

Mobile Learning and Numeracy: Filling gaps and expanding opportunities for early grade learning

Prepared for GIZ by

Carmen Strigel and Sarah Pouezevara
RTI International*

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CONTENTS

LIST OF EXHIBITS	II
EXECUTIVE SUMMARY	I
1 INTRODUCTION	1
1.1 FUNDAMENTALS OF EARLY GRADE MATH AND NUMERACY	1
1.2 WHAT IS MOBILE LEARNING?	6
1.3 ABOUT THIS STUDY.....	8
2 MOBILE DEVICES AND ICT FOR EARLY GRADE MATHEMATICS EDUCATION	10
2.1 WHY MOBILE LEARNING?	10
2.2 MOBILE DEVICES—WHAT DO THEY HAVE TO OFFER?.....	11
2.3 LESSONS FROM COMPUTER-MEDIATED MATH INSTRUCTION AND MOBILE GAMING AND CONSIDERATIONS FOR YOUNG CHILDREN	15
3 MOBILE LEARNING FOR EARLY GRADE MATH—WHAT EXPERIENCE EXISTS?	19
3.1 CATEGORY 1 TECHNOLOGIES: BASIC PHONES	19
3.2 CATEGORY 2 TECHNOLOGIES: FEATURE PHONES	20
3.3 CATEGORY 3 TECHNOLOGIES: SMARTPHONES AND TABLETS	24
4 OPPORTUNITIES AND LESSONS LEARNED	27
4.1 M-MATH FOR STUDENTS	28
4.2 M-MATH FOR TEACHERS	32
4.3 M-MATH FOR PARENTS	35
5 CONCLUSIONS AND RECOMMENDATIONS	37
5.1 CROSS-CUTTING CONSIDERATIONS AND SCALE UP	37
5.2 RECOMMENDATIONS	40
5.3 AREAS FOR IMMEDIATE ACTION AND/OR FURTHER RESEARCH.....	44
ANNEX 1: GLOSSARY	1
ANNEX 2: REFERENCES	3
ANNEX 3: MATHEMATICAL UNDERSTANDINGS AND AFFORDANCES OF MOBILE TECHNOLOGY	9
ANNEX 4: EXAMPLES OF M-MATH PROGRAMS	14

LIST OF EXHIBITS

EXHIBIT 1: ESSENTIALS OF NUMERACY.....	2
EXHIBIT 2: EARLY GRADE MATH LEARNING TRAJECTORIES.....	4
EXHIBIT 3: EGMA SCORES 2009-2012—OVERVIEW.....	6
EXHIBIT 4: VARIATIONS ON MOBILE LEARNING CONFIGURATIONS.....	7
EXHIBIT 5: PENETRATION OF FEATURE PHONES COMPARED TO SMARTPHONES.....	12
EXHIBIT 6: MOBILE DEVICE FEATURE AND FUNCTIONS, AND APPLICATIONS FOR TEACHING AND LEARNING.....	13
EXHIBIT 7: SCREEN SHOTS OF MoMATHS INTERFACE.....	21
EXHIBIT 8: EXAMPLE OF UFRACTIONS GAME.....	23
EXHIBIT 9: SKETCHPAD EXPLORER SCREENSHOT.....	24
EXHIBIT 10: TANGERINE:CLASS FOR LITERACY ASSESSMENT SCREENSHOT.....	25
EXHIBIT 11: EXAMPLE OF TABLET MATH SYSTEM.....	26
EXHIBIT 12: CHARACTERISTICS AND CONSIDERATIONS FOR CATEGORIES OF M-LEARNING PROGRAMS.....	41
EXHIBIT 4B: EXPERIENCES ACCORDING TO M-LEARNING CATEGORY.....	A17

EXECUTIVE SUMMARY

The present study on Mobile Learning and Numeracy examines how mobile learning (m-learning) could influence and improve numeracy education at early grade levels (ages 4-10) especially in low-income countries. Key questions to guide the research include: 1) What are the benefits and challenges of integrating mobile learning into early grade numeracy education? 2) What is the role of a teacher with regard to mobile learning and numeracy education? 3) How can the community and the parents actively contribute to/participate in the child's numeracy education with the use of mobile devices? and 4) How can mobile technology be used effectively in measuring/assessing numeracy gains?

Effectively describing the potential use of m-learning for early grade numeracy in developing countries requires untangling a web of knowledge, theory, and experience from the domains of math instruction, early childhood education, ICT for development, and mobile learning. There is no doubt, though, that the increasing levels of "access" to mobile phones even in the poorest and most rural communities acts as a powerful driver for mobile learning and offers a greater chance, although not without challenges, for longer term sustainability of interventions. Further, our review of research on early grade mathematics and developmental progressions of *what* children learn and *how*, and existing experiences from computer- and game-based approaches, has identified "pedagogical" drivers making a case for mobile learning for numeracy.

However, there is very little practical and rigorously evaluated experience to date in mobile learning for early grade numeracy in the developing world. Existing initiatives are more dominant in the higher grades and particularly in the US and Europe, with a focus on using tablets and smartphones and a variety of educational games and tools for reading and mathematics. However, contextual factors play such a strong role that the same program or software may yield significant effect sizes for mathematics achievement in one implementation, and no impact in the next. Furthermore, few initiatives to date maximize the convergence of features provided for in smartphones and tablets for new pedagogies. There are also issues related to safety and privacy that need to be carefully considered, especially when working with very young children, but also adults. At the same time there are a few promising examples, even using most basic mobile phones, for teacher professional development, parental engagement and advocacy, and early mathematics diagnostics and student assessment. In addition, there are opportunities for new pedagogies made possible by the mobility of the devices, their multi-functionality integrating image, audio and video; or icon- and touch-based interfaces that warrant further exploration for learning.

The conclusions and recommendations of this study have been informed by an international working group that met over two days during the first International Numeracy Conference in Berlin in December 2012. We would like to acknowledge the following participants of this working group for their thoughtful contributions: Michaela Brinkhaus (BMZ); Dorothea Coppard (GIZ); Melanie Stilz (Konnektiv Büro für Bildung und Entwicklung); Jens von Roda-Pulkowski (KfW); Abigail Bucuvalas (Sesame Workshop); Mr. Kann Puthy (Primary Education Department, MoEYS Cambodia); Edward Barnett (DFID).

1 | INTRODUCTION

Since its emergence in academic circles as early as the year 2000, to its increasing pervasiveness in commercial and non-profit sectors, mobile learning (m-learning) has been used for subjects ranging from pre-natal care to elementary science to post-graduate teacher training. The reasons for this are varied, and depend as much on the culture and context in which they emerged, as on the affordances of the devices being used. The extent to which the actual content of the m-learning has been the driving factor is unclear, however. This section introduces the context of this study by presenting some fundamental concepts about early grade numeracy, and some key definitions and assumptions surrounding the idea of m-learning. This will provide the basis for explaining how math as a subject, and the specific pedagogical objectives involved in early grade numeracy, can be approached from a mobile learning perspective. The remainder of the paper will provide specific examples of how those pedagogical objectives, combined with the affordances of mobile devices, can create (or are already creating) learning opportunities for children everywhere, but especially in developing countries where access to quality math instruction in the early grades is often limited.

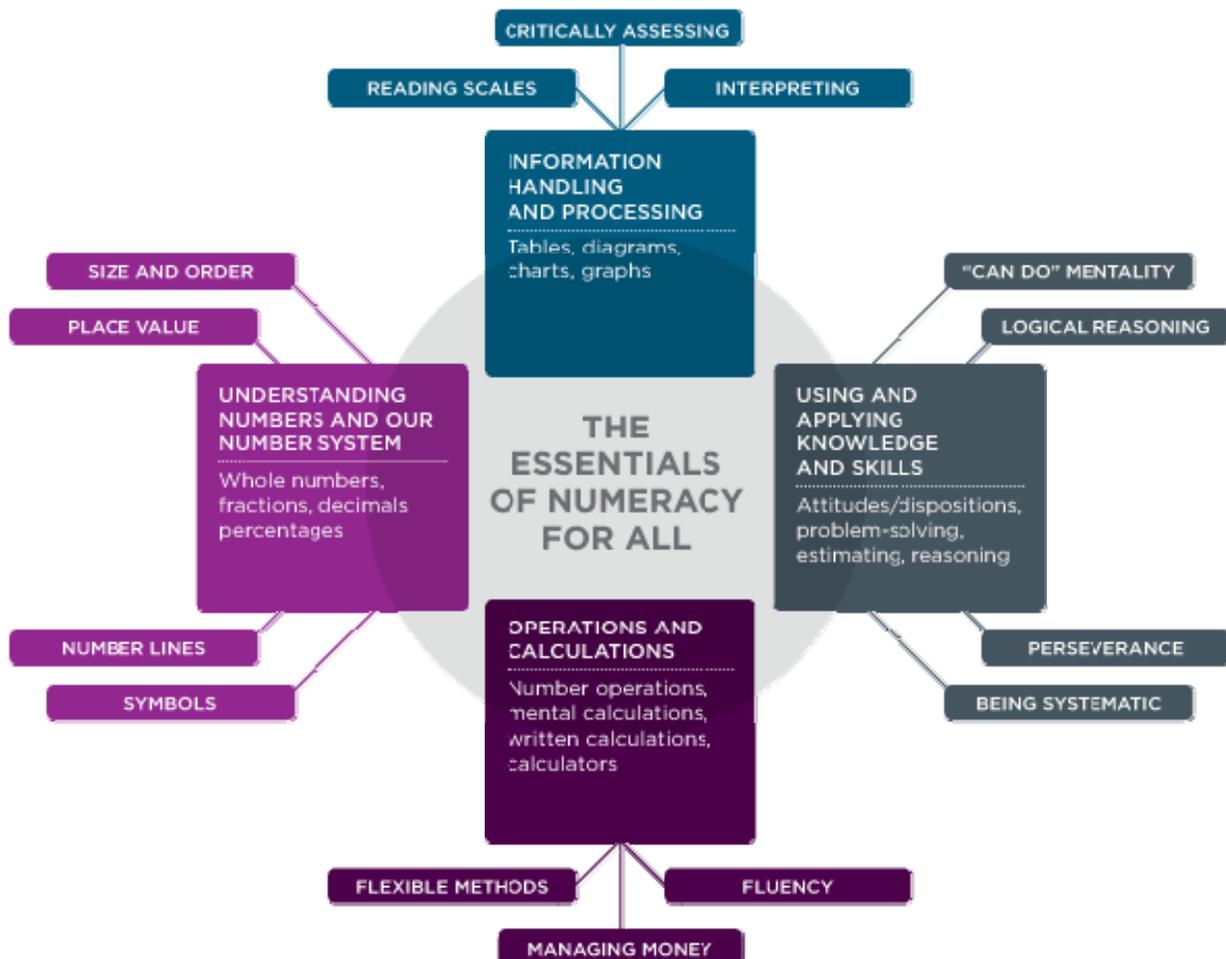
1.1 | FUNDAMENTALS OF EARLY GRADE MATH AND NUMERACY

Across cultures, mathematics permeates many facets of our lives. Whether to decide in which line to queue up, at which market stand the tomatoes are cheaper or how many one can purchase for the money one has, the number of sheep in a flock, how to hit the ball in the upper right corner of the goal, or the design of a new car or building, mathematical concepts are deeply embedded in our activities and contexts. Math skills are essential for adults to function in society, whether employed or not, in formal or informal economies. Many math skills are implicit and used almost without recognizing their mathematical foundations, such as quantity discrimination, notions of time and distance, sorting and grouping, or recognizing and using patterns. Many of these skills are learned outside of school and form a basis on which more formal math learning begins. While exact wording varies and very divergent concepts exist, definitions of *numeracy* commonly use this “real life” aspect as a criterion to delineate numeracy from *mathematics*, and especially school mathematics in the higher grades. For the purpose of this report, we adopt the understanding that “being numerate means being able to use knowledge and understanding about numbers, calculation strategies and data-handling techniques to solve problems and make decisions in many different contexts” (National Numeracy, 2012). Numeracy in this view goes beyond counting, computational fluency, measurement, and geometric understanding, but instead focuses on *applying* these abstract principles to problem solving, decision making, and logic reasoning. Exhibit 1 provides more detail as to what knowledge and skills numeracy entails.

Current research suggests that children are born with an innate, pre-verbal number sense that allows them, even in the absence of formal mathematical education to discern, for example, quantity differences in small sets of objects. Toddlers and pre-school aged children also show some basic arithmetic understanding of addition (adding something) and subtraction (taking something away) (Dehaene, 1997).

“But he has more cookies [than I]”; “My balloon is bigger” – 2-year old children

Exhibit 1: Essentials of Numeracy



Source: National Numeracy, 2012.

Over time, such early understandings progress to more concrete concepts. For example pre-verbal number sense progresses to a symbolic, secondary number sense, which includes using number words as numerical signifiers of objects, and understanding representations. At the same time, symbolic (or verbal) number sense, recognized as a foundational mathematical concept (Jordan et al., 2009), appears to be highly dependent on the inputs children are receiving—that is, the stimulations provided to them through everyday experiences and play or targeted activities at the early age. That means that, although it is argued that children are "... self-monitoring learning machines who are inclined to learn on the fly, even when they are not in school and regardless of whether they are with adults" (Gelman cited in Ginsburg, 2006) and that their innate mathematical knowledge may be more complex and sophisticated than traditionally assumed (Ginsburg, 2006.), evidence points to the importance of carefully planned and integrated activities to support children in their natural development of extending prior knowledge into an explicit level of awareness of mathematical concepts.

Every new concept or technique (e.g., counting on from a cardinal value rather than counting all) a child learns is a building block in a chain of understanding that develops over time. Children who come to school with more limited skill sets picked up in the home and community environment may need additional support in the early grades. Evidence suggests that early math concepts such as knowledge of numbers and ordinality are powerful predictors of later learning, and in fact, early math is a more powerful predictor of later reading achievement than early reading is of later math achievement (Duncan, et. al. 2007). Findings from such research has informed many recent movements in designing developmentally appropriate early childhood education programs and pre-school and early primary math curricula, especially in high-income countries. Evidence-based efforts here are, however, not geared toward conducting lessons that target isolated mathematical learning objectives, but are using playful and integrated practices that promote mathematics understanding (e.g., in sorting and classifying, comparing quantities, or recognizing patterns and shapes).

Children do not see the world compartmentalized into curriculum areas and subject matter, but their understanding and use of mathematics is deeply embedded in their day-to-day activities and thus provides an opportunity for intervention both inside and outside of formal learning environments. With this understanding, instructional good practices focus on differentiating and adapting instruction for students at varied developmental progressions, as well as active engagement of students, appropriate scaffolding and building on prior knowledge, asking probing questions that require children to justify responses, use of manipulatives, cooperative learning, and making connections to the real world (The Education Alliance, 2006).

“this block does not fit here, it is too big” - “you get one cookie and I get one cookie“ - 4-year old child

Mathematical understanding helps children make sense of their world and find solutions to new problems. Fostering early mathematical skills not only serves students’ later academic achievement in mathematics, but helps them develop “...dispositions such as curiosity, imagination, flexibility, inventiveness and persistence that contribute to their future success in and out of school.” (NAEYC&NCTM, 2002, p.5). Children across cultures share many of these developmental progressions and early mathematical interests (NAEYC&NCTM, 2002), and while their nature may vary, virtually all instructional environments—even in low-income countries—will “...contain objects to count, shapes to discriminate, and locations to identify [that]... afford mathematical thinking” (Ginsburg, 2006, p.2). A comparison of curricula from a range of countries revealed a high overlap in curricular goals and expectations in the early grades. Among the most universal topics are 1) number, operations, and relationships; 2) patterns; 3) shape and space/geometry; 4) measurement; and 5) data handling (e.g., picture graphs) (RTI International, 2009).

In the United States, so-called learning trajectories have emerged that map empirical knowledge on the sequence of how children progress in their development of mathematical concepts and skills with instructional practices that promote learning. The focus is placed on the *processes* that allow children to acquire mathematical content knowledge such as problem solving, reasoning, decision making, or representation, thus being in line with our understanding of numeracy. Recognizing that individual variations between children may be large (NAEYC&NCTM, 2002), learning trajectories are research-

based generalizations that provide an understanding of what children in a certain age range may be able to understand or do, rather than a fixed timeline to reach specific learning objectives.

For this study, we have appropriated the concept and research around learning trajectories to explore and map the affordances mobile learning provides for children’s mathematics learning as it seems to be the most viable framework that links evidence-based learning progression to actual instructional tasks and materials that promote these in the domains shared across a great many countries, including in the developing world, and in age ranges central to this study.¹ Exhibit 2 outlines age ranges and map them against developmental and learning progressions for key mathematical areas.

Exhibit 2: Early grade math learning trajectories

Domain	0-4	4-6	6-8+
Number, Subitizing, Counting and Comparison	<ul style="list-style-type: none"> Verbally counts with number words Accurately counts objects in a line to 5 (one-to-one correspondence) and answers “how many” (cardinality) Instantly recognizes collections up to 4 briefly shown (subitizing) 	<ul style="list-style-type: none"> Skip counts verbally and with objects by tens up to 100 and beyond Counts verbally and with objects from numbers other than 1 Identifies and uses ordinal numbers (1st-10th) Mental number line to 10 	<ul style="list-style-type: none"> Verbally labels structured arrangements shown only briefly, using groups, multiplications, and place value Mental number line to 1,000
Patterns	<ul style="list-style-type: none"> Fills in missing elements in patterns for ABAB 	<ul style="list-style-type: none"> Identifies the smallest units of a pattern 	<ul style="list-style-type: none"> Describes pattern numerically, can translate between geometric and numeric representations of a series
Arithmetic (Operations) and Composition	<ul style="list-style-type: none"> Finds sums for joining ^a problems up to 3+2 by counting all with objects 	<ul style="list-style-type: none"> Finds sums for joining and part-part-whole ^b problems with finger patterns and/or counting Solves take-away ^c problems by separating with objects 	<ul style="list-style-type: none"> Uses composition of tens and all previous strategies and known combinations
Space and Shape; Composition, Decomposition of 2D Shapes; Decomposition of 3D Shapes	<ul style="list-style-type: none"> Mentally turns objects in easy tasks Recognizes less typical squares and triangles, but usually not rhombuses Uses manipulatives representing parts of shapes, such as sides, to make a shape that “looks like” a goal shape 	<ul style="list-style-type: none"> Locates objects using maps with pictorial cues Performs slides and flips with shapes, often only horizontal and vertical using manipulatives, performs turns of 45, 90 and 180 degrees. Classifies most common shapes 	<ul style="list-style-type: none"> Follows a simple route map, with more accurate directions and distances Predicts results of moving shapes using mental images Refers to geometric properties and explains with transformations

¹ The learning trajectories serve as a useful reference guide for the reader when linking early grade math subjects and instructional approaches with actual or potential use of mobile devices that can help improve the quality or amount of math instruction. It is important to note that while this study focuses on early grade learning, the actual age of children in need of early math skills instruction may be significantly different in developing countries than in developed ones. Furthermore, there has been little research to date to validate these learning paths in extremely low-resource settings.

