus math path. *Educational Technology and Society*, 15(2), 298–308.
- Shin, N., Norris, C., & Soloway, E. (2006). Effects of handheld games on students learning in mathematics. *Proceedings of the 7th International Conference on Learning Sciences*, 702–708. Bloomington, Indiana.
- Simon, M. (1995). Reconstructing mathematics pedagogy from a constructivist perspective. *Journal for Research in Mathematics Education*, 26(2), 114–145. doi.org/10.2307/749205
- Sinclair, N., Chorney, S., & Rodney, S. (2015). Rhythm in number: exploring the affective, social and mathematical dimensions of using TouchCounts. *Mathematics Education Research Journal*. doi.org/10.1007/s13394-015-0154-y
- Singer, J. (2015). *The effects of ipad devices on elementary school students' mathematics achievement and attitudes*. Northeastern University.
- Slavin, R. E., Lake, C., & Groff, C. (2009). Effective programs in middle and high school mathematics: A best-evidence synthesis. *Review of Educational Research*, 79(2), 839–911. doi.org/10.3102/0034654308330968

- Sollervall, H., Otero, N., Milrad, M., Johansson, D., & Vogel, B. (2012). Outdoor activities for the learning of mathematics: Designing with mobile technologies for transitions across learning contexts. *2012 IEEE Seventh International Conference on Wireless, Mobile and Ubiquitous Technology in Education*, 33–40. Kagawa, Japan: IEEE. doi.org/10.1109/WMUTE.2012.13
- Sommerauer, P., & Müller, O. (2014). Augmented reality in informal learning environments : A field experiment in a mathematics exhibition. *Computers & Education*, 79(2014), 59–68.  
doi.org/http://dx.doi.org/10.1016/j.compedu.2014.07.013
- Song, D., Kim, P., & Karim, A. (2012). Inquiry-based learning environment using mobile devices in math classroom. *The Annual Convention of the Association for Educational Communications and Technology*, 386–392. Louiseville, USA.
- Song, Y. (2014). “Bring Your Own Device (BYOD)” for seamless science inquiry in a primary school. *Computers & Education*, 74, 50-60.
- Spikol, D., & Eliasson, J. (2010). Lessons from Designing Geometry Learning Activities that Combine Mobile and 3D Tools. In *2010 6th IEEE International Conference on Wireless, Mobile, and Ubiquitous Technologies in Education* (pp. 137–141). Taiwan: IEEE. doi.org/10.1109/WMUTE.2010.44
- Sriraman, B., & English, L. (2010). Surveying theories and philosophies of mathematics education. In B. Sriraman & L. English (Eds.), *Theories of Mathematics Education* (pp. 7–32). Berlin, Heidelberg: Springer Berlin Heidelberg. doi.org/10.1007/978-3-642-00742-2\_2
- Sun, Y., & Virginia, W. (2009). Using technology as a tool to reduce mathematics anxiety. *The Journal of Human Resource and Adult Learning*, 5(2), 38–44.
- Sung, Y. T., Chang, K.E., & Liu, T.C. (2015). The effects of integrating mobile devices with teaching and learning on students’ learning performance: A meta-analysis and research synthesis. *Computers & Education*, 94, 252–275.  
doi.org/10.1016/j.compedu.2015.11.008
- Tangney, B., Weber, S., Hanlon, P. O., Knowles, D., Munnely, J., Watson, R., & Jennings, K. (2010). MobiMaths : An approach to utilising smartphones in teaching mathematics. *Mlearn 2010 - 9th World Conference on Mobile and Contextual Learning*, 1–16. Malta.
- Tapia, M., & Marsh, G. E. (2004). An instrument to measure mathematics attitudes. *Academic Exchange Quarterly*, 8(2), 16–22.
- Tavernier, M. (2016). Exploring the suitability of the book creator for iPad app for early childhood education. In D. Churchill, B. Fox, & M. King (Eds.), *Mobile Learning Design* (pp. 249–270). Singapore: Springer Singapore.
- Taylor, R. (1980). The computer in school: Tutor, tool, tutee. *Contemporary Issues in Technology and Teacher Education*, 3(2), 1–10. doi.org/10.1119/1.12996
- Toby, M., Ma, B., Lai, G., Lin, L., & Jaciw, A. (2012). *Comparative effectiveness of Houghton Mifflin Harcourt Fuse: Algebra I*. Palo Alto, CA: Empirical Education Inc. Retrieved February 24, 2013 from  
http://www.empiricaleducation.com/reports.php?Report=HMHFuseFR
- Tomic, D., & Divjak, B. (2011). The impact of game-based learning on the achievement of learning goals and motivation for learning mathematics - literature review. *Journal of Information and Organizational Sciences*, 35(1), 15–30.
- Topping, K. J. (2005). Trends in peer learning. *Educational Psychology*, 25(6), 631–645. doi.org/10.1080/01443410500345172

- Tsuei, M., Chou, H., Chen, B. Measuring usability of the mobile mathematics curriculum-based measurement application with children. In A. Marcus (2013) *Design, User Experience and Usability. Health, Learning, Playing, Cultural, and Cross Cultural Experience*, pp. 304-310. Berlin: Springer.
- Udvari-Solner, A. (2012). Collaborative learning strategies. In *Encyclopedia of the Sciences of Learning* (pp. 636–639). Boston, MA: Springer US.  
doi.org/10.1007/978-1-4419-1428-6\_818
- Vahey, P., Tatar, D., & Roschelle, J. (2004). Leveraging handhelds to increase student learning: engaging middle school students with the mathematics of change. In *Proceedings of the 6th international conference on Learning sciences* (pp. 553–560). Santa Monica, California.
- van't Hooft, M., Swan, K., & Bennett, J. (2009). Learning math while mobile: creating opportunities for elementary math learning. In N. Pachler & J. Seipold (Eds.), *Mobile learning cultures across education, work and leisure*. London: Institute of Education.
- Van den Heuvel-Panhuizen, M., & Drijvers, P. (2014). Realistic mathematics education. In *Encyclopedia of Mathematics Education* (pp. 521–525). Dordrecht: Springer Netherlands. doi.org/10.1007/978-94-007-4978-8\_170
- Van Hiele, P. (1984). The child's thought and geometry. In D. Geddes, D. Fuys & R. Tischler (Eds.), *English translation of selected writings of Dina Van Hiele-Geldof and Pierre M. van Hiele*. Brooklyn, NY: Brooklyn College.
- Vavoula, G. & Sharples, M. (2009). Meeting the challenges in evaluating mobile learning: a 3-level evaluation framework. *International Journal of Mobile and Blended Learning*, 1(2), 54-75.
- Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: toward a unified view. *MIS Quarterly*, 27(3), 425–478.
- Voyer, D & Voyer, S. (2014). Gender differences in scholastic achievement: a meta-analysis. *Psychological Bulletin*, 140(4), 1174-1204. doi.org/10.1037/a0036620
- Wagner, E. D. (2005). Enabling mobile learning. *Educause Review*, 40(June), 40–53. Retrieved from <http://www.educause.edu/ir/library/pdf/erm0532.pdf>
- Wang, Y. S., Wu, M. C., & Wang, H. Y. (2009). Investigating the determinants and age and gender differences in the acceptance of mobile learning. *British Journal of Educational Technology*, 40(1), 92–118. doi.org/10.1111/j.1467-8535.2007.00809.x
- Wijers, M., Jonker, V., & Drijvers, P. (2010). MobileMath: exploring mathematics outside the classroom. *ZDM*, 42(7), 789–799. doi.org/10.1007/s11858-010-0276-3
- Wu, J., & Zhang, Y. (2010). Examining potentialities of handheld technology in students' academic attainments. *Educational Media International*, 47(1), 57–67. doi.org/10.1080/09523981003654977
- Wu, L., Hsiao, H., Chang, K., & Sung, Y. (2006). Construct mathematic path and interactive problem solving discussion in mobile learning environment. In *Proceeding of the IADIS International Conference on Mobile Learning* (pp. 288–292). Dublin, Ireland.
- Wu, W. H., Jim Wu, Y. C., Chen, C. Y., Kao, H. Y., Lin, C. H., & Huang, S. H. (2012). Review of trends from mobile learning studies: A meta-analysis. *Computers and Education*. doi.org/10.1016/j.compedu.2012.03.016

