Integrating Digital and Mathematical Practices across Contexts: A Manifesto for Mobile Learning

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Introduction

Technological advances often spark dual and competing narratives in educational discourse. Proponents point to the increasingly digital nature of children's activities and social relationships outside the classroom, and to the rapidly evolving technical demands of the modern workplace, and worry that traditional school structures and practices remain disconnected from and unresponsive to these changes (Buckingham 2008; Jenkins et al. 2009). At the same time, too many reports point to the failure of promising new technologies to significantly impact student learning or instructional practice, or even to achieve widespread use, because their arrival in classrooms fails to be accompanied by well-articulated or fully elaborated models of their integration into and transformation of classroom practice (Cuban 2001; Means, Penuel, and Padilla 2001; Dunleavy, Dede, and Mitchell 2009; Honey and Hilton 2011). Collins and Halverson (2009) frame this dilemma in terms of a deep and growing divide between novel opportunities for lifelong, active learning—online, at home, on mobile devices—and the resiliency and rigidity of educational institutions and standardized curricular objectives.

Our view is that reconciling these tensions, particularly in a domain like mathematics, requires approaches that simultaneously embrace students' existing, informal digital and mathematical practices and extend conventional, school-based activities beyond the classroom. Many past efforts to integrate computing into schools have failed on both counts. For example, many educational software applications over the last two decades aimed to capitalize simultaneously on the potential for digital media to educate and entertain, only to discover that learning and play

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activities involve distinct genres of participation that are remarkably resistant to integration or change (Ito 2008). At the same time, school settings configured for computing, employing large machines in distant labs or isolated "computers in the corner" classroom arrangements, are incompatible with the activity structures of both traditional instruction and learners' organic forms of collaborative and independent engagement with digital media (Ching, Kafai, and Marshall 2000; Wang and Ching 2003; Ching et al. 2006). For technological innovations to support meaningful transformations in teaching and learning, they must be compatible with and build bridges between the daily instructional practices of teachers and the informal digital experiences of learners. At the same time, they must be flexible enough to allow students and teachers to adapt their practices over time.

Our aim is to outline an approach to achieving that balance by integrating an emerging array of informal practices and tools for mobile computing with a corresponding set of mathematical practices. Contemporary handheld computing devices such as smartphones and media players include tools to support several distinct forms of activity: (a) *capturing and collecting* information and experiences across a variety of settings, through photos, audio and video recordings, numerical and text entry, and other inputs, as well as tagging and cataloging what is found; (b) *communicating and collaborating* with others via phone, network, text, and social networks; (c) *viewing, consuming, and analyzing* various forms of media including music, images, movies, games, and written texts such as news articles; and (d) *designing and creating* personal forms of representation and expression such as digital artwork, digital films, photo slideshows or archives, and blogs or other written reflections. Each of these sets of digital practices with mobile devices has close analogues with key forms of mathematical activity, from collecting empirical data, to communicating mathematical ideas, to viewing and critically examining relationships and patterns across multiple representational modes, to producing representations to express relationships and model phenomena. We see in these distinct forms of digital practice the seeds of several of the central elements of mathematics practice highlighted in the National Council of Teachers of Mathematics (NCTM) process standards of problem solving, communication, connections, and representation (NCTM 2000).

Learning activities and technology resources that invite and enable students to participate in each of the aforementioned mobile and mathematical practices present unique opportunities to integrate learners' experiences inside and outside the classroom. Previous research demonstrates that nonschool contexts can provide rich and practical opportunities for mathematical reasoning and problem solving (Scribner 1984; Lave 1988; Saxe 1988; Cole 1996; Lemke 1997; Nasir 2000; Goldman and Booker 2009; Pea and Martin 2010). Mathematical engagements based in home and cultural contexts, for example, map well onto middle school math standards (González, Moll, and Amanti 2005; Goldman et al. 2006). Additionally, studies of informal science learning provide evidence that learners' experiences with museums, science camps, robots, television and media, gardening, camping, and outdoor adventures strongly contribute to learners' scientific knowledge, engagement, and career choices (Barron et al. 2009; Bell et al. 2009). As yet, however, precious few examples exist of school-based attempts to fully *integrate* formal and informal learning opportunities, and those well-known cases that do exist are situated within curricula distant from the aims and practices of mathematics (Gutierrez, Baquedano-López, and Tejeda 1999; Lee 2003). We see mobile devices as offering distinctive potential for bridging and integrating formal and informal experiences because of their ready portability across settings and their utility in supporting a broad range of activities. Currently, however, many educators are unable to see this utility and are thus more likely to ban students' mobile devices as distractions to learning than embrace their potential (Lenhart et al. 2010).