Domain	0-4	4-6	6-8+
Measurement	<ul style="list-style-type: none"> • May compare areas using only one side of figures, or estimating based on length plus width • Covers a rectangular space with physical tiles, but cannot organize, coordinate, and structure 2D space without such perceptual support • Can compare two containers, e.g., to see which holds more 	<ul style="list-style-type: none"> • Draws and counts some, but not all rows as rows in an area. May make several rows and then revert to making individual squares • Partial understanding of cubes as filling a space • Matches angles correctly. Explicitly recognizes parallels from non-parallels in specific contexts. • Sorts angles into smaller or larger (but may be misled by irrelevant features, such as length of line segments) 	<ul style="list-style-type: none"> • Iterates squares in a row or column to determine area • Multiplicatively iterates squares in a row or column to determine area with linear measures or other similar indicators of the two dimensions • Understands angle and angle measure and can represent multiple contexts in terms of the standard, generalizable concepts and procedures of angle and angle measure

^a An action of joining increases the number in a set. Joining problems can be either $_+6=11$ (“Al had some balls. Then he got 6 more. Now he has 11 balls. How many did he start with?”), with the start unknown, $5+_=11$, with the change unknown, or $5+6=_$ with the result unknown.

^b Two parts make a whole, but there is no action—the situation is static. Part-part-whole problems can either be “partner” unknown (e.g., “Al has 10 balls. Some are blue, 6 are red. How many are blue?”) or the “total” unknown (e.g., “Al has 4 red balls and 6 blue balls. How many balls does he have in all?”).

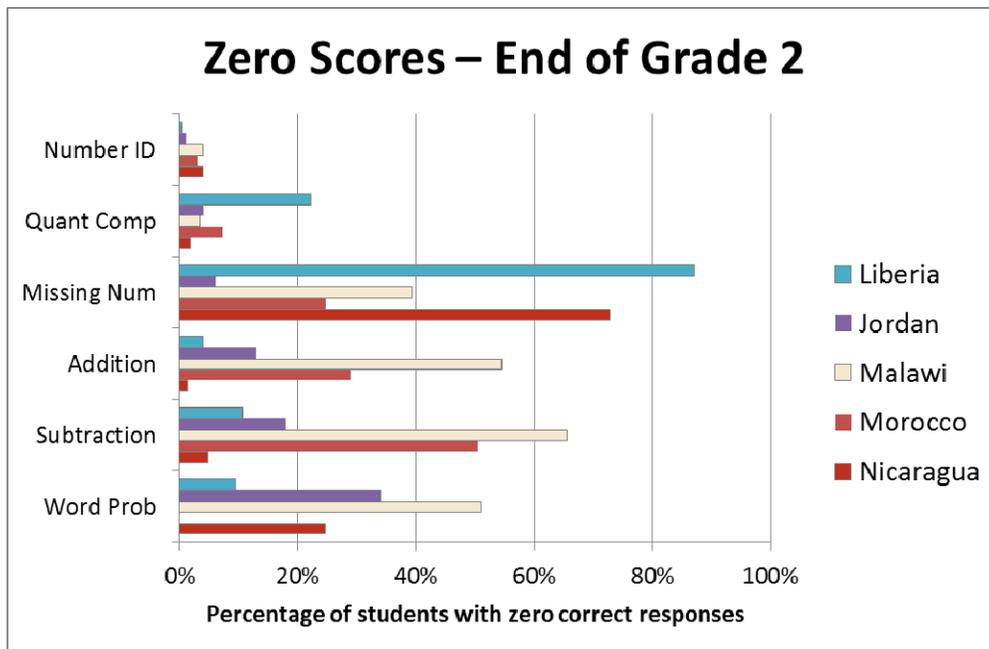
^c An action of take-away decreases the number in a set. Joining problems can be either $_ - 5=4$ (“Al had some balls. He gave 5 to Barb. Now he has 4 balls. How many did he start with?”), with the start unknown, $9-_=4$, with the change unknown, or $9 - 5=_$ with the result unknown.

Source: Adapted from Clements & Sarama, 2009.

Mathematics diagnostics, observations tools and assessments that have been developed include the Early Numeracy Research project, (1999-2001, Victoria, Australia, see Clarke, et al. 2002); the Early Numeracy Project, (2003, British Columbia, Canada, see Ministry of Education, British Columbia); the Early Grade Mathematics Assessment, (2009-date, global, see RTI International, 2009). These tools help inform teachers on a child’s progress along this learning path and to target activities that are developmentally appropriate. For larger groups and populations, such assessments and observations can also help identify patterns of ineffective methods and gaps in achievement and thus inform policy and practice on a systems level. The Early Grade Mathematics Assessment (EGMA), for example, aims to assess students’ performance on the most fundamental and predictive competencies that students need for future success. Locally adapted forms of the instrument have been used in over a dozen low-income countries to date with data being available to the public from DR Congo, Jordan, Kenya, Liberia, Malawi, Morocco, Nicaragua, and Rwanda (Exhibit 3). These results shed light on the performance of students on many of the early numeracy skills outlined above, such as number identification, quantity discrimination (mental number line), missing number (patterns), addition and subtraction, and word problems. A review of results indicates that at the end of grade two in the above mentioned countries, students struggle especially with missing number (pattern) tasks and subtraction, with up to 85% of children (Liberia) not getting a single missing number item correct and up to 65% of children (Malawi)

getting a zero score on subtraction. Word problems also seem to be particularly difficult for children to solve.

Exhibit 3: EGMA Scores 2009-2012—Overview



Source: Ralaingita & Ketterlin-Geller, 2012.

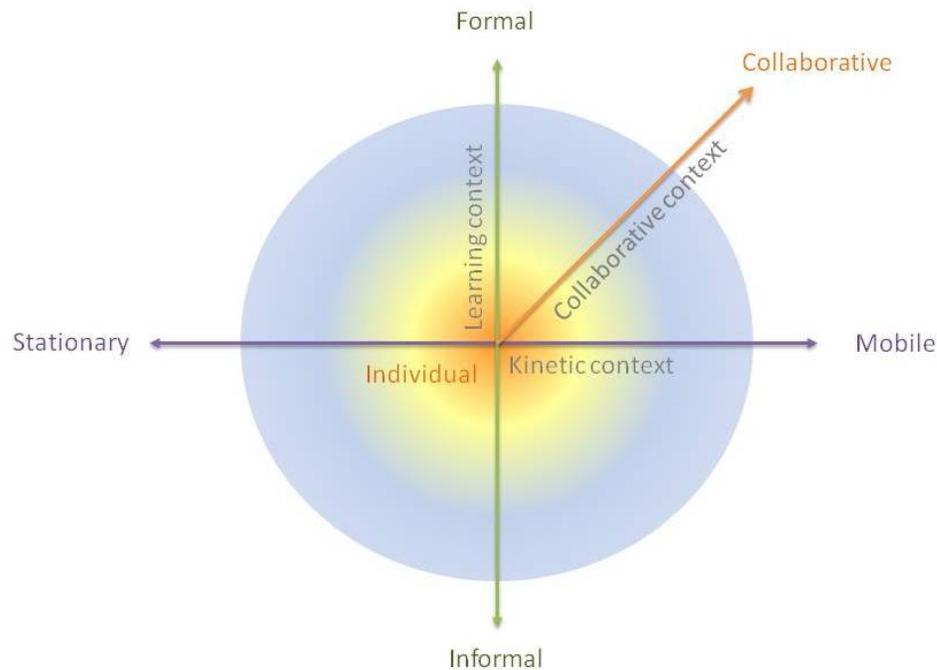
1.2 | WHAT IS MOBILE LEARNING?

Mobile learning (m-learning), though increasingly popular given the rise in mobile phone penetration and advances in wireless and 3G technologies, has been part of the education landscape for decades.² During this time, the term has been conceptualized in many ways, from a *technocentric* perspective, meaning the use of handheld electronic devices for educational activities in or outside of classrooms, to more *learner-centric* “processes of coming to know through conversations across multiple contexts amongst people and personal interactive technologies” (Sharples et al. 2007). The key distinction is whether the focus is on the portability of the device, or on the mobility of the learners. For the purpose of this study, we will use a definition provided to us by Helen Crompton, which has been accepted for publication in a forthcoming handbook on m-learning: “m-Learning is learning across multiple contexts, through social and content interactions, using personal electronic devices” (Crompton, in press). These electronic devices can be simple or advanced mobile phones, portable media players, pocket PCs, portable gameplayers (e.g., Nintendo DS), tablet computers, or even custom handheld devices. The “contexts” can be traditional classrooms, informal learning environments, homes, and communities. In the classroom, the context can cross-multiple curricular areas and involve self-directed learning or collaborative learning with peers. The uniqueness of many technologies today, including mobile

² Portions of this section have been borrowed and adapted from previous publications by the same author, notably a conference presentation from mLearn 2012 (Helsinki, October 14) and EduTechDebate (<https://edutechdebate.org/mobile-teaching/mobiles-for-teaching-and-learning-translating-theory-into-practice/>).

technologies, is their ever-increasing capacity to interact and communicate with each other, and thus another dimension of m-learning is the extent to which it is collaborative/productive or individualistic/receptive. A visual model of the range of m-learning approaches is presented in Exhibit 4, with any m-learning initiative lying somewhere along a kinetic spectrum from mobile to stationary, a learning spectrum from formal to informal, and a collaborative spectrum from individual to collaborative. Yet anywhere we place the program on this grid, the common denominator is that the learning is mediated by a portable electronic device.

Exhibit 4: Variations on mobile learning configurations



Surrounding all of these categories for content-specific mobile learning, there are also entire learning management systems being developed through mobile communications, from SMS-based reminders and schedule planners to sophisticated tablet-based education delivery services that provide a mechanism for managing interactive content, quizzes, test preparation, collaboration, peer support, and certification across subjects.³

Characteristics of m-learning include the spontaneous nature of learning and the way in which learning can become context-specific through interactions between the learner, the device, and the environment. The affordances of m-learning, can be categorized into four main themes: *accessibility* (access to learning opportunities, reference materials, experts/mentors, other learners); *immediacy* (on-demand learning, real-time communication and data sharing, situated learning); *individualization* (bite-size learning on familiar devices; promotes active learning and a more personalized experience); and *intelligence* (advanced features make learning richer through context-aware features, data capture, multimedia). From this perspective it is clear that m-learning today—at least in the developed world

³ For example, T Smart, South Korea (referenced in: http://www.ericsson.com/res/thecompany/docs/publications/business-review/2012/issue1/the_tools_of_education.pdf); eLimu, Kenya (www.elimu.com); and mPrep (www.mprep.it).

where it is possible to be “always connected”—is about the mobility of the learners, not just about the device.

In the developing world, however, m-learning is not only about having “*just the right content, on just the right device, for just the right person, at just the right time*” (Hodgins, 2002), but also having all of this *at just the right cost*. With the staggering increases in ownership, mobile phones and handhelds have become essential parts of daily life for youth and adults alike (GSMA, 2012), and an ever more important common denominator for reaching potential learners. This is true in developing countries as well as developed ones. In the United States, for example, a survey found that there was almost no difference in smartphone ownership based on demographics such as “Title 1” (an indicator for community poverty) or non-Title 1, or rural/urban/suburban youth; the authors conclude that “At least on access to mobile devices, the traditional interpretation of the digital divide appears to be no longer relevant” and mobile learning can be a way to “enable, engage and empower” today’s students, and extend learning beyond the classroom (Project Tomorrow, 2011). The GSMA report (2012) indicates that, at least in the countries surveyed, adolescents have access to mobile phones either of their own or borrowed from friends and family members. They may only own a SIM card, but share a handset with other youth.

There is little data on access to mobile phones by children (under 12 years old) in developing countries, and most case studies of mobile learning in Africa and South-East Asia are limited to higher education contexts, particularly teacher training or health service workers, for example. The use of SMS is widespread as a way to support practitioners in their work through inexpensive and accessible communications and this has been a strategy for increasing interactivity and reducing isolation in a number of open and distance learning (ODL) models for adults. Informal m-learning in the form of mobile games or using social media is possibly the most widespread use of m-learning for young adults and children. Projects such as MoMaths, Dr. Math, and Yoza (cellphone stories) have emerged as the largest and most well-known projects, leveraging the popular MxIT mobile social networking platform that is neither SMS nor web-based, but somewhere in between, making it a fast yet inexpensive instant messaging service popular in low-resource environments. More detail is provided about many of these projects in the sections below.

1.3 | ABOUT THIS STUDY

The “Education for All” (EFA) goals were first decided in 1990 and later re-emphasized in 2000 by 189 countries. The EFA goals include a commitment to “Improve all aspects of the quality of education and ensure the excellence of all so that recognized and measurable learning outcomes are achieved by all, especially in literacy, numeracy and essential life skills.”

Though the past years have seen a significant improvement in elementary school literacy levels in many developing countries, numeracy has remained an important yet widely ignored facet of the international “Education for All” agenda. In response to this gap, and recognizing the importance of early grade numeracy toward reaching the EFA goals, The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH has commissioned three background papers on early grade numeracy to inform working groups at the International Numeracy Conference in Berlin organized by BMZ/GIZ and GPE on December 3-4, 2012.

The present study is part of this series. Although mobile learning has proven to be effective in many instances of improving reading and writing skills, the present study's objective is to examine how mobile learning could influence and improve numeracy education at early grade levels (ages 4-10) in the developing world. As a result, the study aims to formulate concrete implementation and action-oriented recommendations for GIZ consideration. The following questions guided the research:

1. What are the benefits and challenges of integrating mobile learning into early grade numeracy education?
2. What is the role of a teacher with regard to mobile learning and numeracy education?
3. How can the community and the parents actively contribute to/participate in the child's numeracy education with the use of mobile devices?
4. How can mobile technology be used effectively in measuring/assessing numeracy gains?

The data for the study was gathered predominantly via a review of existing research publications, notably the UNESCO-funded *Turning on Mobile Learning* series published earlier this year; a review of industry-relevant conference websites and programs, namely mEducation Alliance 2012, mLearn 2012, WirelessEdTech 2012; and review of academic journals and general web research using key words. Additionally, informal interviews and email conversations were conducted with select experts in m-learning, early mathematics and numeracy, mobile content development, and their intersection, including the following:

- Helen Crompton—University of North Carolina at Chapel Hill, Doctoral Student
- John Traxler—University of Wolverhampton, Professor of Mobile Learning
- Artur Dyro—Young Digital Planet SA, Poland, CEO
- Aape Pohjavirta—Inclusion.fi, CEO
- Wendi Ralaingita—RTI International, Early Mathematics Expert
- Deepa Srikantaiah—Global Partnership for Education (GPE), Education Specialist
- Michel DeGraff—Massachusetts Institute of Technology (MIT), Associate Professor of Linguistics

While the range of mobile devices may include laptops, mobile phones, portable radios, televisions, and eReaders, as well as custom devices (e.g., Vodafone WebBox) or pico/pocket projectors (even available with WiFi and Android OS), this study focuses on the particular contribution of mobile phones, including the whole range of basic phones, feature phones, and smartphones, as well as tablet devices and select eReaders.

As mentioned by several other authors of recent reports on Mobile Learning (e.g., UNESCO, 2012a-e; Trucano, 2012), the available data, especially on existing initiatives, is both scarce and most often does not serve as empirical evidence. Much of the documentation from the developing world is from implementation reports, conference sites and blogs and is descriptive and promotional, rather than analytic and evaluative; or, they are reports of university-led pilot projects that focus on implementation considerations, feasibility, and attitudes toward m-learning, but not learning outcomes. To substantiate argumentation, we have thus included peer-reviewed articles and evaluation reports from examples of mobile learning and numeracy at early and higher grades from the US and Europe. While contextual factors are highly critical, an argument we highlight ourselves based on findings from this desk study (see Section 2.3, below), we believe that in absence of alternatives, such experience is still valuable.

2 | MOBILE DEVICES AND ICT FOR EARLY GRADE MATHEMATICS EDUCATION

In Part 1, we have established that math is a critical early skill—maybe more so than literacy—for children worldwide, and that there is a progression of skills that correspond approximately to a child’s development from ages 4 to 10. Mathematics education in the early grades requires teaching a combination of concepts (logical reasoning), skills (computational procedures), and problem solving, and mathematical fluency requires automatic recall of certain procedures and algorithms. Mathematics instruction benefits from years of experimental research to determine what works; among the strategies that have been tried and tested are computer-based learning and gaming. In this section, we will look at drivers of mobile learning, what specific technology features and functions mobile devices have to offer for teaching and learning, and lessons learned from technology use and particularly mobile gaming in the early grades from around the world.

2.1 | WHY MOBILE LEARNING?

Proponents of mobile learning argue that affordable information and communication technology (ICT) can be a lever for expanding access to important educational content. As 21st century technologies are increasingly smaller, more powerful, and more affordable, mobile devices are becoming a commonplace accessory in people’s daily lives—in developing and developed countries alike. Personal mobile devices help us communicate with one another, find our way, maintain our schedules, receive reminders, make purchases, request and receive information, and more. Much of the communication and information sharing can be considered the most informal and basic type of learning, yet it may also be the most meaningful because it is integrated into authentic situations on demand. In a more deliberate way, the claim is that mobile technologies can not only bring content to the learners where and when they need it, but the communicative and intelligent computing features of today’s devices can also make learning more personalized, meaningful, and engaging. Mobile technologies increasingly provide more resources, computing power and functionality than that which is strictly ‘necessary’ for any given curriculum, thereby allowing learners to advance and expand their explorations of knowledge and skills.

“Mobile” technology is not limited to mobile phones. There are a range of mobile devices that can be appropriate for math learning at all ages and grades, and these devices are also becoming more affordable - certainly more so than traditional desktop computers (the cost of one desktop computer being equivalent to 5 to 10 mobile devices or more in some cases). Numerous reports also cite the increasing availability of mobile phones across the developing world and, thus, the potential of mobile-phone-based m-learning to meet the needs of growing numbers of undereducated youth and adults (UNESCO, 2012a-e; GSMA, 2012; McKinsey & Co., 2012; Vosloo, 2012). This may perhaps be the most important reason to further explore early grade m-math. To the extent that the “bring your own device” (BYOD)⁴ model can be applied, the potential for scalability is enormous. Mobile phones are an opportunity to access the “base of the pyramid,” (the more than half of the world that live on less than \$3

⁴ Bring Your Own Device policies encourage learners to use personal devices in formal educational settings. Though a BYOD policy can reduce costs related to providing devices and related responsibilities in some settings, it can be difficult to implement if ownership of devices is not very high and if the content in use is not compatible with these same devices and their operating systems.

per day), since the mobile phone is one of the lowest common denominators among many people in developed and developing countries. GSMA wireless intelligence estimates that there are 870 million unique mobile subscriptions in the Developed World and 2.33 billion the Developing World (Westhead, 2012). This is especially important from an equity perspective, as the gap in mobile phone ownership among men and women, urban and rural populations continues to decline. In 2010, according to the GSMA, women in Africa were 23% less likely and women in South Asia 37% less likely than men to own a mobile phone. We expect that as of 2012, those numbers will have changed to a more equitable balance, but reliable, up-to-date data could not be found to support this prediction.

EQUITY AND M-LEARNING

There are differing views on the ability of m-learning to create equity in education. A number of programs demonstrate that m-learning approaches have a particular ability to benefit most the marginalized, low-performing, rural students who have the most acute lack of resources (for example, K-Nect). However, these programs were typically those that provided technology to students in a research environment (thus with rigorous implementation, monitoring, and feedback.) It is less certain that m-learning will improve equity more generally by relying on the BYOD principle. Many critics warn that m-learning could exacerbate existing inequalities by relying on BYOD, which is still distributed inequitably, particularly across genders (Murthy, 2011). UNESCO (2012e) notes that “There are notable gender disparities in access to mobile subscriptions in AME [Asia and the Middle East]. A study by Research ICT Africa (RIA) reveals that in Zambia, Senegal, Benin and Uganda, there are substantially more male mobile customers than female. This trend may be attributed to a combination of unequal distributions of income, restrictive social taboos and higher illiteracy rates among women. The inverse holds true in South Africa, Cameroon and Mozambique, where female mobile subscribers tend to outnumber male customers (Gillwald et al., 2010).” There is also a clear opportunity for certain types of mobile devices and tools to address children with special needs and disabilities.