- Yagmur, S., & Cakir, M. . (2016). Usability Evaluation of a Dynamic Geometry Software Mobile Interface Through Eye Tracking. In P. Zaphiris & A. Ioannou (Eds.), *Learning and Collaboration Technologies. Third International Conference, LCT 2016 Held as Part of HCI International 2016 Toronto, ON, Canada, July 17–22, 2016*. (pp. 391–403). doi.org/10.1007/978-3-319-39483-1\_36
- Yang, D. C., & Tsai, Y. F. (2010). Promoting sixth graders' number sense and learning attitudes via technology-based environment. *Educational Technology and Society*, 13(4), 112–125.
- Yang, E. F. Y., Chang, B., Cheng, H. N. H., & Chan, T. (2016). Improving Pupils' Mathematical Communication Abilities through Computer - Supported Reciprocal Peer Tutoring, *Educational Technology and Society*, 19(3), 157–169.
- Yen, J.C., Wang, J.Y., & Chen, I.J. (2011). Gender differences in mobile game-based learning to promote intrinsic motivation. *International Conference on Computers*, 279–284. Corfu Island, Greece.
- Yeung, A. S. (2011). Student self-concept and effort: gender and grade differences. *Educational Psychology*, 31(6), 749–772. doi.org/10.1080/01443410.2011.608487
- Yilmaz, Ç., Altun, S. A., & Olkun, S. (2010). Factors affecting students' attitude towards Math: ABC theory and its reflection on practice. *Procedia - Social and Behavioral Sciences*, 2(2), 4502–4506. doi.org/10.1016/j.sbspro.2010.03.720
- Yorganci, S. (2017). Investigating Students' Self-Efficacy and Attitudes Towards the Use of Mobile Learning. *Journal of Education and Practice*, 8(6), 181–185.
- Yushau, B. (2006). The effects of blended e-learning on mathematics and computer attitudes in pre-calculus algebra. *The Mathematics Enthusiast*, 63(2), 176-183.
- Zan, R., Brown, L., Evans, J., & Hannula, M. S. (2006). Affect in mathematics education: An introduction. *Educational Studies in Mathematics*, 63(2), 113–121. doi.org/10.1007/s10649-006-9028-2
- Zaranis, N., Kalogiannakis, M., & Papadakis, S. (2013). Using mobile devices for teaching realistic mathematics in kindergarten education. *Creative Education*, 4(7), 1–10. doi.org/10.4236/ce.2013.47A1001
- Zhang, M., Trussell, R. P., Gallegos, B., & Asam, R. R. (2015). Using math apps for improving student learning : An exploratory study in an inclusive fourth grade classroom. *TechTrends*, 59(2), 32–39. doi.org/10.1007/s11528-015-0837-y
- Zimmerman, E. (2003). Play as research: the iterative design process. *Design Research Methods and Perspective*, 176-184. Cambridge: MIT Press.
- Zurita, G., & Nussbaum, M. (2004). Computer supported collaborative learning using wirelessly interconnected handheld computers. *Computers & Education*, 42(3), 289–314. doi.org/10.1016/j.compedu.2003.08.005
- Zurita, G., & Nussbaum, M. (2007). A conceptual framework based on activity theory for mobile CSCL. *British Journal of Educational Technology*, 38(2), 211–235. doi.org/10.1111/j.1467-8535.2006.00580.x
- Zurita, G., Nussbaum, M., & Sharples, M. (2003). Encouraging face-to-face collaborative learning through the use of handheld computers in the classroom. *Human-Computer Interaction with Mobile Devices and Services*, 2795, 193–208. doi.org/10.1007/978-3-540-45233-1\_15

## APPENDIX A. CLUSTERS OF LITERATURE SEARCH

Cluster	Source	Search Specifics
Cluster 1	Using indexing database: Scopus Proquest Web of Knowledge EBSCO DOAJ EDITLIB	<p>The following search combinations were used:</p> <ul style="list-style-type: none"> <li>• (Math or Mathematics) AND ("mobile learning" OR m-learning OR mlearning)</li> <li>• (Math or Mathematics) AND (smart phone OR smartphone)</li> <li>• (Math or Mathematics) AND (handheld learning) AND NOT calculators</li> <li>• (Math or Mathematics) AND (tablet) AND (mobile)</li> <li>• (Math or Mathematics) AND (iPad)</li> <li>• (Math or Mathematics) AND phone AND (education OR learning)</li> <li>• Mathematics education AND (mobile OR phones OR handheld)</li> <li>• cell phones AND (math OR mathematics)</li> <li>• Ubiquitous learning AND (math OR mathematics)</li> <li>• (Wireless Internet Learning Devices) AND (math or mathematics)</li> <li>• (wireless handhelds) AND (math or mathematics).</li> </ul> <p>An additional database, EDITLIB of was also used in this section with the following search keywords:</p> <ul style="list-style-type: none"> <li>• mathematics AND phones</li> <li>• mathematics AND iPad</li> <li>• mathematics AND tablets</li> <li>• mathematics AND mobile</li> </ul>
Cluster 2	Hand searching Journals and Conferences	<p>The following journals were hand searched and spot-checked for math and mobile learning studies from 2003-2012:</p> <ul style="list-style-type: none"> <li>• British Journal of Educational Technology</li> <li>• International Journal of Mobile and Blended Learning</li> <li>• International Journal of Interactive Mobile Technologies</li> <li>• International Journal of Mobile Learning and Organization</li> <li>• International Journal of Science and Mathematics Education Research in Mathematics Education</li> <li>• Mathematics Education Research Journal</li> </ul> <p>Conference proceedings of mobile learning conferences were also checked year by year:</p> <ul style="list-style-type: none"> <li>• Mlearn (2003 – 2012)</li> <li>• Iadis Mobile Learning Conference (2005-2012)</li> <li>• Wireless, Mobile Technologies In Education (2004-2005)</li> <li>• Wireless, Mobile and Ubiquitous Technology in Education (2006-2012)</li> </ul> <p>Database listing of mobile learning research projects from IamLearn and Moleleap were checked for projects on mathematics. Papers on mobile learning from UNESCO, World Bank, GSMA and FutureLab were checked for citations of projects on mobile learning. These projects were then retrieved either by using the citation provided or when the link was no longer active, using Google search.</p>
Cluster 3	Citation	<p>Citations from studies above whose fulltexts were reviewed were checked for math-related mobile learning studies.</p>