Connecting Mobile and Mathematical Practices and Learning Activities across Contexts

One of the most difficult challenges to the goal of integrating formal and informal mathematics practices lies not in identifying where or how the mathematics is located within each of these settings but rather in positioning the relevance of informal mathematics to formal curricular practices and outcomes. Moschkovich (2008) argues that rigid curricular definitions create a false dichotomy between "academic" and "everyday" mathematical discourse. Yet research from a sociocultural perspective has shown how nonschool settings such as family life can be rich contexts for mathematical activity (Martin, Goldman,

and Jiménez 2009; Esmonde et al. forthcoming). The typical disconnect between home and school mathematics does a profound disservice to students. This challenge of relevance and accessibility is one math educators have been working hard to address for years, so much so that it is even a recurring theme in popular media (e.g., *Stand and Deliver* and *The Wire*, season 4). Because K-12 mathematics education so often emphasizes the development of procedural efficiency (e.g., rapid and accurate execution of algorithms), forms of mathematical thinking more common in families (e.g., problem posing, evaluation of trade-offs) are rarely seen in the early grades and appear only much later, if at all (Civil 2002b). Children's out-of-school experiences with mathematics therefore represent an untapped resource for furthering their mathematical development. This missed opportunity can further existing inequities because schools tend to privilege mainstream cultural practices and marginalize those of students from nondominant backgrounds, such as cultural and linguistic minorities (Ogbu 1992).

Barriers to building connections between formal and informal mathematics practices include those that are institutional, domain-based, and (until recently) practical. Figure 1 depicts divisions among formal and informal learning contexts (x-axis) and among personal and mathematical sense-making (y-axis). In the first quadrant are formal learning contexts that make active use of students' personal experiences and meanings. Examples of these connections

are prevalent in language arts but either nonexistent or impoverished in mathematics (e.g., the ubiquitous second-grade homework of "go around your house and find examples of a half"). In the second quadrant are informal learning contexts that engage personal experiences and meanings—examples include home environments, community organizations, sports teams, or hobby groups. Often participation in these contexts is voluntary or socially supported; thus, identity affirmation arises more organically from the activities and relationships themselves (Nasir and Cooks 2009). In the third quadrant are formal learning contexts that engage mathematical meanings and practices—typified by NCTM standards for mathematics teaching and learning. Finally, in the fourth quadrant are informal learning contexts that engage mathematical meanings and practices—practices that may look very different from those in the third quadrant, as existing research on family mathematics demonstrates. Bringing together these contexts and meanings, which are more often disconnected for minority students from low socioeconomic backgrounds, requires hybrid tools and practices that can sit at the nexus of the informal, formal, mathematical, and personal. We advocate employing mobile technologies across formal and informal contexts for the dual purposes of (a) making the personal mathematical and (b) making mathematics personal. In this article we elaborate four major repertoires of mathematical practice and of digital practice with mobile devices that can form the basis for the design of learning experiences that can accomplish these dual purposes.
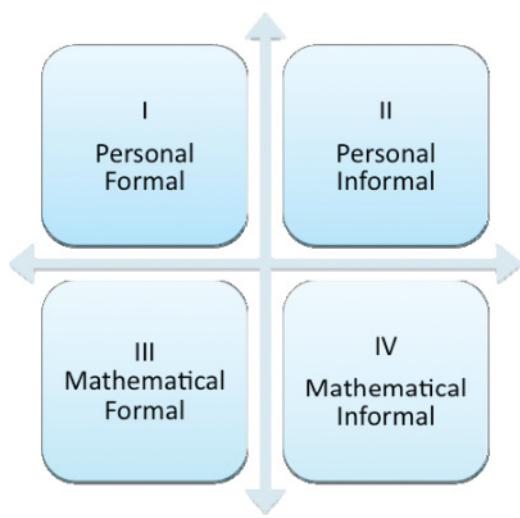
Capturing and Collecting