For the reasons above—access, scale, and engagement—mobile learning across subject areas and grade levels may be an important opportunity to improve both access to and quality of education in developing countries. However, there are also ways in which the quality of early grade math instruction in particular can be improved when combined with the affordances of mobile devices. The following section will describe these affordances and provide some initial examples of their applicability—potentially unique among teaching methods—for teaching and learning.

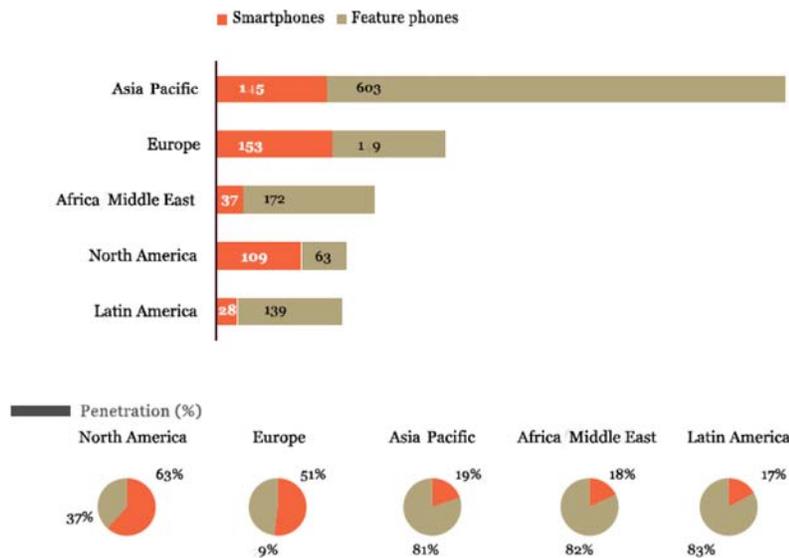
2.2 | MOBILE DEVICES—WHAT DO THEY HAVE TO OFFER?

The wealth of features and functions available through sophisticated smartphone or tablet technologies are particularly promising for a wide range of activities in the early grades. In the low-income contexts that this study is particularly concerned with, such devices are still rare. Nonetheless, prices of sophisticated smartphones and tablets dropped at an average rate of nearly 20% of their initial cost just in the last year (Business Insider, 2012), with sophisticated smartphones now being available for less than USD \$100 even in Africa (e.g., Huawei Ideos smartphone at Safaricom Kenya). Thus the opportunities

provided by this technology for learning may not be too distant a future for large parts of low-income country populations. Exhibit 5, below, provides insight into the global penetration and distribution of feature phones compared to smartphones. Consumer trends indicate that this distribution will continuously change to an increasing penetration of smartphones in coming years.

Exhibit 5: Penetration of feature phones compared to smartphones

Over 50% smartphone penetration in developed markets, less than 20% in emerging markets
 Mobile sales volumes per region in 2011 (millions of units, estimated)



Source: Extracted with permission from Vision Mobile (2011).

Cost is not the only consideration, however; in a context such as Sub-Saharan Africa, where nearly 70% of the population does not have access to regular, stable electricity (International Energy Agency, 2012), power-efficient devices are highly valued and more practical than smartphones or tablet devices with higher power ratings. With the growth in mobile phone penetration, an entire new business domain (Collings, 2011) has emerged around charging cell phones all over the developing world. From truck driver exchanges, to tiny solar panel access points strapped on donkeys, or elaborate multi-device charging stations, users everywhere find ways to charge their devices.

Furthermore, experience across a range of subject matter and age groups (to be described further in the following sections) suggest that even basic mobile phones can become powerful tools for teaching and learning. The spectrum of device types entails different features and combinations of features—some more available and affordable than others. These attributes can be categorized by the following:

- communicative features (SMS, audio playback, voicemail, person-to-person calls)
- data access/content transfer features (SMS push/pull communication with a server, FM/AM radio, mobile web, mobile social networks—twitter, MxIT, Facebook; GPS)
- input features (keypad, touchscreen interface, motion sensors)

- pocket-computer features (playing mobile games, loading multimedia content such as videos, audio, slide presentations, audio playback)

These attributes correspond approximately—but not exclusively—to types of technologies ranging from simple phones to feature phones, to smartphones and tablets. While some features and functions may not be appropriate for direct use by students, consideration needs to be given to teacher- or caregiver-mediated mathematical activities. In the latter context, the devices may function as professional development support, as well as teaching materials/manipulatives in the process.

Exhibit 6 provides an overview of some of the key features available for three categories of mobile technologies: simple phones, feature phones, and smartphones/tablets. The examples here are based on actual practices in m-math and other subject areas, as well as some possibilities that have yet to be explored, but which attempt to leverage the features of mobile devices for math learning.

Exhibit 6: Mobile device feature and functions, and applications for teaching and learning

Device Type	Features and Functions	Illustrative Example for Teaching and Learning
Basic Phone Average cost: USD \$25 Average battery life: 2 weeks, depending on device and usage	Communication: <ul style="list-style-type: none"> • SMS • Voice 	<ul style="list-style-type: none"> • SMS for sending motivational and supportive messages, tips, advocacy, awareness-raising • Call-in podcasts • Voice-based tutor support/instructional help desk • Person-to-person calls for support, homework help
	Content transfer: <ul style="list-style-type: none"> • SMS (ca. 160 characters) • USSD (ca. 182 characters) • FM Radio • Potentially Micro SD cards 	<ul style="list-style-type: none"> • SMS for content sharing and assessment—quizzes, multiple choice questions • Audio-enhanced SMS to short audio sequences and text • Interactive radio-based lessons: songs, quizzes, etc. • Sending commands by SMS (or USSD) to receive automatic feedback (i.e., a definition of word, or a formula)
	Input features: <ul style="list-style-type: none"> • Black and white screen • Alphanumeric keypad input 	<ul style="list-style-type: none"> • Identifying number symbols, names • Number sequences
	Pocket-computer features: <ul style="list-style-type: none"> • Audio playback • Audio recording • Calculator • In-built games 	<ul style="list-style-type: none"> • Preloaded audio content • Basic calculations • Logic and counting games such as tic-tac-toe or Mancala-type games (Seed)
Feature Phone Average cost: 50 \$USD	Communication: All of the above, plus <ul style="list-style-type: none"> • web-based email • photo capture 	<ul style="list-style-type: none"> • Learning communities, peer support, helpdesks • Using photos to capture real-world items and use in learning activities
	Content transfer: All of the	<ul style="list-style-type: none"> • Communicating with online content repositories for

Device Type	Features and Functions	Illustrative Example for Teaching and Learning
<p>Average battery life: 4-5 days to 2 weeks, depending on device and usage</p>	<p>above, plus</p> <ul style="list-style-type: none"> • “Ringtone” download • EDGE • GPRS data • Bluetooth • GPS 	<p>games, exercises, math problems</p> <ul style="list-style-type: none"> • Learning management systems • Location-based content delivery, e.g., providing mathematics content based on local languages predominant in a certain region
	<p>Input features:</p> <ul style="list-style-type: none"> • Color screen • Alphanumeric keypad input 	<ul style="list-style-type: none"> • Same as above, but more attractive to young learners because of screen size, colors
	<p>Pocket-computer features: All of the above, plus</p> <ul style="list-style-type: none"> • WAP • Java 	<ul style="list-style-type: none"> • Using GPRS/data transfer for accessing math exercises and sending results to central server • Use GPRS/data transfer and social media platforms/tools for learning community development or interaction • Java-based math learning content (applets and MIDlets) and assessments
<p>Smartphone, Tablet PC</p> <p>Average cost: US\$100-199</p> <p>Average battery life: 11 hours</p>	<p>Communication: All of the above plus:</p> <ul style="list-style-type: none"> • App-messaging • VoIP 	<ul style="list-style-type: none"> • Access to live tutors
	<p>Content transfer: All of the above plus:</p> <ul style="list-style-type: none"> • 3G/4G Datatransfer • WiFi 	<ul style="list-style-type: none"> • Web-based educational applications, virtual manipulatives • Web-based teacher professional development programs for early math/numeracy instruction • Instructional video clips, coupled with activity tips • Student assessment and school performance data applications with sync to central server
	<p>Input features:</p> <ul style="list-style-type: none"> • Color • Touchscreen • Pen input/writing transforms into digital text • Digital finger recognition • Motion sensor 	<ul style="list-style-type: none"> • Substitute blackboard • Intelligent paper • Classroom presenter with student interaction • App that recognizes and displays number characters by detecting how many fingers were put down for counting and simple arithmetic practice before number writing
	<p>Pocket-computer features: All of the above plus:</p> <ul style="list-style-type: none"> • Interactive multimedia apps • QR/barcode scanning 	<ul style="list-style-type: none"> • Educational apps • Mathematical graphing/sketching software • Teaching support tools for student continuous mathematics assessment and diagnostics • Embedding additional information in real-life environments or textbooks that can be scanned by device to provide additional information/exercises

As mobile devices and phones have evolved, naturally, so have applications that operate within the various platforms, catering to personal organizational, entertainment, and educational needs. Applications have emerged specifically for mobile phones, so-called MIDlets that use very little processing power and function independently of an Internet or data connection, making them ideally suited for low-resource environments where connectivity and sophisticated phone types are rare. Both MIDlets and Applets are java-based applications that, unlike “apps,” are not self-standing programs. MIDlets and Applets are used to run “app”-like content on lower-end mobile device including Java-games. For example, seizing the opportunity, Facebook launched “Facebook for Every Phone” in 2011 as a Java app to make it compatible with over “2,500 different phone models and at least 20 global carriers” (Yirka, 2011). The Myst m-learning and mobile gaming development environment is also built on the basis of Java-enabled phones, particularly the Nokia MUPE software.

Mobile devices are also increasingly able to access a wide array of webapp content, meaning that previous limitations on operating system compatibility have been greatly reduced. Content production for gaming and engaging software (BrainPOP,⁵ numbaland.com) is on the rise and increasingly tailored toward its primary use being on mobile devices (covering the most prevalent operating systems of Android, iOS, Windows mobile, and Symbian). Mobile devices can also be used for delivering electronic lessons or even electronic textbooks with digitally rich content or serve as tools to facilitate student mathematics assessment (Tangerine^{TM6}).

There are also other types of mobile devices that can be used for mathematics, such as pocket calculators (including advanced graphing calculators with touchpads⁷); eInk-based e-Readers, laptop computers with math software, including OLPC XO laptops (see Section 2.3 below); pico/pocket projectors; classroom response clickers; or custom devices like the Vodafone WebBox.⁸ However, it is beyond the scope of this study to expand on all of these in more detail. Also, among the key reasons for studying m-math in the developing context is that we can achieve economies of scale by targeting devices that people already have; this means devices that young children have access to and are capable of using without significant literacy skills or technological awareness. Therefore, when reviewing different mobile math applications, we will keep in mind appropriate technologies for the physical, social, and cognitive abilities (including literacy skills) of early grade learners. However, improving early grade math outcomes also involves teachers, parents, and other family or community members; thus while some m-learning approaches may directly target students, others may involve parents or other adults to mediate the learning process, and so more complex technologies can be explored.

2.3 | LESSONS FROM COMPUTER-MEDIATED MATH INSTRUCTION AND MOBILE GAMING AND CONSIDERATIONS FOR YOUNG CHILDREN

Computer-mediated math instruction. To the extent that mobile devices can be used as miniature and mobile personal computers, with similar learning opportunities for personalized feedback, visualization, simulation/exploration, etc., it is necessary to examine the evidence from computer-mediated math

⁵ <http://www.brainpop.com/about/mobile/>

⁶ <http://www.tangerinecentral.org>

⁷ See http://education.ti.com/educationportal/sites/US/productDetail/us_nspire.html for example.

⁸ http://www.vodafone.com/content/index/media/group_press_releases/2011/webbox.html

instruction in the early grades in order to know which experiences may transfer better to the mobile format because they have already shown positive results in student learning.

In the past 30 years, a significant amount of research was done to explore the impact of a variety of technology applications on mathematics achievement. In addition, several large-scale reviews or even meta-analysis were conducted to shed more light on the consistency of findings across studies. The most recent such review in the United States was conducted in 2011 by Cheung and Slavin (Cheung & Slavin, 2011) at the Best Evidence Encyclopedia at John Hopkins University, examining 74 studies with over 56,000 students total in their sample selected from over 700 studies conducted between 1970 and 2011. Three types of technology interventions were featured in the studies reviewed:

1. Computer managed learning applications, which are comprehensive programs including assessment and adapted tasks assigned to students based on performance (Just one initiative used this type of intervention.)
2. Comprehensive technology interventions including computer-assisted activities and non-computer activities
3. Supplemental computer assisted instruction (CAI), which provides instruction to students assessed as needing supplement to traditional classroom instruction

Stringent criteria were applied to inclusion into the final set for analysis. The key finding from this rigorous review for the 45 out of the total 74 studies that were conducted on programs in primary grades suggest an overall positive, but relatively small effect on mathematics achievement. In terms of type of intervention, the supplemental CAI technology had the largest effect. Further, the review found that programs that included technology use for more than 30 minutes per week yielded bigger effects than those using technology for less than 30 minutes per week; at the same time, the effect size for programs used more than 75 minutes per week was smaller compared to 30-75 minutes per week. A careful review of the various programs and studies included in this review and their context, however, yields that although overall effects seem to be positive, no single technology program produced consistent results. Instead, effect sizes differed significantly for the same mathematics program used across implementation contexts in spite of studies taking place within the same country.

In the context of low-income countries, rigorous studies from interventions are scarce, and *consistent* evidence in regard to mathematics achievement derived from using computer-assisted methods does not, to our knowledge, exist. From 2002-2004, one study (Banerjee et al., 2007) was conducted in Vadodara, India on a program implemented by Pratham that supplemented mathematics classroom instruction with a computer-assisted learning program leveraging a government program that provided four desktop computers for 80% of the primary schools in the city. Grade 4 students were using the program in a shared setting for 2 hours per week. The program mainly featured game-based activities to solve mathematics problems. The program took place for two years and saw 55 schools randomly assigned to the intervention group and 56 schools into the control group. The findings from this showed improved mathematics scores of 0.36 standard deviations in the first year, and 0.54 standard deviations in the second year. According to the researchers from the Poverty Action Lab at Massachusetts Institute of Technology, the latter constituted a “substantial achievement when compared to other interventions.” Some small effect persisted still one year after leaving the program. As an additional metric, the study also reviewed cost of the technology-supported intervention compared to a remedial tutor-based

program. An evaluation of this program yielded improved overall test scores but with smaller gains compared to the technology program. The technology intervention cost approximately USD \$15.18 per child, and the tutor model USD \$2.25; however, the review does not discuss in detail the relative higher program impact of the CAI program vis-à-vis the tutor programs compared to cost. It does however state, “Nevertheless, these results suggest that it may be possible to dramatically increase the quality of education in urban India, an encouraging result since a large fraction of Indian children cannot read when they leave school. Both programs are inexpensive and can easily be brought to scale: the remedial education program has already reached tens of thousands of children across India. An important unanswered question, however, given the evidence of decay in the gains a year after the programs end, is whether these effects are only experienced in the short term, or can be sustained several years after the program ends, making a long-lasting difference in these children’s lives.”

Possibly the most comprehensive and rigorous study of an m-learning (debatably, or of a computer-assisted learning program) in a low-income context to date was published in 2012 by the Inter-American Development Bank on the One-Laptop-Per-Child (OLPC) initiative in Peru. The study took place in 2009/2010 and included 319 public schools (209 treatment; 110 control schools) from small, poor communities in rural Peru. Grade 2 and 6 students were provided with individual OLPC devices, loaded with a range of educational applications including over 200 eBooks. The applications included standard productivity applications for word processing, calculator, paint, etc.; educational games including Tetris, Sudoku and puzzles; programs to create, edit and play music; three programming environments; and a few other applications (e.g., for video recording). Teachers were provided with a maximum 40 hours of training, with limited and sporadic follow-up visits thereafter. The study did not find any effect of the intervention on Math or Language and reading habits. No effects were found in regard to student attendance, student time allocated to doing homework, student motivation, or quality of classroom teaching. However, the study did find some positive effect on cognitive skills. Tested were non-verbal abstract logical reasoning, coding, and verbal fluency. Results were statistically significant for the Raven’s Progressive Matrices test for non-verbal abstract reasoning. This test entailed choosing the figure that completes a pattern in progressively more difficult matching exercises. The coding test utilized Form B of the Wechsler intelligence test, measuring working memory and speed by presenting 10 pairs of one-digit numbers and graphical symbols to students “who then had to complete as many corresponding symbols as possible for a long list of numbers in three minutes.” Thus, for both of these tests it may be argued that they measure some of the concepts underlying early mathematics and numeracy skills—specifically logical reasoning. Furthermore, in regard to the results for Math and reading the authors of the study stated that these “may be explained by the lack of software in the laptops directly linked to Math and Language and the absence of clear instructions to teachers about which activities to use for specific curricular goals,” highlighting both content and curricular integration.

Game-based learning. Across existing programs and interventions reviewed for this study, the notion of game-based learning is very dominant, as, for example, in the above-mentioned intervention in India. In the US, the recent 2012 Horizon report for K-12 education also states that “Game-based learning has gained more traction in recent years as research continues to demonstrate its effectiveness for learning” (Johnson, L. et al., 2006, p.5). A strong connection between numeracy and play has already been noted by Ginsburg (Ginsburg, 2006, p.30): “Mathematics is embedded in children’s play, just as it is in many aspects of their lives; children enjoy playing with everyday mathematics; and children even

spontaneously play with the mathematics taught in school”. Resnick (Resnick, 2006, p.1) further highlights the opportunity of technologies to be mediums of creative design and expression.

Mobile devices, by virtue of the fact that they are easily accessible and therefore available during periods of downtime during the day (e.g., waiting in line, riding the bus) have become an ideal format for short bursts of gameplay. Recent market research citing download statistics in the millions and revenue in the billions shed light on the demand in this industry. According to McKinsey & Company paid education apps generated total revenue of USD \$120 million in 2011 alone (McKinsey & Company, 2012).

While these statistics focus primarily on smartphone applications, games exist in a variety of formats for even the simplest of phones. The “edutainment” industry has long recognized the natural tendency to

MOBILE DEVICES AND YOUNG CHILDREN

At the same time that children are increasingly accessing games and other applications on mobile devices, there are concerns about increasing “screen time” and weakening academic abilities (Chiong & Shuler, 2010). Specifically with regards to math education, there are concerns that many math instructional techniques—including digital resources—may place too much of a focus on correct answers and not enough on critical thinking in early grade math (Ewart, 2012). The rapid computing power of technology makes it ideally suitable for the factual, objective, unambiguous “right answers” that the science of math provides; however, it is a much less suitable replacement for human subjective intelligence that is capable of explaining and discerning nuances in answers or thinking processes that lead to a “right answer.” This is where m-math experiences that are more stationary and formal tend to also be those that most resemble computer-based learning. Computer-based math methods are also suitable for the types of math skills that need to be learned by rote and recalled automatically (number names, values, basic calculations, etc.). These are also the types of activities that are much easier to engage in with young children who can execute (and repeat) simple instructions, who respond to lively visual and auditory cues, etc., and the content is most appropriate for young children.