**APPENDIX B. SAMPLE MAPPING OF STUDIES**

Citation	Weight	Device type used	Country	Nature of activity with mobile device	Learning Strategies Employed	Functional use of mobile device	Year/ Grade	Sample Size	Duration (weeks)	Learning Outcome
Amiratashani (2010)	Medium	Phone	Iran	Students received extra guidance on their maths lesson outside classroom hours via SMS. The nature of SMS received are feedback on their performance and also some practice quizzes and exercises.	Explicit instruction; Formative assessment	Referential; Collaborative	Middle School	100	10	Engagement, Achievement
Baya'a and Daher (2009)	Medium	Phone	Israel	Students used an app called Math4Mobile to aid them in graphing linear functions. They also used the phone's camera, video/audio recorder and voice and text communication as part of the maths activity carried out outside the classroom.	Visualisation of math concepts; Collaborative learning; Problem-based learning	Interactive; Data Collection; Collaborative;	Middle School	32	No data provided	Attitude and Perception

## APPENDIX C. COPY OF ETHICS APPROVAL

A copy of the ethics approval for the pilot study and study 1 is available below. The first scanned image is the initial ethics approval subject to submitting a risk assessment prior to the outdoor based activities. The screenshot of the email communication refers to the approval after the risk assessment has been submitted.

30 January 2015

Dear Ms Fabian,

**Application Number: UREC 15021**

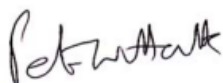
**Title: Using mobile technologies for learning mathematics: effects on student attitudes, engagement and achievement.**

Your application has been reviewed by the University Research Ethics Committee, and there are no ethical concerns with the proposed research. I am pleased to confirm that the above application has now been approved, subject to you providing a risk assessment before the start of the second phase of the study.

You submitted the following documents:

1. Ma\_Khristin\_Fabian\_research\_ethics\_proposal
2. UREC – UsingMobileTechnologiesLearningMaths
3. Fabian Revised Ethics Application
4. list of changes
5. 28 January Fabian Revised Ethics Application

Yours sincerely,



Dr Peter Willatts  
Vice-Chair, University of Dundee Research Ethics Committee

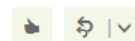
Peter  
Willatts

Digitally signed by Peter Willatts  
DN: cn=Peter Willatts,  
o=University of Dundee,  
ou=School of Psychology,  
email=p.willatts@dundee.ac.uk,  
c=GB  
Reason: I am the author of this  
document  
Date: 2015.01.30 11:10:38 Z



Peter Willatts (Staff)

Thu 19/03/2015, 08:52



Dear Ma,

Thank you for providing the risk assessment for the second phase of your study. I am happy to approve this second phase of your study.

With best wishes,

Peter

This refers to the ethics approval of Study 3.



School of Education, Social Work & Community Education

Dean of School  
Professor Timothy Kelly

School Secretary  
Grainne Barr

Ref: BH/ER/E2015/28

13<sup>th</sup> August 2015

MA Khristin Fabian  
School of ESW  
Univeristy of Dundee

Dear Khristin,

**UREC Application E2015/28**

**Using mobile technologies for learning mathematics: effects on student attitudes, engagement and achievement.**

Thank you for making the suggested modifications to your application. I am now pleased to inform you that the above application has now been formally approved.

Yours sincerely

Dr Beth Hannah  
Chair, ESW Research Ethics Committee

**APPENDIX D. COPY OF CONSENT TO UNDERTAKE RESEARCH FROM COUNCIL**

Approval to undertake research was provided by two councils and copies of these approvals are attached as scanned images below. Names and contact numbers have been redacted.

Dundee DD1 4HN	Our ref RG/TM Your ref Date 13 June 2014
-------------------	--

Dear Ms Fabian

**Maths and Mobile Learning: Effects in student attitudes, engagement and achievement.**

Thank you for your request to undertake research in Perth and Kinross.

I am pleased to confirm that your research has been approved in principle by Education and Children's Services Senior Management, subject to the conditions enclosed.

The final decision to permit the research in their establishment lies with the Headteacher/Head of Establishment and you will be required to provide an original copy of approval letter.

We look forward to receiving a copy of the findings of your research.

Yours sincerely

16 Approval of research request

(a) Approved without conditions	<input checked="" type="checkbox"/>	(b) Approved with conditions	<input type="checkbox"/>
(c) Undecided	<input type="checkbox"/>	(d) Refused	<input type="checkbox"/>

(d). Please tick the appropriate box and give further details/reasons below for categories (b), (c) and

\_\_\_\_\_ are happy to support your research. You may now liaise  
with these schools directly.  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Signature of Authorised Officer \_\_\_\_\_ Date 25/2/15

## **APPENDIX E. PARTICIPANT INFORMATION SHEETS AND CONSENT FORMS**

### **Participant Information Sheet: Headteacher**

#### **Using mobile technologies for learning mathematics: effects on student attitudes, engagement and achievement**

Your school is being asked to take part in a research study which investigates the effects of using mobile technologies towards students' attitudes, engagement and achievement in mathematics. This study is being undertaken by Ma Khristin Fabian from the University of Dundee. Professor Keith Topping and Dr. Ian Barron are supervising the study.

#### **Purpose of the research study**

The goal of this research is to examine how the use of mobile technologies affects learning mathematics and aims to explore how the use of mobile devices compares to other traditional technologies.

#### **Time Commitment**

Two groups are encouraged to take part from your school.

- The tablet group will take part in a study for 14 weeks, happening once a week during their maths class. The teacher will facilitate the learning activities carried out by the students. The learning activities will be carried out in pairs and involve a variety of activities that involve the use of tablets. There are two phases in the project. In the first phase, all activities are carried out within the classroom (for example, students will use the tablets to take pictures of symmetrical objects and then annotate these pictures with the line of symmetry). In the second phase, the activities will be carried out outside the classroom (for example, students will follow a math trail and use various features of the tablets to solve a variety of math problems). These sessions will be video recorded to be analysed later on for teacher compliance and also to evaluate student engagement. The videos will be used solely to inform this study and for research dissemination purposes. Training on how to use the tablet will be provided, prior to the intervention and also during the intervention.
- The comparison group will take part in a survey about the students' attitudes towards mathematics and a short mathematics quiz. This will happen at the 1<sup>st</sup> week and at the 13<sup>th</sup> week of the intervention.