Researchers have been advocating data collection via mobile devices in K-12 mathematics and science education for years (e.g., Soloway et al. 1999). Capturing and collecting technologies such as probeware, sensors, and smart calculators have been promoted as means of making mathematical and scientific practices, as well as their constituent measurement tools, both intimate and accessible to students across a wide variety of contexts and age levels (Norris and Soloway 2004; Squire 2009). Widespread adoption, however, has been minimal, in large part because of the lack of a common platform and minimal availability outside the bounds of teacher collaboration with a research-and-design team (Roschelle 2003). The devices in these studies have also largely been single use,

Fig. 1 Engagements within and across contexts.

and thus their ability to capture and integrate social, personal, and mathematical functions has thus far been absent. Current mobile devices, however, have the potential to address this shortfall by leveraging activities in which learners are already engaged. Research on youth mobile practices demonstrates that taking photos and taking video with mobile devices are only slightly less ubiquitous than texting as popular activities among youth age 13–17 (Lenhart et al. 2010). Capturing and collecting on mobile devices allows youth to carry "pieces" of their valued contexts with them as they move in and out of learning environments. Captured content can then be flexibly applied or engaged with in ways that support students' efforts to integrate mathematical habits and contextualized knowledge, helping them to "see" informal phenomena through a mathematical lens. Making these connections between mathematical ideas and contexts outside mathematics is a critical aspect of learning to participate in mathematical practices (NCTM 2000). Research on the use of digital photos and digital video in classroom and community settings suggests that these technologies provide unique opportunities for student reflection on their academic identities and their roles within the world of school (Davis 2005; Ching et al. 2006).

Communicating and Collaborating

Perhaps the most essential purpose of mobile devices, and the fundamental reason for their near ubiquity among today's youth, is as tools for communication: for talk, text, email, and video chat and as a social media interface. As such, these devices have the potential to facilitate learners' participation in critical aspects of mathematical activity. Providing students with opportunities to organize and express their own mathematical thinking and to participate in mathematically rich classroom discourse has been a central theme in mathematics education research and practice over the last two decades (Ball 1993; Yackel and Cobb 1996; Lampert and Blunk 1999; NCTM 2000). Recently, several innovative research and design projects have begun to map ways of supporting and enriching communication and collaboration in mathematics classrooms using handheld devices connected to local computing networks (e.g., Roschelle and Pea 2002; White 2006; Hegedus and Penuel 2008; Ares, Stroup, and Schademan 2009; White and Pea 2011). These uses of classroom networks have opened up new possibilities for mathematically rich learning activities and classroom interactions, allowing students and teachers to rapidly distribute information, exchange ideas, and construct and jointly manipulate shared artifacts. Contemporary mobile devices offer the potential to extend these networks beyond the classroom to connect students, teachers, and community members even as they move across contexts. In-classroom device networks have powerfully demonstrated the potential for merging peer communication with dynamically linked mathematical representations (Hegedus and Moreno-Armella 2009; White and Pea 2011), and networked devices have offered new possibilities for interaction—such as rapidly distributing information, exchanging ideas, and constructing shared artifacts that can support a variety of engaging and mathematically rich learning activities. Similarly, connections between mobile devices that extend the sharing of mathematical objects and ideas beyond the schoolyard may represent unique opportunities for blending learners' informal digital activity with conventional forms of mathematics classroom discourse.