On the other hand, mobile learning examples that exploit the mobility of the devices by using them to explore math in the world around them (i.e., Math4mobile, Virtual protractor) are those that support more exploratory, conceptual learning and higher order math skills such as algebra. The format tends to be more enjoyable to students than rote, textbook learning. However, the approaches involve much more complex and varied instructions and processes, as well as more manual dexterity and more literacy skills; thus this type of mobile learning is really only feasible with older learners. Many research reports conclude that “data connectivity and communication aspects of mobile devices support social interaction, collaboration, and the construction of learning” (Low and O’Connell, 2006, cited in Botzer and Yerushalmy), but this type of learning requires much more control and self-direction than many young learners are capable of.

Thus it is important to recognize that there are many opportunities for a constructivist approach to m-math at the higher grades using devices that are highly accessible in low-resource contexts. At the same time, there are promising opportunities for powerful m-math applications for early learners, but these most often require devices that are not easily available to the people who need them the most (such as touch-screen tablet devices that are easier for young children with limited manual dexterity and low literacy skills), or they risk over-using drill and practice methods at the risk of undermining more exploratory methods.

Further, there are ethical considerations concerning privacy and safety with various types of m-learning. For example, while location-based services may offer new and interesting opportunities for personalized learning, they also raise concerns in regard to personal safety (when tracking learners’ movements and location in order to deliver those services) and privacy (concerns with such information being stored in the cloud, rather than just on individual devices) (Benford, 2005).

play games for enjoyment and has capitalized on that to integrate educational and public service content into a game-based environment (for example, Games for Change). The Mobile and Immersive Learning for Literacy in Emerging Economies program (MILLEE; Kam, 2009) has been designing games for English language learning that have been tested, with positive results, in India. Moreover, Vogel et al. (2006) cite extensive evidence showing that *simulation* in educational gaming is a “highly effective way to communicate skills and operational knowledge to learners” and conclude that simulations are particularly effective because they allow learners “to practice these behaviors in an artificial environment that mimics the real world.” However, the research base on the longer-term benefits of technology-mediated games and technology for mathematics learning is still scarce, especially on transfer of skills (such as logic reasoning, problem solving, and decision making) to new situations (Schmidt & Vandewater, 2008).

3 | MOBILE LEARNING FOR EARLY GRADE MATH—WHAT EXPERIENCE EXISTS?

In this section we provide examples of how and where mobile technologies have been applied to early math education to date. We include examples directly targeting both students’ direct engagement with the devices and their learning, as well as approaches in which the mobile devices are used by an adult (parent or teacher) or for student assessment. Experience in the area of early grade m-math is still in its infancy, so for each section we will also present promising applications from other fields, mainly early reading, based on what we know about early grade math education, the capabilities of mobile devices for learning, and the expected contexts in which m-learning will be applied in developing countries. The presentation of experiences is categorized according to hardware types, with Category 1 presenting existing projects that maximize features such as SMS and audio for teaching and learning; Category 2 devices that leverage more sophisticated screen types and data-based services including GPRS; and Category 3 devices such as smartphones and tablets with advanced interactive applications and touch-screen interfaces. The examples here are not exhaustive of all experiences, but rather provide an overview of possibilities. For a full catalogue of m-math experiences uncovered during this study, see Annex 4.

3.1 | CATEGORY 1 TECHNOLOGIES: BASIC PHONES

In 2006/2007, under a project called **STEP-AP**, RTI International conducted a small-scale pilot study in 10 schools in Bangladesh in which a 2-week, in-person, in-service teacher training program for teachers of Mathematics and Bangla was re-designed into a 6-week distance learning program supported by mobile technology (Pouzevara & Kahn, 2007). The phones were intended for weekly conference calls with the trainer, sharing photos and short videos of teaching practice, and ad-hoc communications with the tutor and other learners. In a review of mobile learning initiatives in Asia, Valk, Rashid and Elder (2010), highlighted the study, stating:

“... only the Bangladesh teacher training pilot project demonstrates the benefits of mLearning that stem from the facilitation of contextualized, situated, constructive, and collaborative learning. Teacher trainees were able

to immediately apply lessons learned within their classrooms, and, in turn, to discuss results of the newly applied techniques with trainers and other trainees. The collaborative program design based around the use of mobiles also encouraged constructive learning via interaction and participation on the part of the trainees” (Valk, et al., 2010).

In October 2012, Urban Planet Mobile (UPM),⁹ USA was awarded a grant under the USAID-coordinated All Children Reading competition. Their program, **MobiLiteracy Uganda** will use inexpensive, accessible mobile phones and augmented SMS (2-way Text + Audio) to deliver daily age-appropriate literacy activities and related parent education to rural Ugandan parents and their first grade children. Audio is used to compensate for parents’ own low literacy skills as well as to promote phonics. The initiative will be evaluated in a randomized controlled trial¹⁰ in two stages—first to confirm the contribution these daily messages make to an enhanced culture of reading and parental engagement in their child reading, and a phase two evaluation focused on exploring a value-for-money model in which a sustainable pricing scheme is being explored. The program draws on UPM’s proven and sustainable English language program, which has already gained over 100,000 subscribers in Indonesia and has now expanded to dozens of countries. A similar program is being started in the United States this year, but without the unique 2-way Text+Audio, it includes only SMS (Pocket Literacy Coach, 2012). The model could be easily adapted to the math context by developing SMS messages that suggest opportunities for parents to practice math with their children.

Another example of how simple mobile phones, combined with other powerful technologies, can be used by teachers to access educational resources is the **Text2Teach** program, which originally began in the Philippines in 2003, and has since expanded to at least 5 other countries.¹¹ In cooperation with Nokia, users can use their mobile phones to access and download web-based instructional resources. These programs use the Nokia Education Delivery (NED) platform, which provides access to three- to five-minute educational videos on science, mathematics, and English developed by Pearson (UNESCO, 2012f), which are then viewed by the whole class using portable projectors or television sets. These videos are accompanied by lesson plans that describe how to integrate the videos into a specific pedagogical sequence. No specific information is available about the math content covered, but to date experiences have focused on grades 4 through 8

3.2 | CATEGORY 2 TECHNOLOGIES: FEATURE PHONES

There are currently hundreds (if not thousands) of math “apps” on the market. Most of these are designed for touch-screen phones or tablets (iPhone/iPad or Android device) and in the world’s predominant languages (English, Mandarin, Spanish, French, Hindi), but others do exist for feature phones and in minority languages.

One of the most well-known is **Nokia MoMaths**, a program started in South Africa as a multistakeholder partnership involving Nokia technology, Pearson content, an open source learning

⁹ <http://www.urbanplanetmobile.com/mobiliteracy-uganda>

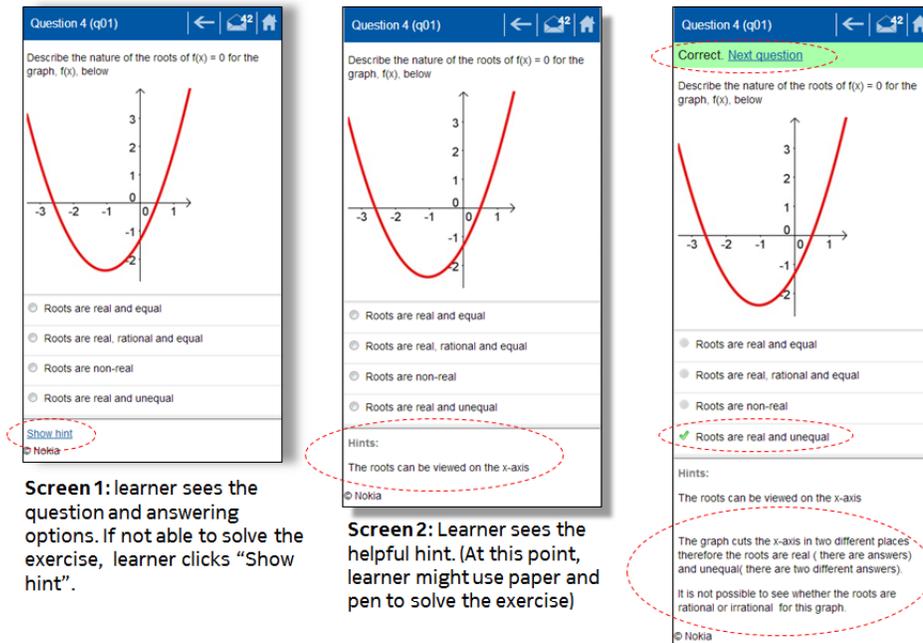
¹⁰ RTI, including the authors of this study, has been subcontracted to conduct the evaluation on behalf of UPM.

¹¹ Similar programs exist with the names: BridgeIT (Nigeria, India, Columbia), Puentes Educativos (Chile), and Elimu kwa Teknolojia (Tanzania). For simplicity, we will refer to all projects in this model as Text2Teach.

management system (Moodle), a private mobile instant messaging service (MxIT), government collaboration, and more. It operates using feature phones to provide free access to more than 10,000 math exercises covering all aspects of the national math curriculum using the MxIT chat platform. Learners can access a quiz bank, or quizzes sent by the teacher, and participate in competitions. An evaluation of the project in 2010 revealed a 14% increase in mathematics competency, with 82% of learners using the MoMath application outside of school hours, during holidays and weekends. (UNESCO AME report). It is now being adapted and implemented to improve teacher competency in Senegal. Exhibit 7, below, shows examples of some of the math exercises.

Exhibit 7: Screen shots of MoMaths interface

Example: Answering to an exercise



Screen 1: learner sees the question and answering options. If not able to solve the exercise, learner clicks “Show hint”.

Screen 2: Learner sees the helpful hint. (At this point, learner might use paper and pen to solve the exercise)

Screen 3: Learner chooses the answer from the options given. The answer is correct. After answering correctly or when there are no tries left, the learner sees all the hints and the full solution for the exercise, and can proceed to next question.

Source: Nokia Developer website. “How it Works” for Mobile Mathematics.¹²

Dr. Math is a popular program in South Africa that leverages feature phones with GPRS connectivity to connect to free, live math tutors. Since 2007, the program has attracted at least 32,000 middle and secondary schools students due to the low data connection costs via the MxIT social networking platform. The tutors are volunteers from universities who usually receive some kind of academic or work credit for participating as tutors. The program has recently launched a pilot spin off called “mathlete” (e-learning Africa, 2012).

¹² <http://projects.developer.nokia.com/Momaths/attachment/wiki/HowItWorks/Exercise%20example.png>

Math4Mobiles leverages the feature phones (non-touch screen) ability for Java ME (Java Micro Edition) applications to support mathematics learning in secondary grades. The initiative was started in 2004 in Israel. Math4Mobiles has been developed based on VisualMath (a successful technology-based curriculum for geometry) and aims to change the ways students learn geometry, function-based school algebra, and calculus. Tools include a range of graphing calculators and dynamic geometry tools, which encourage problem solving through visualizing equations and the relationships between variables. They encourage experimentation based on conjectures and verification through mathematic equations and allow for sharing formulas and answers with other learners via SMS and MMS (multimedia messaging service). According to the developers, Math4Mobile applications have been downloaded free of charge up to 1,000 times per month in countries such as Cote D'Ivoire, South Africa, Ghana, Nigeria, Mozambique, Argentina, Mexico, Bangladesh, Pakistan, and the Philippines (Yerushalmy & Wiseman, 2011). Here is an example of how a Math4mobiles program might be used (adapted from an actual experience; Botzer & Yerushalmy, 2007).

Marcus goes to the town center and videotapes water filling up buckets of two different shapes. He uses the graphing tool to construct a graph representing the relationship between the water height in the buckets and the time elapsed. He adds a verbal explanation and sends the graph to his teacher who provides feedback. Marcus then sends the video to his classmate Anna to complete, and Anna sends Marcus a video of two children walking forward, then turning and walking back. Marcus must now construct a graph showing the distance and time of the two individuals walking.

Some further examples of the types of exploratory questions that can be answered using mobile graphing tools include the following (actual examples assigned to an 8th grade classroom in Daher, 2010):

- Find the relation between the circumference of the trunk of a tree and the circumference of one of its branches.
- Find the relation between the radius of a car's tires and its height.
- Find the relation between the time it takes to fill a container and the height of the water in it. The students worked with different container shapes, one at a time.
- Find the relation between a person's height and speed.
- Find the relation between the time that passes from the moment a ball has been thrown and the distance that the ball travels.
- Find the relation between a person's weight and the number of fingers on his/her hand. (Students were required to study this relation in order to arrive at the constant function—that is, to recognize that some real-world relations are constant.)

Tools like this have been used in higher grades for m-learning experiences that encourage self-directed, exploratory learning but are dependent on the higher cognitive and self-regulatory abilities of older children. In another example using Math4Mobiles, teachers in Israel provided students with algebraic MIDlets that “enabled them to see the graphs of several templates of linear functions. They could see the change in the corresponding straight line as the result of changing parameters in the algebraic form. They also had the opportunity to set points in a coordinate system and to check if a straight line could connect all of them; indicating a linear relation in the real-life phenomenon. They used various tools and

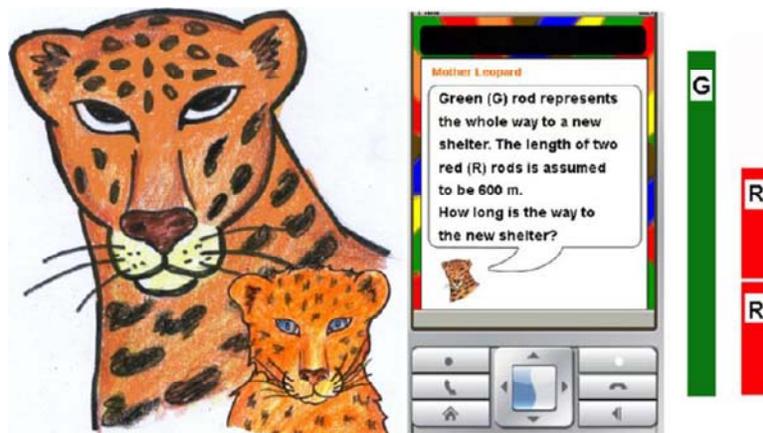
technologies embedded in them, such as: taking pictures, recording video, recording audio, measuring time, transferring of information, voice and text communication, forwarding screen content to learning mates and sending SMS or MMS messages to them” (Baya’a & Daher, 2009).

Feature phones with web access are also being used to access test banks and self-administered quizzes that can help secondary school students prepare for standardized exams. Examples include M-prep (Kenya) and PSU Movil (Chile). In the case of **M-prep**, the system also includes parental outreach and teacher content delivery, but it is a private service on a fee-paying basis. As a strategy to motivate students to increase participation, the system sends out a broadcast message with the name of the top playing/top scoring children (M-prep, 2012).

Some feature phones with very similar features to basic phones are being used to deliver math and literacy content through images, video, or java applications.

UFractions (requires java and WLAN connectivity) is a story-based game in which learners must help a mother leopard raise her cub and in the South African savannah (Exhibit 8). Problems related to fighting against hunger and enemies apply fraction problems that can be solved with the help of visual manipulatives. The solutions are numbers, letters, or choices from the list of different answers that can be entered using the keypad of their mobile device. The input is linked to a website¹³ where children can also see how the leopard and her cub fare based on decisions made collectively. In trials with 8th graders in South Africa, children showed high engagement and enjoyment playing the game. They also engaged actively in groups to discuss answers (Turtiainen et al., 2009).

Exhibit 8: Example of UFractions game



Source: Turtiainen et al., 2009.

Ustad Mobile, in Afghanistan is an application that runs offline on simple feature phones, much the way a dictionary or other simple app can be loaded using an SD card. According to the website of the organization that developed the software under a grant from the United States Department of State—Paiwastoon¹⁴—the application contains “the first letter of the alphabet through grade 3 literacy and numeracy, in both Dari and Pashto... and includes hours of narrated instruction, reading comprehension exercises, quizzes, educational games, and video clips for visual learners.” It also includes built-in metrics that communicate with a central database where teachers can monitor learning time and quiz scores. No specific information could be found about the content of the math lessons.

¹³ <http://cs.joensuu.fi/ubiquelab/ufractions/vs.php>

¹⁴ <http://svr1.paiwastoon.net/?s=Ustad+>

Researchers at Stanford University have been exploring the power of mobile devices in primary classrooms to foster inquiry-based learning. The **Stanford Mobile Inquiry-based Learning Environment** is designed to enable students to design their own multimedia-rich multiple choice questions and share them with peers. In addition to answering the questions, children can rate the questions created by others, and they can visualize data on response rates, ratings, student performance, etc. The instructor has an activity management application to control questions and view student data in real time. Pilot programs using SMILE, though not yet in math classrooms, show that children enjoy the peer learning and find it a good way to review class materials (Seol et al., 2011)

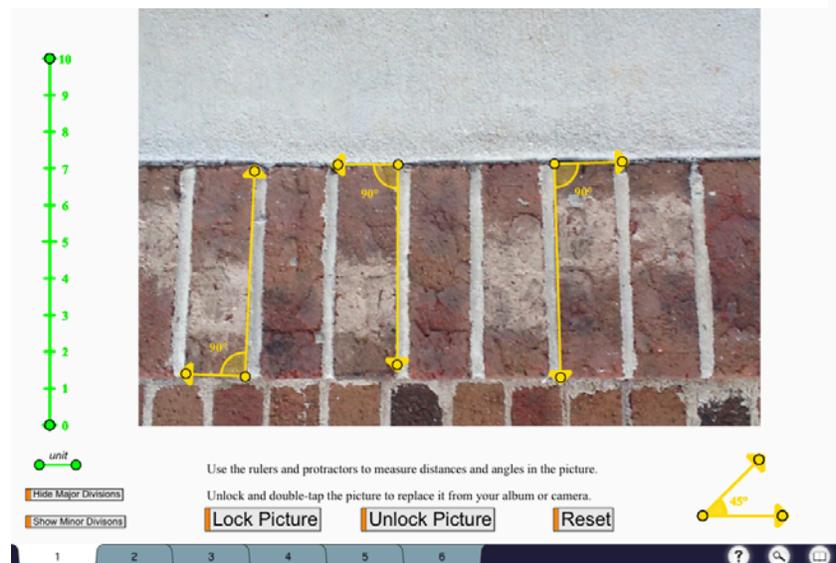
3.3 | CATEGORY 3 TECHNOLOGIES: SMARTPHONES AND TABLETS

In the tablet or touch-screen phone market, the content of the applications ranges from beginning to higher-order math skills, but a large percentage of apps are dedicated to early learners, including pre-school age children. (For examples of mapping many of these apps to functions and features of the “high tech” or smartphone devices and specific mathematical understandings in the early grades, see Annex 3.) For example, Tribe Play, a Chinese developer of mobile educational games for preschool kids available in both the iTunes App Store and on Google Play, reportedly surpassed 1 million downloads recently and has raised USD \$750,000 in funding, demonstrating a clear demand for these products, although we do not know in what specific markets (EdTech Times, 2012).

At older grades, the availability of tablet computers such as the iPad are enabling rich media “augmented reality” math programs that allow students to make use of applications that communicate with the tablet’s built-in camera to explore mathematical concepts in the world around them. For example, Crompton (personal

conversation) describes the use of iPads to teach 4th grade students concepts of angles with an extension of the **SketchPad Explorer** program¹⁵ that overlays a “dynamic protractor” (Exhibit 9) on a student-captured photo, and then allows the student to manipulate the angles. According to Crompton’s research (United States), students benefit from seeing things in three dimensions (tablet) before working in two dimensions (paper). The tool makes measurement more meaningful by allowing them to explore the length of rays and angles,

Exhibit 9: SketchPad Explorer Screenshot



Source: Crompton, H.: Screen capture from iPad

¹⁵ SketchPad Explorer <http://itunes.apple.com/us/app/sketchpad-explorer/id452811793?mt=8> and the add-on *Measure a picture* <http://sketchexchange.keypress.com/browse/topic/all-topics/by-recent/1/448/measure-a-picture>

different positions, and different orientations, which is a big improvement upon textbooks that tend to show angles the same way.