### Project Timetable:

<b>Spring Term</b>		
Feb 9 – 17 or Earlier	Week 0	Consent Forms / Distribution of the tablets
Feb 23-27	Week 1	Pre-test / Introductory Sessions
March 2 - 6	Week 2	Phase 1: Session 1: Looking at the different functionalities of the mobile device as a maths tool
March 8 - 13	Week 3	Phase 1: Session 2: Symmetry
March 15 - March 20	Week 4	Phase 1: Session 3: Area and Perimeter
March 23 - Mar 27	Week 5	Phase 1: Session 4: Data Handling
*March 30 - April 2	Week 6	Post-test (Attitudes Inventory / Maths Test)
<b>April 3 to April 17</b>		<b>School Break</b>
<b>Summer Term</b>		
April 20 to April 24	Week 7	Phase 2: Session 1: Math Trail
April 27 - May 1	Week 8	Phase 2: Session 2: Math Trail and Angles
May 4 - May 8	Week 9	Phase 2: Session 3: Symmetry Outdoors
May 11 - May 15	Week 10	Phase 2: Session 4: Area and Perimeter Outdoor Session
May 18 - May 22	Week 11	Phase 2: Session 5: Data Handling Session 1
May 25 - May 29	Week 12	Phase 2: Session 6: Data Handling Session 2
*June 1 - June 13	Week 13/14	Follow up test (Attitudes Inventory / Maths Test)

### Use of the Tablets

A bank of \_\_\_\_\_ tablets and a charging station are allocated for use by the teacher participating in the tablet group. The tablets can be used for other subjects when required provided that it's the same teacher. However, to avoid compromising research data, I ask for the tablets to not be assigned during maths session of the comparison group. Administration of the tablets will be done by the researcher to some degree via a mobile device management system. The tablets will be content locked to avoid installation of applications that are not for educational use.

### Use of the schools' network

Some of the activities with the tablets will require access to the schools' wifi network.

Please advise if this will be an issue so that an alternative way to network can be worked out.

**Termination of Participation**

Participation is voluntary and the school can withdraw at any point and for whatever reason.

**Confidentiality/Anonymity**

Data collected will not include personal information about the participants from your school. Any data provided as part of your participation in the research will be kept confidential and stored in a secure location. These data will be stored for three years and will be deleted at the end of December 2018. All data collected will be used solely to inform this research study and disseminate information about this research.

**For further information**

Ma Khristin Fabian will be glad to answer your questions about this study at any time personally, by phone 01382-381434, by email [mkfabian@dundee.ac.uk](mailto:mkfabian@dundee.ac.uk) or by post: School of Education, Social Work and Community Education, University of Dundee, Scotland, DD1 4HN.

**Consent Form: Headteacher**

**Using mobile technologies for learning mathematics: effects on student attitudes, engagement and achievement**

This study aims to investigate the effects of using mobile supported learning activities to students' attitudes, engagement and achievement in mathematics.

**By signing below, you are agreeing that you have read and understood the Participant Information Sheet and that you agree to take part in this research study.**

\_\_\_\_\_  
Printed Name of Participant      Participant's Signature      Date

Ma. Khristin Fabian (researcher)



\_\_\_\_\_  
Printed name of person obtaining consent      Signature of person obtaining consent



### **Participant Information Sheet: Teachers (Tablet Group)**

#### **Using mobile technologies for learning mathematics: effects on student attitudes, engagement and achievement**

You are asked to take part in a research study which investigates the effects of using mobile technologies towards students' attitudes, engagement and achievement in mathematics. This study is being undertaken by Ma Khristin Fabian from the University of Dundee. Professor Keith Topping and Dr. Ian Barron are supervising the study.

#### **Purpose of the research study**

The goal of this research is to examine how the use of mobile technologies affects learning mathematics and aims to explore how the use of mobile devices compares to other traditional technologies.

#### **Time Commitment**

You are asked to take part in a study for 14 weeks, happening once a week during your maths class. You will facilitate the learning activities carried out by the students. The learning activities will be carried out in pairs and involve a variety of activities that involve the use of tablets. There are two phases in the project. In the first phase, all activities are carried out within the classroom (for example, students will use the tablets to take pictures of symmetrical objects and then annotate these pictures with the line of symmetry). In the second phase, the activities will be carried out outside the classroom (for example, students will follow a maths trail and use various features of the tablets to solve a variety of maths problems). These sessions will be video recorded to be analysed later on for teacher compliance and also to evaluate student engagement. The videos will be used solely to inform this study and for research dissemination purposes. You will be given training on how to use the tablet prior to the intervention and will also be allocated a tablet device for the duration of the research project.

You are also being asked to take part in two 20 minute interviews to be carried out, one in the middle of the intervention and one at the end. These interviews will be audio recorded.

#### **Termination of Participation**

Participation is voluntary and you can withdraw at any point and for whatever reason.

#### **Risks**

There are no known risks for you in this study.

#### **Cost, reimbursement and compensation**

Your participation in this study is voluntary.

**Confidentiality/Anonymity**

Data collected will not include personal information about you. Any data you provide as part of your participation in the research will be kept confidential and stored in a secure location. These data will be stored for three years and will be deleted at the end of December 2018. All data collected will be used solely to inform this research study and disseminate information about this research.

**For further information**

Ma Khristin Fabian will be glad to answer your questions about this study at any time personally, by phone 01382-381434, by email [mkfabian@dundee.ac.uk](mailto:mkfabian@dundee.ac.uk) or by post: School of Education, Social Work and Community Education, University of Dundee, Scotland, DD1 4HN.

**Consent Form: Teachers (Tablet Group)**

**Using mobile technologies for learning mathematics: effects on student attitudes, engagement and achievement**

This study aims to investigate the effects of using mobile supported learning activities to students' attitudes, engagement and achievement in mathematics.

**By signing below, you are agreeing that you have read and understood the Participant Information Sheet and that you agree to take part in this research study.**

I agree to video recording of the teacher activities (Please delete as appropriate)	YES	NO
I agree to these video recordings being used to disseminate research results (Please delete as appropriate)	YES	NO
I agree to audio recording of the interview (Please delete as appropriate)	YES	NO

_____	_____	_____
Printed Name of Participant	Participant's Signature	Date

Ma. Khristin Fabian (researcher)

_____	_____
Printed name of person obtaining consent	Signature of person obtaining consent

## **Participant Information Sheet: Teachers (Comparison Group – Study 2)**

### **Using mobile technologies for learning mathematics: effects on student attitudes, engagement and achievement**

You are asked to take part in a research study which investigates the effects of using mobile technologies towards students' attitudes, engagement and achievement in mathematics. This study is being undertaken by Ma Khristin Fabian from the University of Dundee. Professor Keith Topping and Dr. Ian Barron are supervising the study.

#### **Purpose of the research study**

The goal of this research is to measure students attitudes and maths scores and how these changes over time.