Viewing, Consuming and Analyzing

Students are often urged to make connections between the math they learn in school and the issues they care about in their families and communities, but they are rarely given much support in building these bridges. Mobile computing devices are well suited to help in this process. Mobile devices make it easy to view media of various sorts, including music, photos, videos, podcasts, webpages, and applications. Given an appropriate context and support structure, these capabilities can be leveraged to bring meaningful mathematical content onto students' devices and provide opportunities for students to coordinate their mathematical practices and representations both in and out of school. Learners can have real-time access to mathematically relevant information and artifacts they have compiled, generated, or received from a teacher, and they can engage with media that span home, school, and community networks' interests and concerns. Existing practices of viewing, comparing, contrasting, and critiquing media can map onto professional practices of critically engaging with mathematical representations. Mobile devices can thus serve as representing machines where students' everyday practices and mathematical practices, while not identical, are comfortably

compatible. Because learners have a single device that coordinates these disparate media, they are literally able to carry valued resources with them as they move across contexts. Likewise, classroom teachers will have opportunities to see and connect with students' home- and community-based practices and thus be better able to support students in their sense-making processes (Civil 2002a; Gutiérrez and Rogoff 2003; González, Moll, and Amanti 2005). The act of viewing and consuming representations in a variety of forms can provide opportunities for learners to reflect on and analyze alignments and distinctions across contexts.

Representing and Creating

We are concerned both with learners' developing personal mathematical toolboxes as well as their ability to imagine themselves becoming members of communities wherein mathematics is central to professional practice. Having students create representations can serve both of these goals. First, the ability to create standard representations, such as tables, scatter plots, algebraic equations, and so forth, is an important learning goal in itself (NCTM 2000). This causes students to make their ideas explicit and visible, which can foster conceptual development (Chi et al. 1989; Chin et al. 2010). Second, when learners create representations, they generate new opportunities to interact with peers around mathematical content, and they begin to represent themselves as relevant participants in a broader endeavor. When learners create representations, they engage in practices and discourses that alter their access to opportunities for participation. Mobile devices can help learners awaken the connections among home, school, and community and give them a forum to generate their own personal and mathematical development (Cassell 2002; Civil 2002a; Barron 2004; González, Moll, and Amanti 2005; Barron 2006; Booker 2010). As they move across settings, they need opportunities to unite their formal education and values-infused learning experiences (Kahne and Middaugh 2008; Pea and Martin 2010). Mobile devices, which travel so easily between contexts, invite students and teachers to borrow problem-posing and problem-solving modes from home and community practices and to work together to define problems that have value to both learners and the broader mathematical community (Barab, Squire, and Dueber 2000).

Conclusion

Mobile technologies have been described as a potential "game changer" for K-12 education because of their ability to put the means for personalized inquiry and investigation literally in the hands of students (Tatar et al. 2003; Nagel 2011). Yet, like other technologies before them such as Internet search engines and laptops, mobile technologies in classrooms will have a negligible impact on the student learning experience if they are resisted, restricted, or only narrowly taken up (Cuban 2001; Collins and Halverson 2009). A major hurdle to the integration of any technology in schools is the perceived distance between the affordances of the device and existing educational and curricular goals (Zhao, Pugh, and Sheldon 2002). However, powerful parallels exist between the kinds of everyday practices students engage in with mobile devices in informal environments and the kinds of formal mathematical practices advocated by mathematics standards for K-12 classrooms. Mobile devices are not only *capable* of bridging the gaps between formal and informal learning in mathematics; they may be *uniquely qualified* for this purpose. They offer, in essence, a means to align multiple contexts into a single, unified learning environment, worthy of curiosity, reflection, and transformative action. However, this potential will not be realized without careful attention both to the ways youth already make meaning of and with those devices in their own lives and to the conventions for mathematical meaning-making that resonate with those digital practices. Mobile learning designs and initiatives should attend explicitly to each of the four areas of activity outlined in this paper. In so doing, educators and researchers can address not only the novel problem of positioning youth mobile practices as a valuable asset to learning rather than a liability; they can also address the long-standing problem of building meaningful connections between students' lives in and out of school.

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