Franklin and Peng (2008) developed a case study in which the **iPod Touch** was used to help socioeconomically disadvantaged and special needs 8th graders in the United States learn about algebraic equations through math videos. The students worked in teams to create math videos using iMacs and iMovie software and then distributed these as podcasts to other students. Content of the movies focused on concepts such as slope, absolute value, and elimination. Participants felt that the technology and the process of creating and sharing the movies helped children have a deeper understanding of mathematical concepts and gave them increased opportunity to access math instruction outside of the classroom.

In 2010, the Turkish Government launched the **Fatih Project (Turkey)** as a massive public investment in integrating technology in education. The initial goal to equip all classrooms with a projector and a laptop was first revised to provide a smart board in each classroom, and by July 2011 the project was expanded to include distribution of tablets to every student in the country (approximately 16 million). In a first pilot effort, launched in February 2012, smart boards and 12,800 tablets were distributed in 52 high schools around the country. There are no results yet available from the pilot.

A number of applications exist that leverage mobile devices as data collection devices for student continuous assessment and progress monitoring. In the United States, several schools have adopted **mClass:Math** on iOS devices from Wireless Generation¹⁶ that combines universal screening, progress monitoring, and guided diagnostic interviews with reporting and analysis. The software has been adopted predominantly in the U.S. and has been aligned there with the Common Core Standards for Math in grades K-3.

RTI International developed **Tangerine:Class** (Exhibit 10) as an open source software tool to facilitate formative classroom- and curriculum-based early reading and mathematics assessments in consideration of the low-resource and multilingual environments commonly found in developing countries. The system assists teachers in systematically collecting, analyzing and using students' results from mastery checks and progress monitoring measures to inform their teaching through a data capture, analysis and reporting tool and data-utilization guidance. Tangerine:Class will be field trialed for early reading in Kiswahili and English in Kenya throughout 2013. The software is built on the Tangerine™ platform, which has been used in national EGMA in Kenya, Liberia, and Dominican Republic to date.

Several examples exist where mobile technologies act as a bridge between students and supplementary

Exhibit 10: Tangerine:Class for Literacy Assessment Screenshot

version 2189125 Update Enumerator admin Logout

Baseline letters Baseline Words

Student grouping report

Name	Percentile	Status
Ken	87	Great
Moana	79	Good
Tomas	26	Poor
Alima	10	Concerning

Back

Source: Strigel, C.: Screen capture from tablet

¹⁶ <http://www.wirelessgeneration.com/assessment/mclass-math/overview>

instructional content on the web.

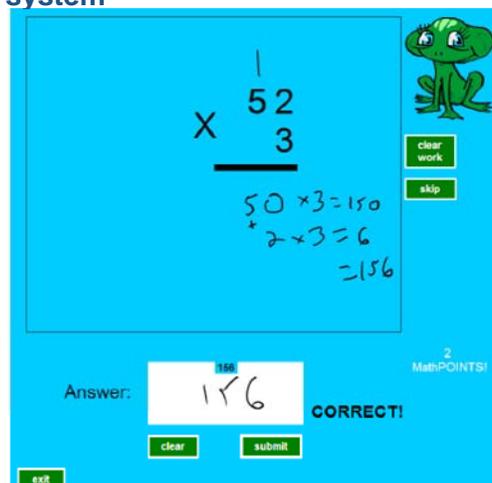
K-Nect (USA). This project, operating in North Carolina, was funded largely by the Qualcomm Foundation Wireless Reach program. It targets 9th and 10th grade math students from low-income communities. Teachers assign math problems to the students to complete at home on a mobile device (Pocket PC). This device also allows the students to access a content repository of supplementary instructional resources in case they are unable to solve the problem. If they are still unable to solve the problem after using the supplemental resources, the devices allow them to access peer support. Student results are sent back to the teacher, and students are provided with additional problems to check mastery (see K-Nect Online.)

Harppi-Tec / Ympyra Monterrey (Mexico). This project is operating out of a university initiative by the *Tecnológico de Monterrey* campus in Mexico City. It targets 5th and 6th grade students who are considered “at-risk” based on standardized test scores. Similar to K-Nect, students are given mobile devices allowing them to access supplemental, web-based resources for math. These resources used visual and interactive methods to explain key concepts and formulae related to volume, area, perimeter, fractions, decimals, and percentage. The platform also provided practice problems as multiple-choice questions, with guiding feedback in the case of a wrong answer, and links to the supplementary visual explanations as hints, where needed (Robledo-Rella, 2012).

Tablet Math System (USA). In this experience, tablet PCs with math problems were provided to 4th grade classrooms in Pennsylvania. Children rotated in small groups to the tablets to work independently for 30 minutes. The interface allowed students to solve the problem manually and gave immediate response to students. A teacher interface allowed teachers to assign problems and view student results. This project differs slightly from the two above in that the programs, and thus the pedagogy, on the tablet computer is not equivalent to what the students could access on a connected desktop PC. For Mathematics learning, this difference is not insignificant, as the pen input enables the software to show *how* a student approached a math problem and not just the answer they came up with (as in a more traditional mouse-and-keyboard-input computer program). This, in turn, allows teachers to dynamically adjust their teaching according to demonstrated student needs. (See Exhibit 11).

Innovations for Learning’s “**TeacherMate Differentiated Instruction**¹⁷” system is primarily for literacy instruction, but the organization also has early mathematics content. The system is managed by the teacher, who assigns activities and assessments to individual students or groups of students in classrooms. Students then engage in the interactive activities on handheld devices. The TeacherMate Online Management System is accessible via any internet connection. Teachers can add or change

Exhibit 11: Example of Tablet Math system



Source: Petty, 2007

¹⁷ <http://www.innovationsforlearning.org/teachermate.html#b>

student's names; create and modify student groupings; set skill levels for the class, group, or student; and see student progress reports. Student data and recordings are captured each time students access the TeacherMate software. Through wireless syncing, student scores and recordings are synced to and from the online management system populating summary and detailed performance reports to guide future instruction.

Learnetic S.A., Poland, an educational software publisher and e-learning technology provider is re-designing and distributing its entire content library for mobile delivery. This currently includes comprehensive curricula, that is, digital interactive learning resources for the full range of Mathematics, Physics, Chemistry, Biology and Science curriculum topics commonly found in national curricula, for students between 10 and 19 years of age.

The added value of the mobile devices in this case are to overcome lack of internet access at home, but from a pedagogical perspective the projects are not enabling “mobile-learning” in the advanced learner-centric model described above where the mobility of the learner allows them to interact with the environment around them. Instead, they are applying the pedagogy of stationary educational technology by adapting the technology for mobile internet access. The projects operate within the formal educational system—that is, they are integrated as part of the school curriculum—but the pedagogy is largely independent of the mobility of the devices. However, the projects involve different levels of collaboration. In the case of K-Nect (USA), the students are encouraged to engage in peer-to-peer collaboration enabled by the pocket PCs, whereas the Monterrey (MX) example appears to be more of a self-directed and independent learning activity.

Our original framework from Exhibit 4 can also be used to *roughly* categorize different experiences into Formal/Stationary, Formal/Mobile, Informal/Stationary, or Informal/Mobile categories, (see Exhibit 4b, Annex 5) and then by the extent to which they are individual activities or collaborative in nature. This is not a value judgment, but merely helps us identify common characteristics, and thus, implementation considerations, of each type of experience. We will come back to this topic in the Conclusions and Recommendations section of this report.

4 | OPPORTUNITIES AND LESSONS LEARNED

Based on the review of experiences above, this section will summarize lessons learned and considerations for future exploration of this topic. The analysis up to this point has focused on the attributes of the technology and the characteristics of instructional practices for math. In presenting findings and recommendations, we have taken the perspective of the learner, highlighting affordances that mobile learning provides, particularly based on what research tells us how children are learning early mathematics, and how to design m-math for different target groups, from students to teachers to parents. Many of the above-mentioned experiences come from more developed countries or programs with significant sources of funding; however, in low-income or developing country settings, the choices of technology and pedagogy depend on a number of different factors, including whether a child is able to access a formal school setting; whether teachers in that school are trained and proficient in math; and what type of support is available outside of school. Therefore, it is recommended to look at these different target beneficiaries as entry points for introducing children to mathematics, keeping them

engaged, increasing the time they spend with mathematics, and helping them move along the learning trajectory toward grade-appropriate learning objectives.

4.1 | M-MATH FOR STUDENTS

Opportunities. Our review of existing initiatives in mobile learning and numeracy across the world – including looking at the features and functions currently available on a range of mobile devices, and a careful investigation of what mathematical proficiency entails in the early grades - points to a particularly promising opportunity provided for m-math. Our findings indicated, however, that existing experiences seem to have adopted and originated from a very techno-centric perspective, with the starting question being “How can we use this particular mobile device for math?” While integrating often great content and approaches, these did not maximize opportunities provided for m-math that are informed by research in *how* children learn mathematics in the early grades, and what domains and topics are developmentally appropriate given the age range under investigation. Below are some examples of how and why m-math directed at student use can address these topics:

1. Mathematics education in the early grades relies heavily on providing children with many different examples to illustrate, practice, and apply one concept across a range of situations (Clements & Sarama, 2009). Mobile technologies, especially feature phones, smartphones, and tablets, can host large amounts of content (games, apps, books, audio files, etc.). Thus, if developmentally appropriate, these devices can help mitigate the lack of a wide range of resources and materials critical for mathematics learning in the early grades and not easily made or supplied locally, including scissors, glue, crayons, colored papers, shape and form models, fill materials, building blocks, as well as tape recorders, projectors, and a variety of exercise books and activity sheets. Most of all, and different from traditional computers, resources on mobile devices are more accessible due to icon-based input systems easy to navigate even for very young children.
2. Student work on mobile devices, at least those with more advanced features, can be saved and thus, for example, a construction from building blocks at the beginning of first grade can be compared to one made at the end of the year by the same child to illustrate gains in sophistication (e.g., from simple structures to multistory closed buildings and arches) and learning progression.
3. Effective mathematics education in the early grades leverages children’s innate mathematical sense and abilities (see section 1.1), their joy and natural pre-disposition for math (Copley, 2010). Mobile technologies can provide stimulating, developmentally appropriate resources for teachers and parents to choose and appropriate for students to complement traditional activities and materials.
4. Young children experience and explore not only mentally, but also physically. Effective early mathematics education engages the whole child through audio-spatial, kinesthetic and tactile learning experience. The portability of mobile devices facilitates seamless and concrete interaction of the child with its environment. Such “context aware ubiquitous learning” is a truly unique attribute of learning with mobile devices and may include, for example, children taking a picture of an item in his or her environment and overlaying it with a dynamic protractor to help foster

understanding of measurement and angles¹⁸ (Crompton, personal conversation). Haptic technologies are also increasingly appearing in mobile devices, and the application of these for improving children’s tactile connection to mathematics is sure to provide future opportunities, particularly for children with disabilities and learning difficulties¹⁹.

5. Similarly, children’s exploration of the world around them is originally oral and, later, highly tactile; touching, feeling, turning, and dropping are key manual activities, especially at the early ages. Touchscreen interfaces provide the added advantage for hands-on exploration, including turning triangles, dynamically changing the length of their sides,²⁰ and composing and decomposing a variety of shapes.

The tables in Annex 3 provide illustrative mobile-technology-enhanced activities for select aspects of the learning trajectories discussed in Section 1. We are highlighting this content-centric perspective as a direct result of some of the gaps identified in the review of existing experiences that seem to have adopted a very technology-centered perspective to drive utilization of mobile technologies in promoting early grade mathematics. We drew on Clements and Sarama (2009) for the type of activities appropriate given the specific mathematical understanding sought.

Although the content of Math4Mobile is targeted at the secondary level, such tools could be valuable for early mathematics, such as the graphing tool for domains such as measurement (see Annex 3). The augmented textbook tool allows embedding of QR (quick response) codes into student textbooks, and upon scanning, these codes provide additional examples, visualizations, and exercises. This tool may also have particular potential in environments where there is a moderate amount of student ownership of textbooks and relatively high penetration of internet-enabled mobile phones.

Lessons learned. There are two main ways to evaluate m-math practices and their added value. First, this can be done by reviewing the actual learning environment and what math content is being taught to answer the question “Does the technology-mediated method improve upon more traditional active or paper/pencil methods for the subject being taught?” In many cases, the ability of technology to provide instant feedback, link theory to real-world applications, chart progress and identify gaps will be some of the ways that this question is answered in the affirmative.

Second, independently of content, we can look at the impact of mobile learning on the way learners behave, including interaction with teachers and other learners and how classroom dynamics change, to answer the question “Does the mobile-mediated environment add value in the way that it changes learner behavior and interaction with the content, thus affecting the learning outcomes.” For example, what is the impact of learning at one’s own pace, more frequent and regular interaction with the content, more cooperation between children and peer learning, and other factors.

¹⁸ Given that a key misconception in angle measurement is that it is measured as the length of the sides of the angle, this is not a trivial activity.

¹⁹ For a review on the state of haptics, see <http://www.cs.ubc.ca/labs/spin/publications/spin/luk2006chi.pdf>. Related to haptics for learning disabilities and math education, see http://news.cnet.com/8301-27083_3-57392568-247/haptic-app-helps-visually-impaired-learn-math/

²⁰ Given that many textbooks portray shapes in limited forms and often singular orientation—with the hypotenuse on the bottom—the recognition that triangles can also appear in a variety of orientations and sizes is critical.

In both cases, we need to be careful to focus on the added value of the mobile device. As Trucano (2012) cautions, some reviews of “individual m-learning projects [...] could have been cut-and-pasted from reports on computer-based e-learning initiatives (e.g., ‘student motivation increases,’ ‘teachers report expecting improved outcomes’), with little attention or insight into what the particular affordances and trade-offs and costs and impact of a devices mobility might be.” In some cases in the developing world, the affordance may be that the mobile device is simply more cost effective than a desktop device, even though the pedagogy remains largely the same. Nevertheless, the tendency to treat the ambiguous term “m-learning” (is the “m” for “mobile/movement,” or for “mobile phone/device”?) as the game-changer needs to be looked at very carefully.

The examples in Annex 3 show many ways in which mobile devices may add value through the learning environment and what is being taught. The technology-mediated method provides opportunities that traditional methods cannot—for example, exposing children to a larger set of examples of mathematical thought; allowing access to instruction and repetitive practice with feedback in the absence of a teachers; and a holistic approach to a broad spectrum of math concepts beyond simple calculation, but also measurement, data, spatial skills, and others. Tatar, Roschelle, Vahey, and Penuel (2003) provide a useful categorization of the types of activities made possible by one-to-one mobile devices in the classroom: (a) distribution: sending the same document to all students, (b) differentiation: sending different parametric definitions to each student in a systematic way, (c) contribution: forwarding a function or mathematical data constructed by one student to a friend or teacher, (d) harvesting: following the collaborative work of several students, constructing a set of functions or data that are related to each other but different; and (e) aggregation: combining functions or data that are in some way related and presenting it, usually in public (anonymously or not).

It appears that regardless of the type of activity and the extent to which it is dependent on the features of the mobile device, one common added value comes from the way that the technology disrupts the typical teaching methods and changes classroom dynamics. The Mexico Harppi-Tec / Ympyra program demonstrated that while using the mobile devices, math classrooms self-organized to create a working environment supportive of the teachers’ role in mentoring. The most “overactive” students self-selected and organized themselves to provide technical support to their peers. The development platform allowed the teacher to see who was having problems and in what subject areas and help focus support on those children (Pohjavirta, personal conversation). From a pedagogical perspective, the same formative review exercises could have been done on stationary, desktop computers; however the ability to access the exercises on mobile phones, both within and outside of the classroom, changed classroom dynamics and brought new incremental knowledge into classroom.

This type of positive social interaction and improved group dynamics has been reported in many m-learning programs, such as the Israel Math4mobiles program and the North Carolina K-Nect program. In the former, students reported feeling more like a group and engaging in peer support.

“We work in a group. We help each other and collaborate to carry out the activity. We discuss the activity ... everyone listens to the other and respects him, even if he was not right. At the same time every one of us has his own mobile phone and uses it to find the mathematical relation. Sometimes we do not graph the right function, so we try again and again. This teaches us

patience. Sometimes we get disappointed but we go on and on till we find the right relation and graph. Carrying the activity teaches us to be leaders too. We compete with each other to be the leader” (Baya’a & Daher, 2009).

In the latter, students reported in interviews that “the ability to connect with other students and teachers at any time is the strongest benefit of the smartphones and makes the difference in completing homework and being prepared for class” (UNESCO, 2012b). Can this group dynamic be achieved with methods other than mobile learning? Certainly, but there does seem to be something about technology mediated communication (including multiuser games, social networks, and networked learning) that enables the formation of communities even where no physical contact is present. This may be related to the way these mobile activities fill the spaces throughout the day and remain always present. Additionally, “communal” learning—or learning that requires peer review and feedback, not just a grade from the teacher—has been shown to be a more powerful motivator for children across subject areas (Davis & Davis, 2005). Reports from many of the examples reviewed also describe the effect of the friendly competitive aspect of the games and collaborative activities, such as the data visualization and reviews in the SMILE program or the rankings provided by drill-and-practice type programs such as Harppi-Tec / Ympyra or mPrep Kenya. Pohjavirta (personal conversation) describes how important it is that the design of such ranking systems shows an individual’s general ranking among others in the class, but not the names of other children; thus there can be no mistreatment of children shown to be at the bottom of the list. In their research under the Harppi-Tec / Ympyra Monterrey program, they could see that activity peaked when an individual’s ranking dropped. This “competition without negative aspects” allows children to make mistakes in a safe environment and appeared to benefit both good and slow learners to rapidly improve their level. Similarly, the mPrep Kenya program noted the impact of the public broadcast messaging on activity levels:

Although we experimented with using airtime as a reward on February 28, there was minimal impact. Unsurprisingly to any teacher, student usage peaks when MPrep begins to use praise messages. These messages praise students based on active usage, highest scores, and most improved. As soon as we began using these praise messages on March 20, we observed a surge in interest in MPrep. In order to keep this enthusiasm elevated, we instated a common classroom and psychological principle noted as “uncertain incentives.” Because students were unsure of what they would be awarded for and whether they would be awarded as a group or as an individual, they continued their engagement over time (MPrep, 2012).

Some critics will warn that it is only the novelty of the technology that has an effect on motivation and time on task, and thus learning gains cannot be attributed to the software or instructional approach. In such a situation, the novelty effect can be expected to wear off quickly, leaving students and teachers in the same instructional situation they were in earlier. Indeed, Robledo-Rella (2012) cites that novelty may have been one of the reasons for the popularity of the mobile learning program in Mexico City. Student feedback indicates that it definitely was a factor in the Math4mobiles program in Israel, where the researchers specifically collected information about attitudes and perceptions of the mobile learners. However, given the specific objectives of the learning trajectories in math, this may not be a concern, since specific instructional practices, once the target skill set has been mastered, will be expanded and changed to be developmentally appropriate; therefore, if the novelty of the new devices serves as

motivation to practice and gain new skills, then that is a positive side effect, even if limited in time. However, this is another consideration when reviewing experimental studies that cite the benefits of a given technology or approach. The most well-documented example of m-math at scale is the Nokia MoMath program, which although it has shown to improve test scores, it has also shown to be declining in use. According to Varska (2012), usage is going down in formal school situations due to lack of government support; in other words, if teachers don't have strong incentives to use new methods in class, they quickly go back to the way they always did things.