#### **Time Commitment**

Your class is being asked to take part in a survey. I will facilitate the survey about your student's attitudes towards mathematics and a short mathematics quiz at the 1<sup>st</sup> week and at 13<sup>th</sup> week.

#### **Termination of Participation**

Participation is voluntary and you can withdraw at any point and for whatever reason.

#### **Risks**

There are no known risks for you in this study.

#### **Cost, reimbursement and compensation**

Your participation in this study is voluntary.

#### **Confidentiality/Anonymity**

Data collected will not include personal information about you. Any data you provide as part of your participation in the research will be kept confidential and stored in a secure location.

All data collected will be used solely to inform this research study. Activities that will be carried out to disseminate information about this research will not have identifiable information about your participation.

#### **For further information**

Ma Khristin Fabian will be glad to answer your questions about this study at any time personally, by phone 01382-381434, by email [mkfabian@dundee.ac.uk](mailto:mkfabian@dundee.ac.uk) or by post: School of Education, Social Work and Community Education, University of Dundee, Scotland, DD1 4HN.

**Consent Form (Teachers: Comparison Group)**

**Using mobile technologies for learning mathematics: effects on student attitudes, engagement and achievement**

This study aims to investigate the effects of using mobile supported learning activities to students' attitudes, engagement and achievement in mathematics.

**By signing below, you are agreeing that you have read and understood the Participant Information Sheet and that you agree to take part in this research study.**

\_\_\_\_\_  
Printed Name of Participant    Participant's Signature    Date

Ma. Khristin Fabian (researcher)



\_\_\_\_\_  
Printed name of person obtaining consent    Signature of person obtaining consent

## **Participant Information Sheet: Students (Tablet Group)**

### **Research study on student attitudes, engagement and achievement**

#### **Purpose of the research study**

This research will help me to tell whether there are benefits in using tablets in learning mathematics.

#### **Time Commitment**

You will take part in a study for 14 weeks happening once a week during your one of your maths classes. On the first session, you will be given a short survey about your attitudes towards mathematics and also a short mathematics quiz. After this, you will be given an introductory session on how to use the tablets. Afterwards, you will participate in various activities that use the tablets. These activities are carried out within the classroom and also in the school grounds. After these sessions, you will also be asked to rate the activities that you carried out. There will also be another survey about your attitudes midway in the programme and also at the end of the programme. A maths quiz will also be carried out in the end. These quizzes and surveys are NOT marked by your teachers but will only be used by myself to evaluate the programme.

Some sessions will be video recorded. These videos will not be shared but will only be used by myself for the research project. There will also be group discussions to be carried out sometime during the programme and at the end. These group discussions will be audio recorded.

#### **When you don't want to take part anymore**

Participation is voluntary and you can withdraw at any point and for whatever reason.

#### **Your privacy:**

Any information you provide as part of your participation in the project will be kept confidential and stored in a safe place. Your personal information will not be shared with anyone.

#### **For further information**

My name is Ma. Khristin Fabian and I am happy to answer your questions about my work. You can also address your questions to me through your teacher.

**Consent Form (Tablet Group)**

**Research study on student attitudes, engagement and achievement**

This research will help me to tell whether there are benefits in using tablets in learning mathematics.

**By signing below, you are agreeing that you have read and understood the Participant Information Sheet and that you agree to take part in this research study.**

I agree to the video recording of the activities (Please delete as appropriate)	YES	NO
I agree to the audio recording of the interview (Please delete as appropriate)	YES	NO

_____	_____	_____
Printed Name of Participant	Participant's Signature	Date

Ma. Khristin Fabian (researcher)



_____	_____
Printed name of person obtaining consent	Signature of person obtaining consent

**Participant Information Sheet: Students****Research study on student attitudes, engagement and achievement****Purpose of the research study**

This research will help me to tell about your attitudes and maths scores and how these changes over time.

**What you will do:**

You will be given a short survey about your attitudes towards mathematics and also a short mathematics quiz. After 13 weeks, there will be another survey about your attitudes and a short mathematics quiz. This quiz and survey are NOT marked by your teachers but will only be used by myself to evaluate the programme.

**When you don't want to take part anymore:**

Participation is voluntary and you can withdraw at any point and for whatever reason.

**Your privacy:**

Any data you provide as part of your participation in the research will be kept confidential and stored in a secure location. Your personal information will not be shared with anyone.

**For further information**

My name is Ma. Khristin Fabian and I am happy to answer your questions about my work. You can also address your questions to me through your teacher.



**Consent Form (Students)**

**Research study on student attitudes, engagement and achievement**

This research will help me to tell about your attitudes and maths scores and how these changes over time.

**By signing below, you are agreeing that you have read and understood the Participant Information Sheet and that you agree to take part in this research study.**

\_\_\_\_\_  
Printed Name of Participant    Participant's Signature    Date

Ma. Khristin Fabian (researcher)



\_\_\_\_\_  
Printed name of person obtaining consent    Signature of person obtaining consent

## Parental Consent: Information Sheet

### Using mobile technologies for learning mathematics: effects on student attitudes, engagement and achievement

#### Dear Parent/Guardian,

My name is Khristin Fabian and I have approached your child's school to take part in a research study that investigates the effects of using tablets towards students' attitudes, engagement and achievement in mathematics. This study is being undertaken by myself and supervised by Professor Keith Topping and Dr. Ian Barron under the research programme at the University of Dundee.

The head-teacher of the school is interested and willing to cooperate with my research. Your child is being asked to take part in the maths activities that will happen once a week for 14 weeks. This period covers the introductory sessions, maths attitudes inventory survey, maths quiz and the actual participation in the tablet-enabled activities. The tablet devices for this project will be provided in class. Part of the activities will be video recorded and a sample of students will also be asked to participate in group interviews which will also be audio recorded. These recordings will not be shared with anyone and will not include any identifiable information about your child.

If you are **not** willing to agree to your son or daughter taking part, I would be grateful if you could sign the attached form and return it to school by Tuesday, February 17. If you would like to know more about the project, I would be very happy to chat with you. If you wish to do this, please feel free to contact me via email at [mkfabian@dundee.ac.uk](mailto:mkfabian@dundee.ac.uk) or by the address above. You can also contact me via the head teacher.

Many thanks for taking the time to read this letter and for your help.

Yours sincerely,

Khristin Fabian

**Re: Using mobile technologies for learning mathematics: effects on student attitudes, engagement and achievement**

I **do not** wish my child \_\_\_\_\_ (print name) to take part in the project.

Signed.....Parent/Guardian

Please print your name.....

Ma. Khristin Fabian (researcher)

\_\_\_\_\_  
Printed name of person obtaining consent    Signature of person obtaining consent

**Please return this form to the school by Tuesday, February 17 only if you DO**

**NOT wish your child to participate in the tablet-enabled activities.**

## APPENDIX F.      END ACTIVITY EVALUATION

Name: \_\_\_\_\_ Male \_\_\_\_\_ Female \_\_\_\_\_

**Instruction:**

Complete the sentence by placing a dot on the line. The nearer the mark to the word, the higher your level of agreement with the statement.