Our findings indicate that there is still a lot to be learned about how the youngest learners approach learning with other types of mobile devices—especially in contexts with little historical exposure to media and technologies—and how much demand there is in developing contexts for self-directed learning opportunities not directly linked to the classroom

4.2 | M-MATH FOR TEACHERS

Opportunities. M-math initiatives that are student-directed, but for use within formal classrooms or connected to the classroom curriculum naturally must involve teachers in many ways. However, there is also the opportunity to design mobile technologies for teachers in order to (1) help them teach a lesson (independently of whether children have mobile devices or not); (2) engage in professional development to improve both math content and pedagogical skills; or (3) use mobile devices for continuous assessment of students.²¹

As a teaching support tool, mobile phones have the potential to deliver content to the teachers that otherwise would not be available through local textbooks or teaching materials, or which makes learning math more engaging. This is the case in the examples from Text2Teach and similar programs (BridgeIT, Puentes Educativas), where mobile phones are used to communicate with a remote server or website to download teaching resources. These resources may be for direct use by students (e.g., a video that the whole class watches using a mobile projector or television) or instructional supports only for teachers (e.g., a lesson plan, a model video demonstrating a teaching strategy). Other types of materials that could be downloaded for direct use by early grade math student may include, for example, short videos or “podcasts” from Sesame Street, songs, or visual representations of numbers.

While not specifically m-learning initiatives, open educational resources available through sites like TESSA (Teacher Education in Sub-Saharan Africa) or OLE-BeLL (Open Learning Exchange – Basic e-Learning Library) may be accessed through web-enabled telephones or tablets to provide instructional support for teachers. TESSA²² currently includes over 50 lessons across 15 early numeracy subjects such as exploring number and pattern, exploring shape and space, investigating measurement, and data handling. Resources like these would need to be optimized for viewing on low-cost tablets but would provide important suggestions and activities for teachers with little formal pre-service training. Where it is not possible to download files from the Internet (or where file size is prohibitive), materials can also

²¹ Mobile devices can also be used for a range of classroom and school administrative tasks, but these will not be discussed here since they are largely independent of the subject of math.

²² <http://www.tessafrica.net/site-map>

be directly installed on mobile phones using the SD memory card. This approach is being used successfully in Bangladesh for an English language-learning program for teachers.²³

Teachers accessing resources through mobile devices in many ways addresses both instructional support and professional development. UNESCO²⁴ has recognized the critical need to address the “teacher gap” and is focusing much of their attention on teacher training, including “Supporting teacher professional development through diversified strategies including ICT.” Their recent mobile learning series devotes six issues to regional reports and a global summary of issues “exploring the potential of mobile technologies to support teachers and improve practices” and concludes that “While not a panacea, mobile devices, often functioning in concert with other technologies, have a track record of improving educational efficiency and helping novice and experienced teachers alike acquire complex skills and complete meaningful work in classrooms.”

ODL for professional development is possibly the only way to reach the scale necessary to address the teacher shortage that many countries, particularly those in sub-Saharan Africa are facing. Using mobile technologies now has the potential to improve the quality and efficiency of more traditional correspondence-based ODL programs, and specifically, to improve the quality of math teaching. ODL programs for teachers have existed in a variety of forms for many years, and are increasingly using mobile technologies as a way to support teachers remotely through communication with tutors, sharing resources, or exchanging videos of teaching practice for feedback, for example. While most of these cover math in some way as part of the basic curriculum for teacher training, few have focused on math only, and not because math is particularly suitable for m-learning, but because this is where the professional development need lies. For improving the math content knowledge of teachers, many of the same student-directed methods above can also be used with teachers, and as is the case with the MoMaths program, originally designed for students in South Africa and now being piloted in Senegal for teacher training.

Finally, teacher communities of practice and social networks are also a potential way to support teachers’ pedagogic and content knowledge in the area of math. Simple communications technologies like Twitter can be used to share math teaching tips (see #mathchat). A Flickr group has been formed called “Math in the real world,” where teachers share photos of the ways in which everyday objects can be used in math lessons. While the former can function using a basic mobile phone, the latter may require a more advanced smartphone with internet connectivity; both, for the moment, operate in an English language environment.

In the area of continuous assessment, mobile devices can be used to administer regular mastery checks, access test question banks, or communicate progress scores to parents or district administrators. The value of this is not only in the digitization of this administrative process (allowing results to be stored and shared electronically in a timely way), but especially in leveraging the technologies to take on the analytical task of translating the results into clear, meaningful, and actionable messages for the teacher. For example, the Tangerine:Class tool, currently configured for literacy assessments, but customizable for math as well, provides a variety of graphs and ranked class lists that can help teachers easily identify

²³ English in Action, implemented by the British Council

²⁴ <http://unesdoc.unesco.org/images/0021/002177/217775E.pdf>

children who are struggling and, importantly, see detailed changes over time at the student level. Mobile technologies with adaptive designs (intelligent tutoring and learning systems) can also help students and teachers alike tailor a series of review questions or problem sets according to the performance on the previous questions. At the classroom level, such adaptive or query-able question banks can potentially help teachers find specific content that matches the specific level of the students. Currently, the only examples of math assessments through mobile phones are at the secondary level, and are directed at students who are able to access test questions to prepare for national standardized exams (Paraguay, Chile). We have not uncovered any examples of teachers using mobiles for diagnostic or mastery checking of math skills in the classroom. However, the the CibleCI project in Senegal, which used a question/response application for feature phones intended for first grade students' learning reinforcement, revealed that teachers actually felt the tool was more useful as an assessment tool than a learning tool. (Scharff et al., 2012).

Lessons learned and considerations. With few actual experiences of mobile math approaches being used by teachers, particularly in developing contexts, we must look to examples of mobile learning in other subject areas in order to understand what potential issues are faced by teachers and how to address these in program planning. For example, there are differing views on the effectiveness of broadcast radio and Interactive Radio Instruction (IRI) for teachers; however, given its potential for scale—like m-learning—it continues to be an important approach to teacher training. One of the biggest challenges with IRI is that it is dependent on fixed broadcast times often not suitable for teachers, broadcast signals that can be subject to interference, and quality of radio devices. New technologies such as portable .mp3 players and cell phones with micro SD cards and audio/video playback capabilities are overcoming these barriers, allowing teachers to listen to equivalent radio programming at the time that suits them. However, there is still a lack of data on whether or not certain subject areas are better suited for audio instruction than others; math as a subject largely dependent on visual symbols may be more difficult to teach through audio only, but given the multi-media capacity of mobile devices, any programming should include both audio and visuals to support it.

Since the emergence of computers in education, a challenge has always been to make sure teacher professional development keeps up with advances in technology. This still applies with mobile learning technologies. Similarly, a barrier to student-centered learning technologies has always been a reluctance to empower students to drive their own learning agenda, and thus reduce the role of teacher to a learning facilitator. This is often felt by teachers as a reduction in status or power, and at higher levels, national curriculum developers and policy makers also have a deep interest in maintaining control over content. With new technologies and the emergence of the web, it is increasingly harder for anyone to control access to learning, and children are often surpassing their parents in technological capacity. For mobile learning to be successful, including mobile math, teachers need to be reeducated to assume the role of mentor and facilitator rather than content expert. This is the current model that is emerging—not without criticism—of the “flipped” classroom that makes use of digital learning resources viewed by children outside the classroom as a replacement for the traditional classroom “lecture,” thus freeing classroom time to focus on reinforcement and deepening of the lessons through activities, project-based learning and peer collaboration.

Teachers also clearly need training in technology use for all of the three categories above—teaching, professional development, and assessment, or in any case where m-math will be used in the classroom

by students. There is not yet clear information on how much training is effective, but from experiences in other subject areas (such as teacher training in active, student-centered methods, or reading instruction) we know that one-off training is not sufficient and requires continuous support and follow-up to encourage, troubleshoot, motivate, and enhance the training of teachers while guiding them through the change process. In an example of mobile learning integration in the United States, teachers participated in professional development activities for a full two years prior to implementation of the technologies for teaching and learning (UNESCO, 2012g). In other examples, training was at least 10-16 hours initially, but usually followed up by support from the researchers or implementation team. Thus m-learning approaches should also be used as a way for coaches and mentors to keep in touch with teachers between training programs or support visits.

One documented lesson learned from the Text2Teach program (and similar programs under different names, such as BridgeIT in Tanzania, and Puentes Educativos in Chile) is that simple technologies that make teaching, lesson planning or assessment easier are more likely to be readily adopted by teachers than those that are more complicated and unfamiliar. M-learning that leverages mobile phones and simple technologies like SMS are ideal because they build on devices and actions that teachers are already very familiar with, which is a likely reason why these types of programs are readily adopted. Experience with tablets and smartphones is still in its infancy, but the intuitive interface of tablets and most apps on the market makes it likely that they would not pose a significant barrier or require extensive training. This is an area that requires much more research, however, in the context of the developing world.

On the other hand, while there is much potential for mobile technologies to deliver teaching content to teachers, there is a risk that in attempting to reach scale, the content of such programs imposes a one-size-fits all approach. Programs like TESSA allow teachers to contextualize the lesson plans, make changes, and then resubmit the resources to the database. However, this requires much more training and, at present, more multi-purpose technologies that allow for document editing, printing, etc. Possibly math, as a somewhat universal subject, will not suffer as much as other subject areas by transferring from one context to another; nevertheless, every attempt should be made to ensure that implementation approaches allow for contextualization and flexibility, particularly so that the imparting of numeracy can draw on examples relevant to the young learners' everyday lives.

In the area of assessment, one important caution is around confidentiality issues concerning where assessment results are stored and how they are shared. For example, we must be cognizant of the fact that many people in the developing world share a phone, and therefore confidentiality issues surface if one expects to share assessment results by SMS.

4.3 | M-MATH FOR PARENTS

Opportunities. According to the NCTM (the United States professional association of math teachers),²⁵ “mathematical experiences for young children should take advantage of familiar contexts, building on relationships within families, linguistic and cultural backgrounds, and the informal knowledge of early learners.” As previously discussed (section 1), foundational math skills are learned primarily outside of

²⁵ NCTM position statement <http://www.nctm.org/about/content.aspx?id=12590>

school and should be present before a child's first day of school. The lack of early childhood (pre-school) mathematic practice is an important gap in math achievement in developing countries today and an area where parental involvement will make all the difference.

The biggest opportunity for parental involvement is with simple SMS-based technologies, building on the proven success of text-based advocacy and information sharing programs such as Text4Baby (USA) or Wired Mothers (Tanzania), which distribute information and tips for maternal and newborn health care to mothers, and even more so the 2-way Text+Audio as for the UPM Parental outreach program described above. Given the content and nature of early mathematics, messages with day-to-day activities using objects found around the home and community could be sent to parents promoting number sense, oral counting skills, and one-to-one correspondence.

Parents of children in developed countries may be familiar with the “pass-back” effect—that is, when a parent or other adult passes their own mobile device to a child (Chiong & Shuler, 2010). The term evokes the image of a parent behind the wheel who “passes back” their phone to an impatient young passenger or who otherwise uses the phone to keep a child busy while waiting (in a line, at a restaurant, etc., though according to the study the most frequent time of use was while traveling). Chiong & Shuler, in their summary of studies of iPhone and iPod touch educational apps among young children in the USA recommend increasing access to promising educational apps as a way to improve school readiness by using them for this type of short burst of learning. While this is very much a reality in higher-income contexts, it is questionable whether or not this effect would be seen in lower-income contexts for a variety of reasons. However, the use of educational mobile phone applications by children in their homes, facilitated by parents or older siblings, addresses a critical need to improve basic school readiness in developing countries. If parents can be encouraged to use their phones as an opportunity to teach number recognition, number sequences, and eventually simple arithmetic, they will have already given their children a head start that will help them learn more efficiently from the first day of school.

Lessons learned. Programs to involve parents through mobile technologies—although among the most important ways that m-learning should be leveraged to help improve early grade numeracy—are the most rare. There are few lessons to draw even from programs in other areas such as literacy or health in developing countries. An important lesson from children's media use in the United States, including the use of educational applications on mobile devices, is that it must be a whole-family activity, involving parental support and motivation.

Some of the examples cited earlier also highlight effects that the student-directed m-math programs had on parents. For example, the mPrep program in Kenya gives parents access to a dashboard where they can monitor children's progress in different subjects (progress according to the subject-matter quizzes of the mPrep system). This is on a paid basis, per term, and clearly requires technological and literacy skills. Thus it is likely that programs like this will benefit children who are already at an academic advantage because their parents clearly invest in their children's education, but will be difficult for the most at-risk children and their families to engage with. On the other hand, the Harppi-Tec / Ympyra mobile phone experience demonstrated that parents in this context will naturally get involved in order to both know and supervise what their children are doing with the technology, as well as to refresh their own math skills.

5 | CONCLUSIONS AND RECOMMENDATIONS

The previous sections have provided a broad overview of the potential role that mobile learning can play in addressing early grade numeracy skills for children in developing countries and have highlighted some existing practices around the world. Finding the right fit for m-learning requires both deconstructing the way children learn math into specific, age-/grade-appropriate learning objectives, and looking at very specific mobile device types, available content, and their attributes. From there we can imagine countless ways that the affordances of mobile devices can be leveraged to improve early grade numeracy. However, this exercise of matching learning objectives to teaching methods is not the end game; a number of implementation considerations must factor into the decision to try mobile learning for math in the first place, and to improve the chances for a successful and sustainable program. This is where our Exhibit 4: Variations on Mobile Learning Configurations, can be a useful tool for determining the type of implementation arrangement that is appropriate for each context. The following sections will describe first, some of the cross-cutting considerations that are present regardless of which type of mobile learning arrangement, device, or learning outcomes are targeted; then we summarize by describing how the categories of mobile learning can be a starting point for planning future m-math programs.

5.1 | CROSS-CUTTING CONSIDERATIONS AND SCALE UP

Technology, electricity, and connectivity. In any m-learning program, choice and maintenance of technology will be a key consideration. This paper has already described elsewhere how all device functions should be considered as ways to deliver, reinforce, or assess math learning, and importantly, in the early learning context, device features and functions must be evaluated in terms of a young learner’s cognitive, academic (literacy), and motor skills. A key consideration when planning for an m-learning program will be whether one wants to leverage existing devices or provide devices. While there are clearly important economies of scale to be leveraged with the “BYOD” (bring your own device) model, this model also introduces complications in terms of interoperability, maintenance, and support, since someone needs to know how to operate these different devices and ensure that math applications function the same on all devices. It will also be much harder for teachers to use and support a variety of different devices—they will already most likely be struggling to integrate one new type of device and pedagogy into their classrooms. Some experts also caution that the BYOD model will introduce or increase existing inequalities and worsen marginalization of the populations it is intended to reach (see box on M-learning and equity).

Of course, the hardware is just one aspect of m-learning. Although there are many opportunities to apply the native features (i.e., number keypads, calculator, camera, voice communication, SMS) of mobile devices to learning activities, math instruction can be improved with specific, targeted software, applications (apps, applets, MIDlets), and tools designed specifically for that purpose. There are many commercial math apps available for tablets or smartphones, but very few that are Java-based or otherwise work on simple or feature phones. Trucano (2011) and Yerushalmy & Wiseman (2011) lament the fact that the Android market is taking focus away from Java-based games. Trucano notes that many developers and potential funders from development agencies or philanthropies are reluctant to devote resources to create educational applications that run on low-end phones since they assume they will have limited shelf life, as “eventually everyone will have a smart phone anyway” (Trucano, 2011). Until there

is a business model or an otherwise demonstrated demand for other types of applications, simple phone users will continue to be left behind.

In the developing world, where simple mobile phones are the most ubiquitous, they also have the advantage of being easy to charge in most village centers. Charging kiosks have become a local income generating opportunity for entrepreneurs everywhere, and most simple mobile phones charge quickly and have a battery life of up to 2 weeks. Smartphones and tablets present more of a challenge for battery life. Although many have a long battery life compared to laptop computers (upwards of 8 hours), they also take a long time to charge and are much more valuable, thus possibly less likely to be entrusted to an unsecured village charging kiosk. The increasing rates of ownership of all types of phones across the developing world demonstrate that electricity is not a barrier to phone ownership; and thus, where m-math projects are exploiting the BYOD principle, users will likely continue to be resourceful in finding solutions to electricity cuts and other power disruptions. Similarly, users who find value in a web-based product or service will find ways to get connectivity when they need it, through community internet centers or 3G USB dongles and hotspots. Electricity and connectivity are more likely to be a challenge to m-math in situations where m-learning will be expected to be integrated into classroom teaching, with students using the devices on a one-to-one or even small group basis. In this case, a power source will be required on the school premises, and hardware managed by school staff to ensure appropriate usage, preventative maintenance, and preparedness for classrooms, including charging devices in advance. This type of asset management is more challenging for low resource schools without a power source, secure storage, and staff responsible for hardware. On the other hand, finding alternative sources of power for the school premises should not be a problem; the IT market is full of various solar chargers, car battery chargers, and other innovative solutions for powering mobile devices. However with many new tablet devices and smartphone types on the market every year, it is hard to know how they will perform after years in use, both in terms of overall functionality, as well as battery life, screen performance, and general breakage.

Language/literacy and math. Many ICT-enabled math resources, such as web-based programs, reference sites, live tutors, etc. hold potential for mobile learning on web-enabled mobile devices, but they assume a level of proficiency in reading that many early grade learners may not have. Furthermore, most of these resources are presently in English. For teachers who are proficient in English, there is potential in online communities such as Twitter (#mathchat), ShareMyLesson or Flickr (Math in the real world) to engage in conversations and receive ideas for activities and teaching strategies in the math classroom. French-speaking teachers will find a great resource in the Sesamath community. There are no doubt resources and communities in some of the other larger languages of the world, but undoubtedly very few for the local languages that most teachers in the developing world use in their teaching. Culture and language play a critical role in mathematics learning. Guberman (Guberman, 1999), in his review of cultural aspects in young children's mathematical knowledge, aggregates evidence from a range of studies that point to the fact that social class (see also Korb, 2009) and culture, as well as language, play a role in the acquisition of mathematical skills. A well-known example is the review of Asian language compared to English, and the advantages the former provides through its explicit number system that aligns its verbal representations to the base-10 numeration system. That is, the number 25 is spoken as "two ten five." That regularity strengthens verbal number sense, facilitates skills acquisition in counting, understanding of place value, and base-10 structure and arithmetic.

According to experts (DeGraff, personal conversation) the logical reasoning and active learning that mathematics classes require are dramatically enhanced when the classroom language is the home language; unfortunately, the language of instruction in many countries, and the language of most widely available mobile applications will not be the child's home language. Even countries with dual language policies or transitional bilingual programs often choose to teach science and math subjects in English (or another global or regional language) and teach social science subjects in the local language. Therefore planning for any math instructional improvement programs, including m-learning, needs to take into consideration the language(s) of the child and community, as well as the language of the technology. There may be an opportunity to leverage mobile technology to allow children to practice math in the language of choice, even when teachers are not proficient in all of the classroom languages. There is currently no concrete example of this, however.