**For example,**

If you found the activity very valuable, then mark the line as

Valuable —●———— Unrelated

If you found the activity not very valuable and slightly unrelated then mark the line as

Valuable —————●———— Unrelated

(1) I found the activity

Irrelevant ————— Useful

(2) I found the use of the tablet

Irrelevant ————— Useful

(3) I found the activity

Clear ————— Confusing

(4) I found the use of the tablet

Clear ————— Confusing

(5) I found the activity

Distracting ————— Stimulating

(6) I found the use of the tablet

Distracting ————— Stimulating

(7) I found the activity

Innovative ————— Dull

(8) I found the use of the tablet

Innovative ————— Dull

Continue to the back of the page

- (9) I found the activity  
Boring \_\_\_\_\_ Fun
- (10) I found the use of the tablet  
Boring \_\_\_\_\_ Fun
- (11) I found the activity  
Gets in the way \_\_\_\_\_ Helpful
- (12) I found the use of the tablet  
Gets in the way \_\_\_\_\_ Helpful
- (13) I found the activity  
Effective \_\_\_\_\_ Ineffective
- (14) I found the use of the tablet  
Effective \_\_\_\_\_ Ineffective
- (15) I found the activity  
Easy to understand \_\_\_\_\_ Too technical
- (16) I found the use of the tablet  
Easy to understand \_\_\_\_\_ Too technical
- (17) I found the activity  
Satisfying \_\_\_\_\_ Frustrating
- (18) I found the use of the tablet  
Satisfying \_\_\_\_\_ Frustrating
- (19) Overall, I am satisfied with the ease of completing the tasks in this activity.  
Strongly disagree \_\_\_\_\_ Strongly agree
- (20) Overall, I am satisfied with the amount of time it took to complete the tasks in this activity  
Strongly disagree \_\_\_\_\_ Strongly agree

-----END-----

## APPENDIX G. MATHS ATTITUDE INVENTORY

Name: \_\_\_\_\_ Male \_\_\_\_\_ Female \_\_\_\_\_

Instruction: This inventory consists of statements about your attitude towards mathematics. There are no correct or incorrect responses. Rate your agreement with the statement by placing an dot on the line.

Example: I like apples over oranges.      Strongly \_\_\_\_\_ Strongly  
Disagree      •      Agree

- |  |                      |       |                   |
|--|----------------------|-------|-------------------|
| 1. I have usually enjoyed studying mathematics in school.                      | Strongly<br>Disagree | _____ | Strongly<br>Agree |
| 2. I like to solve new problems in mathematics.                                | Strongly<br>Disagree | _____ | Strongly<br>Agree |
| 3. I really like mathematics.  | Strongly<br>Disagree | _____ | Strongly<br>Agree |
| 4. It makes me nervous to even think about having to do a mathematics problem. | Strongly<br>Disagree | _____ | Strongly<br>Agree |
| 5. Mathematics is NOT important in everyday life.                              | Strongly<br>Disagree | _____ | Strongly<br>Agree |
| 6. Mathematics is one of the most important subjects for people to study.      | Strongly<br>Disagree | _____ | Strongly<br>Agree |
| 7. I am happier in other class than in maths class.                            | Strongly<br>Disagree | _____ | Strongly<br>Agree |
| 8. Mathematics is a boring subject.  | Strongly<br>Disagree | _____ | Strongly<br>Agree |
| 9. I am always confused in my mathematics class.                               | Strongly<br>Disagree | _____ | Strongly<br>Agree |
| 10. I feel a sense of insecurity when attempting mathematics.                  | Strongly<br>Disagree | _____ | Strongly<br>Agree |

Continue to the back of the page

- |   |                            |                   |
|---|----------------------------|-------------------|
| 11. High school mathematics would be very helpful no matter what I decide to study in future. | Strongly _____<br>Disagree | Strongly<br>Agree |
| 12. Studying mathematics makes me feel nervous.   | Strongly _____<br>Disagree | Strongly<br>Agree |
| 13. Mathematics is an unnecessary subject.  | Strongly _____<br>Disagree | Strongly<br>Agree |
| 14. A strong mathematics background could help me in my professional life.                    | Strongly _____<br>Disagree | Strongly<br>Agree |
| 15. I am always under a terrible strain in a mathematics class.                               | Strongly _____<br>Disagree | Strongly<br>Agree |
| 16. I am good at using computers.   | Strongly _____<br>Disagree | Strongly<br>Agree |
| 17. I am good at using things like DVDs, MP3s and mobile phones.                              | Strongly _____<br>Disagree | Strongly<br>Agree |
| 18. I like using mobile technologies for mathematics.   | Strongly _____<br>Disagree | Strongly<br>Agree |
| 19. Mathematics is more interesting when using mobile technologies.                           | Strongly _____<br>Disagree | Strongly<br>Agree |
| 20. Using mobile technologies in mathematics is NOT worth the extra effort.                   | Strongly _____<br>Disagree | Strongly<br>Agree |


-----END-----


## APPENDIX H. CRITICAL INCIDENT ANALYSIS


### Session 1

CID	Time	Breakdown/ Breakthrough	Context
1	Session 1, 1 min	Breakdown	<p>Tablets not charged</p> <p>The tablets were being distributed to the students and two pairs of students came back with the tablets not being charged.</p>
2	Session 1, 2 min	Breakdown	<p>Some students were not sure what to do.</p> <p>Students were given two pieces of handouts. The first one contains procedures on how to use Skitch and the other one contains the tasks they have to do and the steps they need to take to carry it out. Students were given a demo on how to use the app just before the session but there was no clarification whether everyone has understood.</p>
3	Session 1, 2 min	Breakdown	<p>Some students were taking the tablets out of their rotating cases.</p> <p>Some of the cases, obstruct the view of the camera when not rotated to the right angle so students elected to remove the tablets from the case.</p>
4	Session 1, 2.5 min	Breakdown	<p>Students were not clear about what to do.</p> <p>The teacher clarified to the class the task—that they need to take pictures of objects that has two lines of symmetry and not just any object. The teacher also clarified that they may need to get up and move and find something that has two lines of symmetry.</p>
5	Session 1 2.5 min	Breakthrough	<p>Students discuss properties of symmetrical object.</p> <p>After the teacher clarified the task, students discuss what object would have two lines of symmetry. Having identified that a rectangular object would meet the requirement, a student went up to find that fits the property being asked.</p>



CID	Time	Breakdown/ Breakthrough	Context
6	Session 1, 3 min	Breakdown and breakthrough	<p>Some students do not have a good grasp of the topic</p> <p>A pair of student were taking each other's photo as an example of a symmetrical object. (breakdown) The teacher asked what it was they were trying to do and corrected their misconception. By having students take photos of symmetrical objects from their environment, the artefacts students produce allow the teacher to target student misconceptions about symmetry.</p>
7	Session 1, 3 min	Breakdown	<p>Students asked for clarification on how to use the application.</p> <p>When the researcher walked around the class, students in one table took the opportunity to clarify the task of how to save a file and how to draw a line using Skitch. It turned out that students were using the tablets camera to take pictures rather than Skitch so they weren't able to follow the procedure.</p>
8	Session 1, 4 min	Breakthrough	<p>A teaching assistant is explaining to the student what makes an object symmetrical by using the actual object and point out its line of symmetry.</p> 
9	Session 1, 4.5 min	Breakdown and Breakthrough	<p>It is not possible to check on students work remotely.</p> <p>The way to check students' progress with the task is to go around the different groups and see students' work.</p>
10	Session 1, 7.5 min	Breakdown	<p>Students were not sure what to do next. Students have completed the task with Skitch. The other task is to use a different app to create symmetrical pictures. Although this was listed down in the task sheet, some students were not sure what to do.</p>

CID	Time	Breakdown/ Breakthrough	Context
11	Session 1, 8 min	Breakdown	<p>The task was to find an object that has the most lines of symmetry. A student explained, “it’s a circle, let’s take a picture of the smiley face.”</p> <p>This indicates a misconception of the properties of symmetrical object. Here students were looking for objects that match the shape that meets the property being asked for but did not consider that real world objects would have other things like patterns that would affect its symmetry.</p>
12	Session 1, 9 min	Breakdown	<p>Students were not sure how to use the application. The handout that outlines the steps to use the application does not help all students be clear about the steps in using the application.</p> <p>Having finished the first part of the task with Skitch. Students move on to tasks that asks them to create symmetrical pictures using a different application. Some students were not sure what to do so they asked for a demo on how to use the application.</p>
13	Session 1, 10 min	Breakthrough	<p>A student reads out the procedure to their partner as he tries to fiddle with the tablet to complete the task.</p> 
14	Session 1, 10.5 min	Breakdown	<p>Students complained that they lost their work.</p> <p>Students explained that their work was not saved. It turns out to be a problem with the application as the pictures taken were not immediately visible in the photo gallery. However, as this wasn’t a known issue at the time, students were asked if they could start again.</p>

CID	Time	Breakdown/ Breakthrough	Context
15	Session 1, 11 min	Breakdown	<p>Locked tablet.</p> <p>The tablets were locked down to prevent students from accessing the tablet settings. It turned out that lock was not properly set in some tablets which blocked some students from being clicking the Switch Window button which is the tool that allows them to multi-task.</p>
16	Session 1, 12 min	Breakthrough	<p>In a pair, one student was directing the other student holding the tablet which object to take a picture of. Initially he was standing at the back of the one holding the tablet but had to come up front to point out exactly which item to take a picture of.</p> 
17	Session 1, 12.5 min	Breakthrough	<p>Students were showing their work with other groups.</p> <p>A pair of student started work on the last task and was impressed about the application. They went to other groups to show what they have done.</p>
18	Session 1, 14.5	Breakdown	<p>Teacher reminded the class to work on the tasks and not just take random pictures. It turns out that a pair of student was only exploring the application but not working on the task.</p>
19	Session 1, 15 min	Breakthrough	<p>Student commented that they liked the app.</p>


CID	Time	Breakdown/ Breakthrough	Context
20	Session 1, 15.5 min	Breakthrough	<p>Student helped another pair of students how to view their work.</p> <p>Some students thought that they lost their work because the gallery doesn't show it. One of the students was able to figure it out so he showed the other students how to fix it. This pair also turned out helping other student pairs who had the same problem.</p>
21	Session 1, 17.5 min	Breakdown	<p>The application won't run.</p> <p>A pair of student was working on the last task but having issues launching the application from their tablet. They were given a different tablet to help them complete the task.</p>
22	Session 1, 18.5 min	Breakthrough	<p>Students completed the task but continue to explore the different features of the application.</p> <p>Some pairs of students finished earlier. As they wait for the rest of the class to finish, they continue to explore the different features of the application that allowed them to create symmetrical features. Some were taking portraits to see how their faces changes using the symmetry camera. Some were going to other groups to showcase what they've done.</p>
23*	Session 1, 6.5 min	Breakthrough	<p>A teacher saw the students taking pictures of themselves so the teacher asked the pair if the face is symmetrical. This was followed by the teacher asking the students to reconsider whether the face is symmetrical or not.</p>

## Session 2


CID	Time	Breakdown/ Breakthrough	Context
1	Session 2, Before session start	Breakdown	Change in the implementation of Task 1  It was not possible to connect to the internet at that time so task 1, where students will do the measurement of area and perimeter of places they know using an app, was changed into a class activity. This limited the amount of exploration student can do with the application.
2	Session 2, 2 min	Breakdown	Some tablets were not charged.  The tablets were charged in the morning but as the session also starts at the first period, there wasn't enough time to charge the tablets.
3	Session 2, 4 minutes	Breakdown	The application was not in one of the tablet  Using an administrator account, applications were pushed to the tablets wirelessly, however, it appears that some tablets missed the over-the-air update which resulted into one of the tablets not having the right application.
4	Session 2, 5.5 min	Breakdown	Student was not sure about the meaning of some words in the task sheet.  The task was for the students to explore what happens to the area when the perimeter increases. One student was not sure about the meaning of the term increase.
5	Session 2, 6 min	Breakdown	Students found the task too difficult.  The process of proving and disproving mathematical statements appeared to be too difficult for the students at this level. Some students needed a lot of prompts from teacher and researcher.
6	Session 2, 7.5 min	Breakdown	Students ask about the symbol shown on the tablet. Context: Area and perimeter was displayed as a (area) and d (distance). This was missed in the introduction.
7	Session 2, 12 min	Breakdown	App is not showing the area and perimeter.  The application is supposed to display both area and perimeter but in some tablets, the area is not shown, in other tablets only the perimeter is shown. Students were told to solve for missing measurement manually.

## Session 3

CID	Time	Breakdown/ Breakthrough	Context
1	Session 3, 0-4 mins	Breakdown	<p>Some students in groups of are not participating.</p> <p>Context: Some of the students had to work in groups of three, others worked in pairs, there were 3 groups working in pairs and 4 groups working in groups of three and 2 students working on their own.</p> <p>During the first minute into the session, in one group of three students with two boys and one girl in the middle and the tablet positioned in the middle all three students appear to be participating. A minute later when the control of the tablet shifted to the boy on the right of the girl, the other student farthest from the tablet has taken a back seat. This non-participation was observed again 4 min into the session</p> <p>Non participation was also observed in a group of three boys with the one in the middle holding the tablet. (4 min)</p> <p>And also in a group of three girls (4.5 min) with the girl on the right of the middle girl holding the tablet. Although in this case, it was the middle girl who was not participating and the two other girls were discussing.</p> <p>In another group, one of the students working in pairs doesn't appear to be collaborating and the other person appears to be only watching over (1 min)</p>
2	Session 3, 6 min	Breakdown	<p>The application closed.</p> <p>A group lost all their work because the application suddenly closed. They had to start all over but managed to finish on time.</p>
3	Session 3, 7.5 min	Breakdown	<p>Application not responding</p> <p>The application was not responding and had to be restarted. Similar to Incident 3, the group lost their work and had to start again.</p>