Scale-up and sustainability. An important question is whether there are sustainable business plans for m-learning, or whether there needs to be. UNESCO sums up the problem of sustainability well when they write

The majority of mobile learning projects in AME were initiated by individuals or organizations backed by private corporations or donor agencies. These supply-side initiatives generally follow a predictable trajectory: an initial injection of funds and resources enables the project to be launched in a pilot phase; partnerships are established with additional stakeholders; monitoring and evaluation is occasionally included; project reports are produced, sometimes with recommendations for scaling up; promotional materials are distributed that suggest the pilot was successful; and after the pilot phase ends, resources are usually not available to sustain the project (UNESCO, 2012e).

A more micro-level view shows that much of the initial funding goes into development of technologies to support the learning program, but with no specific goals for scale-up. The pilots are usually driven by academics wishing to show the value of m-learning approaches, but if the technology cannot be readily adapted or distributed after the research period ends, then it does little good to prove the point. At present there is no proven business model for distributed m-learning from the content perspective unless learners themselves (or their parents) are willing and able to pay for content; the only stakeholders motivated from a business angle are hardware providers and telecommunications companies who supply the connectivity and build a client base. Until this barrier is overcome, it will be difficult to achieve m-math solutions that are driven by intrinsic motivation—i.e., parents who are willing to invest time and money in purchasing devices and applications that encourage their children to learn, and students willing to spend the time to improve.

Content and training. On the other hand, one could argue that even a very specific but well-designed program is still valuable even if its scale is limited to a specific population and point in time. Subsequently, there is a risk that innovative applications may be discouraged from starting up because of a lack of a clear sustainability or scale-up model. The issue of appropriate content—who develops it, for what audience, and are the right skills being targeted—is also a cross-cutting consideration. We have discussed previously that competitive gaming can be a strong motivator for children, but the extent to which we can count on game-based learning to improve the wide range of math skills required by early

learners remains limited. If scale-up strategies rely on open-source or commercial development of content, then how can anyone ensure the appropriateness of the content and methods, or at least evaluate the quality of a program before investing in it? Furthermore, some scale-up strategies may be tempted to rely on in-game or in-app marketing in order to cover costs, but the ethics of such an approach is questionable for early learners. The work being commissioned by the GIZ desk study on early grade numeracy may help uncover priority skills that could be promoted through mobile learning, but depending on what those priority skills are, it remains to be seen whether mobile devices can be the best teaching method. The extent to which content is simple and intuitive to use, yet powerful for learning specific skills, will also have an impact on the type and extent of training that is required to implement it. Currently adequate teacher training in even basic teaching, content, and classroom management skills is limited in developing countries, and one-off training programs have been shown to have limited effectiveness when there is not continuous follow-up and incentives for teachers to demonstrate change. Thus content development needs to also consider the relative trade-off between a potentially rich learning experience facilitated by a sophisticated m-learning design (for example, the math4mobile or virtual protractor examples that involve exploration of the world outside the classroom and use of photo and video) against the teacher training that will be required to integrate this type of learning in the classroom. On the other hand, other models of m-math such as iPhone or iPad tablet apps are designed to be intuitive enough for even very young learners to use with little guidance (Chiong & Shuler, 2010) and can thus be implemented with much less teacher training, or even used primarily outside the classroom avoiding teacher training at all.

5.2 | RECOMMENDATIONS

In Part 1 of this paper, we introduced mobile learning as covering a range of possible scenarios, where both the learners and the devices are mobile in differing degrees. The reasons why such different scenarios have emerged appear to be linked to very context-specific drivers of m-learning in each case and whether the emphasis is on access or pedagogy.

We need to move away from generalizations about all computers or all technologies, and consider instead the specifics of each technology and the context of its use. Some technologies, in some contexts, foster creative thinking and creative expression; other technologies, in other contexts, restrict it. Rather than focusing on the division between techno-critics and techno enthusiasts, we need to focus on the difference between activities that foster creating thinking and creative expression (whether they use high tech, low-tech, or no-tech), and those that don't. [Resnick, 2006]

Exhibit 12 summarizes the four distinct categories of m-learning programs (from Exhibit 4), with more detail about what specific types of activities and considerations are characteristic of that category. Then we refer back to this table to provide suggestions for developing m-learning programs, before making additional broad recommendations for consideration.

We recommend that when developing a mobile learning program, stakeholders must clearly define category they aim to target, then choose technology and design implementation accordingly. Policies and procedures will be different if one is expecting mobile devices to be used primarily in the classroom and

with teacher guidance (formal/stationary and formal/mobile), or outside of the classroom through self-directed, on demand learning (informal/mobile, informal/stationary).

Exhibit 12: Characteristics and considerations for categories of m-learning programs

(1) Formal/Stationary

- *Example:* Students use tablets in the classroom to play math games, and/or continue playing games outside of the classroom (at home, after school). Teachers use mobile phone to receive lesson plans or teaching materials.
- *Characteristics:* Mobile devices act primarily as miniature computers, providing much of the same pedagogical affordances of computer-based learning. The curriculum is well defined, and math applications are aligned to the curriculum and used with teacher guidance. There may be scenarios where students are communicating more with each other and with the teacher, depending on the device type, than they would with a typical computer configuration.
- *When to use:* When your objective is to enhance learning outcomes by changing classroom dynamics and introducing pedagogy that is more systematic, controlled and consistent across schools. When you want to take advantage of the proven affordances of CBL for math learning, but do not want or need to invest in full-featured desktop computers. When you want to remove some of the workload of the teacher by providing a way for groups of children to work independently, or by providing a range of pre-designed lessons.
- *Considerations:* This model will probably only work when devices are provided by the school/school system. Teacher training will need to focus on classroom management and skills differentiation.

(2) Informal/Stationary

- *Example:* Students play mobile phone math games on the bus or at home. Parents receive SMS messages that provide suggestions of activities that they can do with their children to improve math skills; parents use their phones to help children recognize numbers and number sequences. Teachers use mobile phone applications to improve their own math skills.
- *Characteristics:* Learning is not directly linked to the classroom curriculum, although it should support it, and as such, teachers may not be involved in supporting or monitoring activities and learning outcomes.
- *When to use:* When the driving motivation for m-learning is to take advantage of the widespread availability of mobile phones in communities, and the apparent motivation that digital gaming/learning creates, in order to increase time spent learning math by providing content and activities that match the common features of those phones. When you are trying to reach out of school populations and vulnerable groups in order to improve equity of education.
- *Considerations:* BYOD is more appropriate for this model, but this may exacerbate existing inequalities since it is dependent on existing resources in the home. Without explicit instructions from teachers, use requires motivated, self-regulating individuals.

(2) Formal/Mobile

- *Example:* Mobile phones provide contextual support for field trips, e.g., though QR Codes scanned by a smartphone or retrieval of information using SMS commands; students take photos and use mobile tools to explore shapes, angles, and trajectories of real-world objects. Teachers are using mobile phones as support during an ODL-model in-service training program.
- *Characteristics:* The content of the activities is linked to the classroom curriculum and monitored by a teacher, but the activities depend on the learners being mobile, and using the various features of the devices to explore the environment around them.
- *When to use:* When you want to encourage active, collaborative learning that links theory to real world applications; when you want to encourage creative exploration and discovery learning on a flexible schedule with a broad range of possible outcomes to promote discussion, debate and peer learning.
- *Considerations:* This type of pedagogy is much more difficult to integrate into typical school systems and is probably only practical with older learners who can be self-managing or very skilled teachers who can manage large groups. It takes time and requires flexibility in relinquishing control of learning in favor of self-directed exploration. It usually requires specific tools (i.e., graphing software, or phone cameras) and thus hardware must be provided by the school in order to ensure equivalent equipment by everyone in the group.

(3) Informal/Mobile

- *Example:* Students, parents and teachers use their mobile phone to translate words in the street or shops, to calculate prices or exchange rates, to map services, etc.
- *Characteristics:* Learning is not linked to the classroom curriculum
- *When to use:* See above. Could also be a way to target older youth or even adults with informal math skills reinforcement integrated into life-skills or adult literacy programs.
- *Considerations:* This may be the most unlikely kind of mobile learning that can be deliberately supported by an external program. This type of mobile learning is highly intrinsically motivated and is increasingly becoming part of how we do things day-to-day supported by mobile devices. However, by showing examples of how math is used in everyday life, and how mobile devices can support those of us who have appropriate literacy and analytical skills, this can be a potential way to build support for mobile learning in and out of the classroom. Without explicit instructions from teachers, use requires motivated, self-regulating individuals.

The above categories may not cover all possible configurations of an m-learning program, and the boundaries between each are somewhat fluid, however there are relatively clear choices to be made with regards to target population—in school or out of school—and device types—existing, or provided by the project. The most logical starting point, however, is by asking what the driving rationale is for engaging in an m-math initiative. It is important to justify this decision from the outset, otherwise a program risks starting from a technocentric perspective and thus attempting to fit activities inappropriately into the m-learning mold when there are other more appropriate methods for achieving the objectives. However, a pre-requisite step is firstly to identify the problem or learning gap to be addressed. It may seem like such a basic prerequisite hardly needs to be stated; however, to maintain a focus on the ultimate goal of improving learning outcomes, we are making it explicit that a careful instructional needs analysis must first be carried out. This may be informed by math assessment methodologies described in the numeracy and assessment desk study (Davis, J. and Sitabkan, Y., 2012).

Step 1: Conduct instructional needs analysis to determine learning gaps.

Guiding questions may include:

- a) *What fundamental math skills are children missing in the early grades? Are they coming to school with basic pre-school math readiness?*
- b) *Where there is a learning gap there is most likely a teaching gap: what is preventing teachers from teaching math effectively? Is there a gap in teachers' own content knowledge?*
- c) *Are there appropriate math textbooks and manipulatives available equitably for all children? If not, why?*
- d) *Is math education perceived as enjoyable and relevant for children?*
- e) *Are parents involved in supporting children's math instructional support? If not, why? Is there a gap in parents' content knowledge?*

From there, one can begin to explore whether or not mobile learning might be an appropriate way to address some of the gaps, depending on whether the needs analysis uncovers problems primarily with access to teaching materials, level of engagement and time on task, or teacher competency.

Step 2: Define your m-learning rationale. Do you want to:

- a) *Leverage existing mobile devices for pushing content to learners,*
- b) *Change classroom dynamics and introduce more student-centered, inquiry based learning, that links theory to real-world applications,*
- c) *Increase student time on task both inside and outside of the classroom, by introducing self-directed math practice with automatic feedback,*
- d) *Support teachers with teaching content and lesson plans, and school-based professional development.*

It is very likely that all of these scenarios are somewhat desirable, thus the key question is whether you can achieve the objective with other methods, and if not, why. However, if the rationale is primarily a) or c), then the key driver is leveraging widespread access to mobile technologies in order to provide supplementary resources to students, parents and teachers by leveraging the pocket PC features of

mobile devices. If the answer is b) or d), then the emphasis is more on changing traditional pedagogies by leveraging the portable and communicative features of mobile devices. In both cases, an appropriate next step would be to review the available technologies, and determine whether a BYOD solution may work or if the project will have to provide the technology.

Step 3: Technology landscape review. Guiding questions may include:

- a) *What technologies are most commonly available in the target area (basic phones, feature phones, smartphones)? Who has access to them (parents, children?)*
- b) *What type of data access is possible through the most common types of phones? (SMS, 3G, GPRS?)*
- c) *What are costs of connectivity, including voice calls, SMS messages, web access, data transfer?*
- d) *Is it feasible to consider providing devices if no sufficiently similar devices exist?*

After reviewing the available technical infrastructure, the process should come back to the needs analysis and particularly the content gaps in order to investigate whether the most important needs can be addressed through features of available technologies.

Step 4: Matching content needs to technological availability

- a) *Can the needed math skills be effectively taught (or reinforced, or enhanced) through any of the input, output or communicative features of the available devices?*
- b) *Are there any non-technological methods available that can achieve the objectives?*
- c) *What value added may the mobile devices provide even if non-technological alternatives are available (e.g., increasing time on task; increasing student engagement; creating a link between students and parents; etc.)*

The scope of this desk study will not allow a great deal more detail into all of the possible next steps and scenarios, which will start to vary depending on rationale and local context. However, based on the literature review of other experiences—particularly larger-scale programs such as Nokia MoMaths—there are three key areas of an m-learning program that need to be simultaneously developed: 1) technical infrastructure and software; 2) teacher [or user] training; and 3) content (Nokia Developer, 2012²⁶).

Each of these three pillars will require specific stakeholder input, partnerships, and expertise. All activities should be paying close attention to long-term sustainability and integrating formative research and impact evaluation into programs in order to add to the knowledge base in this area with evidence of what works.

²⁶ <https://projects.developer.nokia.com/NED/wiki/overview>

5.3 AREAS FOR IMMEDIATE ACTION AND/OR FURTHER RESEARCH

Leveraging mobile learning for mathematics will be subject to many of the same challenges, questions, and processes as mobile learning in other domains have undergone (or are in the process of undergoing)—one of the biggest being a resistance to change and skepticism. This skepticism is natural and responsible in a context where limited funds may be diverted from other more proven methods or activities into this somewhat unproven and rapidly changing domain. Yet the few experiences we have uncovered in m-math and m-learning in other areas leave us concluding that this is still an area with a lot of potential that needs to be explored further, and this is where donors can play an important role. Based on the desk study and discussions among a working group of development professionals during the International Numeracy Conference in Berlin (December 2012), we have narrowed down the critical areas for immediate action and further research to the following, which will be discussed in more detail below.

1. Use **balanced advocacy** to raise awareness of the potential of m-learning
2. Support more **rigorous research**
3. Support **enabling environments**

Balanced advocacy. Currently there are many misconceptions and narrow viewpoints related to m-learning in general. As Exhibit 4 points out, activities may be categorized as “m-learning” even though they are very different pedagogically and practically, and in terms of whom they target and why. In other cases, skepticism about the value of m-learning leads to policies that prohibit the use of mobile phones in schools on the grounds that they are a distraction, and even where m-learning is starting to be integrated in schools, teachers or administrators may be reluctant to change classroom dynamics to facilitate their effective use. Therefore an important first step is to continue to raise awareness of m-learning, provide the rationale for pursuing it (access, affordability, pedagogy, engagement), and provide examples of positive experiences that can inspire new champions. This may involve the following concrete actions:

- Supporting publication of articles and papers (such as this desk study), particularly case studies of lesser-known experiences
- Centralizing a database of experiences (including pilot projects, research, publications, etc.) that can act as a central information source
- Dissemination of this desk study and request for comments and additional experiences (to be developed into supporting articles and papers and to contribute to the database)

There is currently one active and well known website, MobileActive, that publishes examples of mobile learning programs in all fields, including education, and has a searchable database of projects. However, a recent blog post²⁷ from one of the founders indicates that it may no longer be supported. Thus there is a gap that may be picked up on by a particular donor such as the GPE who may be interested in supporting at least the education component of the site; alternatively, it would be important to extract the examples from the site before it does disappear. Another catalogue of math-specific applications exists at EdSurge.com,²⁸ but not exclusively for mobile applications.

²⁷ <http://www.mobileactive.org/ch-ch-ch-ch-changes>

²⁸ <https://www.edsurge.com/math#/default>

Support more rigorous research. An important part of any such clearinghouse would be to include studies of the effectiveness of m-math programs at the learner outcomes level. Many current research reports focus on feasibility, attitudes, functionality, classroom dynamics, and so forth but do not contain rigorous measures of student learning gains compared to alternative methods, nor do they elucidate the cost-per-learning-gain effect of changes that are observed. Thus it will be important to clearly define the parameters of “rigorous research” and develop a theory of change that articulates clearly how the use of mobile devices for mathematics learning is expected to lead to changes in student learning outcomes. (For example, is it through increased time practicing math because it is more fun or accessible outside of classrooms? Is it because the mobile devices provide a way to increase understanding of complex concepts by linking them to concrete, real-life situations?)

This may involve the following concrete actions:

- Define terms and develop a theory of change
- Map existing research to theory of change
- Promote targeted evaluations and impact assessments
- Conduct and evaluate pilot projects

In addition to research in learning outcomes using mobile technologies, there is a need for further investigation of other topics through qualitative studies. The first topic is to continue exploring more about how the youngest learners interact with technologies. Most existing m-math experiences are in middle and secondary school using feature phones. M-learning with very young learners (grades 1-3) is currently dominated by large touchscreen devices such as the iPad, but few research examples could be found that documented early learning outcomes in these environments; none related to math.

Promote enabling environment. An enabling environment for early grade m-math is one where efforts to provide high-quality teaching and learning (including professional development and assessment) through mobile devices will not be hindered by policies, costs, or technologies. Achieving this will be dependent on many of the cross-cutting issues raised above, and will certainly be promoted in part through the first two recommendations (raising awareness and supporting more evidence of what works). However, there are many additional areas where changes need to take place at the systems level in order to promote an enabling environment. For example:

- **Policies:** Adopting policies that allow (or even provide) the use of mobile phones in schools, that subsidize costs of communications for educational purposes, that support expansion of infrastructure and accessibility, and that recognize and value informal and out-of-school learning opportunities, including alternative forms of professional development for teachers.
- **Content:** Increasing the availability of free and open content optimized for mobile devices, as well as affordable (or open-source) mobile content development platforms, and increasing the availability of content in different languages.
- **Interoperability:** Promoting international standards for educational content (file formats, communication protocols, display, etc.) that will allow content to be compatible with a wider variety of devices, thus making the BYOD model more feasible.

The UNESCO Working Paper on Mobile Learning and Policies (UNESCO, 2012h) contains a comprehensive overview of these and many other considerations for creating enabling environments,

thus this study will not go into more detail. However, some initial concrete actions that could be taken include:

- Working with economists and entrepreneurs to design a business model (or models) that make m-learning content development, distribution and adoption attractive to all stakeholders, including parents, teachers, educational publishers, telecommunications operators, and national governments.
- Funding development of innovative, cross-platform mobile math applications, games and mobile content development platforms through grants, competitions, challenges, etc., with an emphasis on widely available technologies including Java and simple text for mobile phones.
- Work with telecommunications operators and/or national governments to find solutions to dependency on a few for-profit mobile operators for mobile communications.

ANNEX 1: GLOSSARY

Applets: A very small application, esp. a utility program performing one or a few simple functions. (Wikipedia)

App(s): App is an abbreviation for application software, or software for specific purposes. It is increasingly becoming synonymous with mobile applications, or software for mobile devices.

BYOD: “Bring Your Own Device.” This is a trend in which students bring their own technology to use in a learning environment, rather than using devices provided by the institution. This is also referred to as BYOT, or “Bring your own technology.”

Cardinality: Understanding that the last number in a sequence represents the total amount; answers the question of “how many.”

Interactive Radio Instruction (IRI): Instruction through radio which allows for a return of communication via telephone, fax, e-mail, etc.. (UNESCO). IRI is directed at teachers and students listening together, whereas broadcast radio is just for one audience.

Java: a general-purpose, concurrent, class-based, object-oriented language that is specifically designed to have as few implementation dependencies as possible. It is intended to let application developers “write once, run anywhere” (WORA), meaning that code that runs on one platform does not need to be recompiled to run on another. (Wikipedia).

Mathematics: A form of reasoning involving the use of symbols to represent ideas and solve problems.

MUPE: Open-Source Game Development with the Multi-user Publishing Environment (MUPE) Application Platform.

Ordinality: The concept that numbers represent more than/less than relationships. Ordinality determines the relative position of an item in a set.

MIDlets: Java programs for embedded devices, usually games and applications that run on a mobile phone.

M-Learning: Learning across multiple contexts, through social and content interactions, using personal electronic devices.

Native application (“App”): A program that resides on the handheld device with full functionality not requiring an Internet connection.

Numeracy: Using mathematical skills and competencies efficiently to make sense of the world.