CID	Time	Breakdown/ Breakthrough	Context
4	Session 3, 10.5 min	Breakdown	<p>Students did not finish on time.</p> <p>Students were tasked to create two survey questions but the allocated 10 minutes was not enough for all to finish so some groups only managed to create 1.</p>
5	Session 3, 11 min	Breakthrough	<p>Students discuss with their groups the answer to the surveys created by the other groups.</p> <p>The survey students created was administered to the rest of the class by passing the tablets from one group to another. Students appeared to be engaged in the process as they answer the survey questions the other student groups created.</p>
6	Session 3	Breakthrough	<p>Students working on their own appear to be engaged in the activity (1 min)</p> 

## Session 4

CID	Time	Breakdown/ Breakthrough	Context
1	Session 4, 4.5 min	Breakthrough	The teacher went up a chair to point out the existence of complimentary angles in the beam.
2	Session 4, 5.5	Breakdown	Tablet is not charged. The tablet was swapped with a different tablet so this means that previous pictures taken were lost.
3	Session 4, 6 min	Breakdown/ Breakthrough	<p>Students decided not to use the QR code to see the order of the task.</p> <p>The teacher saw a pair of students writing something down on paper. She asked what they need the paper for as the activities only required the tablet. They replied that it was so that they don't have to scan the QR code that shows the task order every time. (here the breakthrough shows how students tackle problems in the activity).</p>
4	Session 4, 7 min	Breakthrough	Student is discussing with a partner which picture to take.
5	Session 4, 8 min; 10 min	Breakdown	<p>Student is not engaged.</p> <p>A student commented: This tablet hate me. To put this in context, this student had problems with tablets since Session 1.</p>
6	Session 4, 8.5 min	Breakthrough	<p>Students adjust the objects in their environment to fit the properties that they need.</p> 
7	Session 4, 12.5 min	Breakdown	Students were directed to share the images to the teacher tablet using a wireless network, however, it was not initially seeing this. It took more than three mins to fix the issue.
8	Session 4, 15.5 min	Breakthrough	Teacher was explaining supplementary angles to a group of students by pointing out an object in the room.
9	Session 4, 18.5 min	Breakdown	A student still didn't know what to do with the activity.



## Session 5

CID	Time	Breakdown/ Breakthrough	Context
1	Session 5, 1 min	Breakdown	Student cannot see the screen clearly.  It was bright and sunny outside and this affected the brightness of the screen which were not initially an issue in class.
2	Session 5, 3 mins	Breakdown and Breakthrough	One tablet did not have the application installed.  One of the tablets did not have the application installed so there was a need to go back to the classroom to get another tablet (breakdown) As they wait for the replacement tablet, they continue to search for the items that they have to look for and managed to catch up with the rest of the class (breakthrough)
3	Session 5, 5 min	Breakdown	There appears to be a misconception of what an angle is and what appears to be an angle.
4	Session 5, off-camera	Breakdown	Student prefers to work on a camera.  The tablet application kept crashing so students were given a camera to work on as they wait for a replacement tablet. When the tablet came, however, students opted to keep working on the camera.
5	Session 5, 7 min	Breakthrough	Students create representations of abstract concepts.
6	Session 5, 8 min	Breakdown	Students are not engaged on task.  
7	Session 5. 9 min	Breakthrough	Students share with other groups items that they have found. When students find something from the list they share it with another group.

## Session 7

CID	Time	Breakdown/ Breakthrough	Context
1	Session 7, 1 min	Breakdown	<p>There was a misunderstanding on which application to use.</p> <p>There were two applications that can be used to measure the height misconception about finding the area of a standing object vs an object on the ground. as it turns out, the two different applications to measure height and width becomes a bit confusing.</p>
2	Session 7, 1 min	Breakdown	A student commented that the measurement is off. This issue is caused by not calibrating the tablet correctly.
3	Session 7, 3 min	Breakdown	There were too many difficulties with using the application so several students were asking for support.
4	Session 7, 4.5 min	Breakdown	<p>Students were getting confused about the task.</p> <p>Context: for this activity only, students were split into advanced group and normal group to allow differentiation of task. The normal group had to take a picture of an object and annotate it with its measurement (using skitch for annotating and the measurement applications). For the advance group they also have to create an augmented reality representation of these objects. The complexity of the task confused the students.</p>
5	Session 7, 5.5 – 7.5	Breakdown	<p>Students do not know how to work out the area by using the measurement.</p> <p>Context: students were not able to make the link between the task of measuring the dimensions of an object and how it links to solving for the area.</p>
6	Session 7, 11 min	Breakdown	<p>A student was not sure how to check if the measurement is correct or not.</p> <p>“my app says 3.91 what is it meant to be. there is no way to verify.”</p>
7	Session 7,	Breakdown	Students were not engaged.

	13.5		as some students are being directed what to do, other students not in control of the tablet are not engaged.
8	Session 7, 18 min	Breakdown	Students were not clear what to do next.  Context: This was for the advanced group who were going to create an augmented reality representation. The plan was to work through the project with them (in addition to the orientation they got before the session).
9	Session 7, 19.5 min	Breakdown	Student doesn't know how to use the application.  One of the app used for the project is Skitch which is an application they have used in several occasions. One student, however, forgot how to use the application.
10	Session 7, 22 min	Breakdown	Tablets were getting wet.  It started raining so the tablet screens were getting wet.

### Session 8

Half of the data was corrupted for Session 8

<b>CID</b>	<b>Time</b>	<b>Breakdown/ Breakthrough</b>	<b>Context</b>
1	Session 8, 1 min	Breakdown	It was a windy day so the students were not very comfortable working outside.
2	Session 8, 1.5 min	Breakdown	Visibility of the screen  Students can't see the screen clearly so they can't make the right measurements
3	Session 8, 4.5 min	Breakdown	Students in the group forgot to assign roles  Context: the activity was done in groups of four students, 1 tablet was used for measurement, 1 tablet for recording, students were measuring the distance of the throw but no one was assigned to record it.
4	Session 8, 7 min	Breakdown	The activity cannot be carried out outdoors because of the weather condition.  The teacher suggested to move the activity in class
5	Session 8, not known	Breakdown/ Breakthrough (no video footage)	The app measurement was off.  Inside the class the other task was to measure the height. The measurements, however, were off and students verified this as they compare the measurements from the tallest student in class with the shortest one in class.
6	Session 8, not known	Breakdown (no video footage)	In a collaborative worksheet, it was not possible to track student input  An app was used to allow the students to key in the measurements then sync those gathered data into a master spreadsheet, one student keyed in a derogatory remark beside the name of another student and caused the students to be upset. As all the tablets were logged in under the same account, this was not possible to check.
7	Session 8, End of session	Breakdown	Students did not finish on time.  Due to the incident in CID 6 above there was no follow up discussion done.