SD Card: An abbreviation for Secure Digital (Panasonic) memory card format used for mobile devices.

Street math: Mathematics used out of the classroom, as opposed to “school mathematics.”

Subitizing: Instantly recognizing the cardinal number of a small set of objects (i.e., a pattern of dots) without counting them.

Webapp: An application that uses web and browser technologies to access information or to accomplish a task using a browser-enabled device. These require Internet connectivity to function and often involve group communication or collaboration.

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ANNEX 3: MATHEMATICAL UNDERSTANDINGS AND AFFORDANCES OF MOBILE TECHNOLOGY²⁹

Table 1: Number, subitizing, counting, and comparison

Mathematical Understanding	Affordances of Mobile Technology—Student Direct Use
Verbally counts with number words, counts from numbers other than 1, skip counts and with objects by tens	<ul style="list-style-type: none"> • Low tech: Use audio playback to play and engage children in number sing-songs, playback stories that include mathematical vocabulary for numbers (e.g., “One, two, three, four, five, once I caught a fish alive”), counting, comparison, and space (e.g., “In, on, under”) • High tech: Interactive videos; Number activities/apps (e.g., “Kids Numbers and Math Lite”; Leverage multi-touch finger detection ability of mobile device for counting (“Little Digits”)
Accurately counts objects (one-to-one correspondence) and answers “how many” (cardinality)	<ul style="list-style-type: none"> • Low tech: Javagames that practice counting objects (e.g., “Connect Four”) and that connect counting of objects to the number of objects in the collection (“How many in all?”) • High tech: Interactive activity allowing for actual touching of objects while counting and providing feedback if an item has already been counted (e.g., count the balls on this soccer field). Activities such as objects matching and making small, later larger, collections (e.g., give each child a plate and a cup by dragging them to their place on the table).
Instantly recognizes small collections up to 6, then in sets, briefly shown (subitizing)	<ul style="list-style-type: none"> • High tech: Advanced Snapshot games promoting increasingly sophisticated strategies, including grouping, multiplication, and place value to move from perceptual to conceptual level, potentially including timer to promote game-based competition. Snapshot activities entail showing a set of objects briefly, hiding them and then asking how many there were.
Identifies and uses ordinal numbers (1st-10th)	<ul style="list-style-type: none"> • High tech: Interactive activities that require ordering or related mathematical thinking (also e.g., interactive videos that require “completing” a set of tasks orally “Tell me which container to open, the first, the second, or the third?”).
Mental number line to 10, then 1000	<ul style="list-style-type: none"> • Low tech: Quiz-type game asking “Which number is bigger, 8 or 5”; “Which number is smaller” types of questions that promote automaticity. Score keeping for motivation. • High tech: Interactive activities that allow children to explore and foster understanding of spatial representation of numbers (e.g., “Motion Math Zoom”³⁰)

²⁹ Adapted from Clements, D.; Sarama, J. (2009). *Learning and Teaching Early Math: The Learning Trajectories Approach.*; Ammons, S., Wagner, J. (n.d.). *Mathematics in Preschool.*

http://www.k12.wa.us/SpecialEd/EarlyChildhood/pubdocs/Mathematics_in_Preschool.pdf

³⁰ <http://motionmathgames.com/motion-math-zoom/>

Table 2: Patterns

Mathematical understanding	Affordances of Mobile Technology—Student direct use
<p>Fills in missing elements in patterns for ABAB, later ABBABBABB</p>	<ul style="list-style-type: none"> • Low tech: Use audio playback to expose children to songs and stories, e.g., poems that have or are about patterns (e.g., “It’s Pattern time”³¹); Java games to extend a pattern, e.g., complete a string of beads to make a necklace, where the child selects the next bead to string. • High tech: Interactive activity that allows children to drag and drop items to complete a pattern (dog, cat, dog, cat, dog, __; Sing-along pattern songs with visual/videos that encourage whole-body engagement (clapping, snapping, hopping, etc.).
<p>Identifies the smallest units of a pattern</p>	<ul style="list-style-type: none"> • High tech: With teacher help, leverage mobile devices with cameras to find patterns in the children’s environment. Use picture editing apps to mark up pattern (e.g., BeFunky³²), e.g., in sand, on t-shirt, on floor, on leaves.
<p>Describes pattern numerically, can translate between geometric and numeric representations of a series</p>	<ul style="list-style-type: none"> • High tech: Interactive activity that requires children to listen to a narrative and represent it with shapes/forms through drag and drop with feedback for practice, e.g., “Grandma Jean is sewing a new hairband with circles for Nelly. The hairband has circles on it. Every third circle is blue. Draw the hairband.”

³¹ <http://www.songsforteaching.com/jennyfixmanedutunes/itspatterntime.htm>

³² https://play.google.com/store/apps/details?id=air.com.befunky.BeFunkyPhotoEditor&feature=related_apps#?t=W251bGwsMSwxLDEwOSwiYWlyLmNvbS5iZWZ1bmt5LkJKRnVua3lQaG90b0VkaXRvciJd

Table 3: Arithmetic (operations), place value, and composition

Mathematical Understanding	Affordances of Mobile Technology—Student Direct Use
<p>Finds sums for joining³³ problems up to 3+2 by counting all with objects</p>	<ul style="list-style-type: none"> • Low tech: Use mobile phone calculator to check mentally calculated results; SMS-based quizzes for simple calculations • High tech: Interactive activity that allows children to practice sums dragging and dropping items, e.g., into a shopping bag with target numeral given (or e.g., “First Grade Math”³⁴)
<p>Finds sums for joining and part-part-whole³⁵ problems with finger patterns and/or counting</p>	<ul style="list-style-type: none"> • High tech: Variation of activity above with larger numbers, leveraging a variety of scenarios and requiring use of a variety of methods
<p>Solves take-away³⁶ problems by separating with objects.</p>	<ul style="list-style-type: none"> • Low tech: Use mobile phone calculator to check pre-calculated results; SMS-based quizzes for simple subtractions and word problems including “take-away scenarios” • High tech: Interactive activity that allows children to practice subtraction by dragging items away from, e.g., taking some out of a box with stones to get the correct target number.
<p>Uses composition of tens and all previous strategies and known combinations</p>	<ul style="list-style-type: none"> • High tech: Interactive activity that allows children to practice operations, e.g., by accumulating cards or items with various numbers, e.g., 10, 5, and 1 to add up to a target number (e.g., Addingtons³⁷); Number Snapshot activities matching dots to numerals up to 50.

³³ An action of joining increases the number in a set. Joining problems can either be $_ + 6 = 11$ (“Al had some balls. Then he got 6 more. Now he has 11 balls. How many did he start with?”), with the start unknown, $5 + _ = 11$, with the change unknown, or $5 + 6 = _$ with the result unknown.

³⁴ https://play.google.com/store/apps/details?id=com.infinut.firstgrade.lite.math&feature=more_from_developer#?t=W251bGwsMSwXLDEwMiwiY29tLmluZmludXQuZmlyc3RncmFkZS5saXRILm1hdGgiXQ..

³⁵ Two parts make a whole, but there is no action – the situation is static. Part-part-whole problems can either be “partner” unknown, e.g. “Al has 10 balls. Some are blue, 6 are red. How many are blue?; or the “total” unknown, e.g. “Al has 4 red balls and 6 blue balls. How many balls does he have in all?”

³⁶ An action of take-away decreases the number in a set. Joining problems can either be $_ - 5 = 4$ (“Al had some balls. He gave 5 to Barb. Now he has 4 balls. How many did he start with?”), with the start unknown, $9 - _ = 4$, with the change unknown, or $9 - 5 = _$ with the result unknown

³⁷ <http://www.knowledgeadventure.com/games/addingtons.aspx>

Table 4: Space and shape, composition, decomposition of 2D shapes, decomposition of 3D shapes

Mathematical Understanding	Affordances of Mobile Technology—Student Direct Use
<p>Recognizes less typical squares and triangles, but usually not rhombuses; later classifies most common shapes</p>	<ul style="list-style-type: none"> • High tech: Pattern matching games, e.g., interactive activity dragging and dropping shapes into appropriate placeholders; matching activities that require child to match shapes of different sizes or orientation (e.g., “Geometry 4 Kids”³⁸)
<p>Uses manipulatives representing parts of shapes, such as sides, to make a shape that “looks like” a goal shape</p>	<ul style="list-style-type: none"> • High tech: Interactive activity allowing children to build and manipulate shapes (e.g., “Geoboard,”³⁹ or “Geometry Pad+”⁴⁰)
<p>Locates objects using maps with pictorial cues</p>	<ul style="list-style-type: none"> • High tech: Interactive activity allowing children to experiment with objects’ movements in a four-quadrant grid using simple Logo commands (e.g., “Turtle Graphics”⁴¹)
<p>Performs slides and flips with shapes, often only horizontal and vertical using manipulatives, performs turns of 45, 90 and 180 degrees; later predicts results of moving shapes using mental images</p>	<ul style="list-style-type: none"> • High tech: Interactive Snapshot activities for Geometry, “student identify an image that matches the “symmetric whole” of a target image from multiple-choice selections’. Interactive activity that promotes students predicting, e.g., the quantity and form of a certain shape to cover another (e.g., Tangram⁴²-style puzzles), or trajectory of a ball, using mobility of device to navigate (e.g., Teeter⁴³-type games)
<p>Follows a simple route map, with more accurate directions and distances</p>	<ul style="list-style-type: none"> • High Tech: Battleship type interactive activities requiring interpreting grid structure components, practicing precision of location, and conceptualizing labels as signs of location and distance (Sarama et al. 2003) (e.g., Battleship for Kids⁴⁴)
<p>Represents various angle contexts as two lines</p>	<ul style="list-style-type: none"> • High Tech: Interactive activity promoting student estimation and measurement of angles in real-life context, using phototaking feature of device (e.g., “Sketchpad Explorer”⁴⁵ -Measure a Pictures)

³⁸ <https://play.google.com/store/apps/details?id=com.nthfusion.geometry&hl=en>

³⁹ <https://itunes.apple.com/us/app/geoboard-by-math-learning/id519896952?mt=8>

⁴⁰ <https://itunes.apple.com/us/app/geometry-pad+/id542572141?mt=8>

⁴¹ http://www.appzoom.com/android_applications/education/turtle-graphics_ifey.html

⁴² <https://play.google.com/store/apps/details?id=com.magmamobile.game.Tangram&hl=en>

⁴³ https://play.google.com/store/apps/details?id=com.gfagame.teeter&feature=search_result#?t=W251bGwsMSwxLDEsImNvbS5nZmFnYW1lLnRlZXRLciJd

⁴⁴ <https://itunes.apple.com/us/app/battleship-for-kids/id542635542?mt=8>

⁴⁵ <https://itunes.apple.com/us/app/sketchpad-explorer/id452811793?mt=8>

Table 5: Measurement

Mathematical understanding	Affordances of Mobile Technology—Student direct use
Aligns two objects to determine which is longer or if they are the same length	<ul style="list-style-type: none"> High Tech: Interactive activity allowing children to identify on various examples length as an attribute and recognizing longer, shorter, the same length (e.g., “Kids Science:Measure”⁴⁶)
Can compare two containers, e.g., to see which holds more	<ul style="list-style-type: none"> High Tech: Interactive activity allowing children to compare two containers (e.g., “Measurement”—Fill me up⁴⁷), or using the graphing tool (e.g., Math4Mobiles⁴⁸) to construct a graph representing the relationship between the water height in two buckets and the time elapsed filling them at the well
Partial understanding of cubes as filling a space	<ul style="list-style-type: none"> High Tech: Interactive activity that helps children predict and then test how many cubes are needed to fill a box using, e.g., drag and drop features (e.g., “K12 Math Sampler”)
Matches angles correctly. Explicitly recognizes parallels from non-parallels in specific contexts.	<ul style="list-style-type: none"> High Tech: Interactive activity that allows students to practice in a range of examples recognizing parallel from non-parallel angles. Combine activities that allow for taking pictures in real life and overlaying a dynamic protractor with practice (e.g., “GeometrIQ:Geometry Puzzle Game”⁴⁹)
Sorts angles into smaller or larger (but may be misled by irrelevant features, such as length of line segments)	<ul style="list-style-type: none"> High Tech: Have children estimate, measure, and sort angles in their environment, leveraging mobility of device and protractor app (e.g., “Angle Meter”⁵⁰)

⁴⁶<https://play.google.com/store/apps/details?id=com.infinit.firstgrade.measure#?t=W251bGwsMSwxLDIxMiwY29tLmluZmludXQuZmlyc3RncmFkZS5tZWZdXjlll0>.

⁴⁷ <https://itunes.apple.com/us/app/measurement/id408627880?mt=8>

⁴⁸ <http://www.math4mobile.com>

⁴⁹https://play.google.com/store/apps/details?id=com.playply.GeometrIQ&feature=search_result#?t=W251bGwsMSwxLDEsImNvbS5wbGF5cGx5Lkdib21ldHJJUSJd

⁵⁰ <https://play.google.com/store/apps/details?id=com.iYOK.AngleMeterV10&hl=en>

ANNEX 4: EXAMPLES OF M-MATH PROGRAMS

The table below summarizes some of the most relevant m-math experiences that were studied for this report, and provides the source of information for future reference. The project name indicated in the first column is not always an official project name, but oftentimes the author’s own shorthand reference for the project. The technology referred to in column three refers back to the three categories described previously: 1) simple phones, 2) feature phones, and 3) smartphone/tablets. In this table we have also provided a few examples of alternative devices such as Nintendo Gameboy handhelds. Column 4, “m-learning type” refers to the categories described throughout the report, and presented visually in Exhibit 4, i.e., where the project sits on the spectrums from mobile to stationary, formal or informal, and collaborative or individual learning. An updated version of Exhibit 4 is included after the table to show, visually, how each of these projects can be mapped to the categories. Finally, the “Type of project” column provides a brief description of what type of organization sponsored the project, whether it was a pilot or at scale, etc.

Country/Project name	Grade(s)	Technology	M-learning Type	Type of project	Reference
Afghanistan – Ustad Mobil	1-3 and adults	2	Informal, stationary, individual	Donor-sponsored, led by local NGO and supported by national education ministry.	http://svr1.paiwastoon.net/?s=Ustad+
Australia - Pocket PCs	multiple	3	Formal, mobile, collaborative	Meta-review of use of Pocket PCs in education	Ng, W., & Nicholas, H. (2009). Introducing pocket PCs in schools: Attitudes and beliefs in the first year. <i>Computers & Education</i> , 52, 470-480.
Chile – Eduinnova	1	Gameboy or netbook (collaborative question generation and answer; games)	Formal, stationary, collaborative or semi-collaborative	Academic research project; large-scale; multi-country pilots	UNESCO Latin America teacher report; Nussbaum http://www.oecd.org/edu/cei/39414787.pdf
Chile – Puentes Educativos (BridgeIT, Text2Teach model)	5,6	9 (SMS, videos)	Formal, stationary, individual (group viewing, but not collaboration through mobile devices)	Donor-funded pilot implementation (200 schools)	UNESCO, 2012. Turning on mobile learning in Latin America[...]
Columbia - Raíces de Aprendizaje Móvil (BridgeIT, Text2Teach model)		4,5	Formal, stationary, individual	Ministry of Education and donor collaborative implementation in vulnerable	UNESCO, 2012. Turning on mobile learning in Latin America[...]

Country/Project name	Grade(s)	Technology	M-learning Type	Type of project	Reference
				areas (40 schools)	
El Salvador -PocketTutor	unknown	TeacherMate (math drill and practice)	Formal, stationary, uncertain	NGO-led pilot project	UNESCO Latin America teacher report. TeacherMate only literacy now
India – Sesame street	1,2	3	Informal, stationary	Donor grant (Qualcomm)	Digital Initiatives of Sesame Workshop India. Undated flyer.
Israel – math4mobile	8-10	2 (java)	Formal, mobile, collaborative	Academic research project	http://www.math4mobile.com/
Kenya – mPrep	secondary	1,2 (SMS, content distribution)	Formal and informal, stationary, semi-collaborative (test preparation with advocacy, rankings, etc.)	For profit initiative	http://textmprep.com/home/ , http://mprep.it/about-us/our-story/ , http://mprep.it/wp-content/uploads/2012/10/MPrep-Impact-Report-RELEASE.pdf
Mexico – Edumovil	primary	various	various	Academic research project	UNESCO Teacher report, Latin America
Mexico – Ympyra	5	2	Formal, stationary, semi-collaborative	Academic product development pilot	Robledo-Rella, V., G. Aguilar, S. Shea, R. Pérez-Novelo, E. Ortega, J.C. Olmedo, J. Noguez and E. Tamés. (2012). Design and Evaluation of Mobile Learning Resources in Mathematics for Public Elementary Schools in Mexico. [Paper sent directly to the authors.]
MoMaths	10	2 (web access, visually enhanced quizzes)	Formal or informal, stationary, semi-collaborative	Private-sector led, multistakeholder initiative	http://projects.developer.nokia.com/Momaths
Multiple – Nokia Education Delivery System (Text2Teach model)	5-8	2	Formal, stationary, individual	State, NGO and private sector collaborative pilot project	https://projects.developer.nokia.com/NED/wiki/overview
Paraguay – learning assessment through mobile phones	Secondary	1 (SMS)	Formal, stationary, individual (learning assessment, test-preparation)	Ministry of Education pilot program. Large-scale (18,000 students)	UNESCO, 2012. Turning on mobile learning in Latin America: Illustrative initiatives and policy implications. Paris, UNESCO Working Paper Series on Mobile Learning
Senegal – CibleCI / TargetFirstGrade	1,2	2 (java)	Formal or Informal, stationary, individual	Academic product development	Scharff, C. et al. (2012). From Idea to Deployment in Students' Global Software Development Projects: The Case of an Education App for First Grade Pupils in

Country/Project name	Grade(s)	Technology	M-learning Type	Type of project	Reference
					Senegal. [Conference paper sent directly to the authors]
South Africa – Ufractions	8	2,3	Formal, stationary, collaborative	Academic research project	http://www.igi-global.com/article/motivations-play-ufractions-mobile-game/65085 (Payment required), http://eprints.dcs.warwick.ac.uk/402/1/UFractions_Mobile_Game_in_SA_FINAL.pdf
South Africa, M4Girls	10	3 (videos, games)	formal or informal, stationary, semi-collaborative	State, NGO and private sector collaborative pilot project	http://www.mobileactive.org/case-studies/m4girls-empowering-female-students
Trinidad and Tobago – MobileMath	secondary	unknown	unknown	unknown	http://www.igi-global.com/article/investigation-into-mobile-learning-high/56334
USA - Elmo the Musical		3	Informal, stationary	Non-profit initiative	http://www.sesamestreet.org/parents/theshow/episodes/elmo-the-musical
USA – iPod Touch and iMovies for algebra	8	3	Formal, stationary, semi-collaborative	Academic pilot	Franklin, T., & Peng, L.-W. (2008). Mobile math: Math educators and students engage in mobile learning. <i>Journal of Computing and Higher Education</i> . 20:69–80
USA – Knect	9,10	3 (pocket PC to access web content)	Formal, stationary, semi-collaborative	State, NGO and private sector grant-funded collaborative effort	http://www.tomorrow.org/research/ProjectKnect.html
USA – Tablet math system	4	3 (tablets)	Formal, stationary, semi-collaborative	Academic research project	Petty (2007). http://repository.cmu.edu/cgi/viewcontent.cgi?article=1096&context=hsshonors
South Africa – Dr. Math	secondary	2 (web access, instant messaging)	Formal or informal, stationary, highly collaborative		

Exhibit 4b: Experiences according to m-learning category

