Uncertainty in Teacher Education Futures

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Chapter 11: Mobile STEM learning scenarios [1]

Abstract

In both the professional rhetoric and academic literature mobile learning is frequently positioned to realize the aspirations of STEM educators who seek to implement inquiry based learning within authentic and collaborative contexts, mimicking the processes and settings real STEM practitioners experience. The reality maybe somewhat different, as this study demonstrates, with students often shackled by the physical boundaries of the classroom and limited degrees of choice granted to them as independent agents in the learning process. Rather than mediating access to external expertise and collaborative know-how, data derived from a recent international online survey of STEM educators, suggests mobile technologies are only rarely used to support the sharing and exchange of data between students or to engage in 'conversations' and dialogue with 'outsiders' in the way real STEM practitioners commonly behave. This conundrum forms the basis of this chapter which adopts scenario production and analysis as a methodological approach to help STEM educators reconceptualise their use of mobile technologies across various different futures. These 'futures' are set out neither as predictions nor prognoses but rather as stimuli to encourage greater discussion and reflection around the use of mobile technologies in STEM education. In considering four alternative futures for STEM education we conclude that 'seamless learning', whereby students are empowered to use their mobile technologies to negotiate across boundaries (e.g. between school and out of school activities), may be the most significant factor in encouraging educators to rethink their existing pedagogical patterns, thereby realizing some of the aspirations which have yet to be achieved in inquiry-based STEM education. The chapter concludes with an analysis of the ways in which teacher education might respond to future challenges and opportunities emerging from recent research in mobile learning.

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Introduction:

This chapter illustrates the processes and challenges associated with the construction of STEM oriented future scenarios to support teacher educators. It focuses on how teacher educators and teachers currently exploit the affordances of mobile devices to support their students' STEM learning, and expands upon the discussion and implications of pervasive computing covered in Chapter 4. Mobile learning (m-learning) considers the process of learning mediated by handheld devices such as smart phones, tablet computers

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and game consoles (Schuler, Winters, & West, 2012). The ubiquity, flexibility and increasingly diverse capabilities of these technologies have created considerable interest amongst STEM educators (Aubusson, Griffin, & Kearney, 2012; Burden & Kearney, 2016; Cheng & Tsai, 2013; Foley & Reveles, 2014; Johnson, Adams Becker, Estrada & Martín, 2013; Marty et al., 2013; Schuck, 2016; Song, 2014) who have begun to investigate their application for learning 'on the move' (Sharples, 2013,) across a variety of formal and increasingly informal contexts, particularly supporting inquiry-based teaching approaches (Zhang et al., 2010). Claims of enhanced collaboration, social interactivity, in situ data collection and sharing, communication between peers, teachers and experts, and customisation of individual's learning have been reported (Mifsud, 2014). However, as new mobile technologies continue to proliferate and diversify in their potential pedagogical affordances, there has been a tendency for teachers to default to traditional teaching approaches in formal classroom or virtual settings, focusing on teacher-directed approaches and content delivery (Rushby, 2012). The challenge is to find ways to explore more diverse pedagogical opportunities, and this chapter addresses this challenge in two ways.

Firstly, it draws upon a recent international study (Kearney, Burden, & Rai, 2015) investigating how educators are currently using distinctive pedagogical features of mobile learning, which include collaboration, personalisation and authenticity. These three constructs provide a renewed focus on important aspects of socio-cultural theory for educators and researchers working in and examining mobile learning contexts (Kearney, Schuck, Burden, & Aubusson, 2012). The recent study developed and validated a survey instrument based on these three established constructs to interrogate current mobile learning practices amongst 195 teachers in school and university education. This chapter focuses specifically on data from teachers of science, technology, engineering, and mathematics (STEM) subjects (n=69) to report on self-perceptions of their own mobile learning practices in STEM education, including aspects of online collaborative networking and student agency.

Secondly, using this data source the chapter extrapolates to predict and analyse prospective scenarios in STEM education using future scenario thinking as a conceptual framework and methodology (Schuck & Aubusson 2010; Snoek, 2013; Snoek et al., 2003: see also Chapter 6). Using the twin variables of collaborative networking and student agency which have been identified in both the m-learning literature (e.g. Traxler, 2008) and our own empirical data, the chapter will propose four possible futures for STEM education, based on the adoption and exploitation of the pedagogical affordances of mobile devices. Explicated through the use of rich vignettes, these scenarios inform a subsequent discussion foregrounding various futures for STEM education in traditional and emerging learning spaces, with a particular focus on these signature mobile pedagogies, to highlight opportunities for contextualised, participatory STEM inquiry-based learning.

Mobile Pedagogy: Examples in STEM Education

Research studies have examined m-learning through various theoretical perspectives and frameworks such as activity based approaches, authentic learning, action learning and experiential learning (Sharples, Taylor, & Vavoula, 2007). More recently, Kearney et al. (2012) developed a pedagogical framework of mobile learning, which draws on socio-cultural understandings. This framework privileges three distinctive features of m-learning: personalisation, authenticity and collaboration (see Fig. 11.1). The rationale behind these scales is provided through the use of subsidiary themes under each of the central features, which pinpoints the critical features of m-learning from a pedagogical perspective. How learners ultimately experience these pedagogical characteristics is influenced by the 'time-space' configuration of the learning context (Ling & Donner, 2009): the organisation of the temporal (scheduled/flexible; synchronous/asynchronous) and spatial (e.g. formal/informal, physical/virtual) aspects of the m-learning environment (Traxler, 2009) as depicted in Fig. 11.1. This configuration is often described in the literature through words such as ‘anywhere, anytime’, ‘on the move’ and ‘multiple contexts’ (Mifsud 2014).

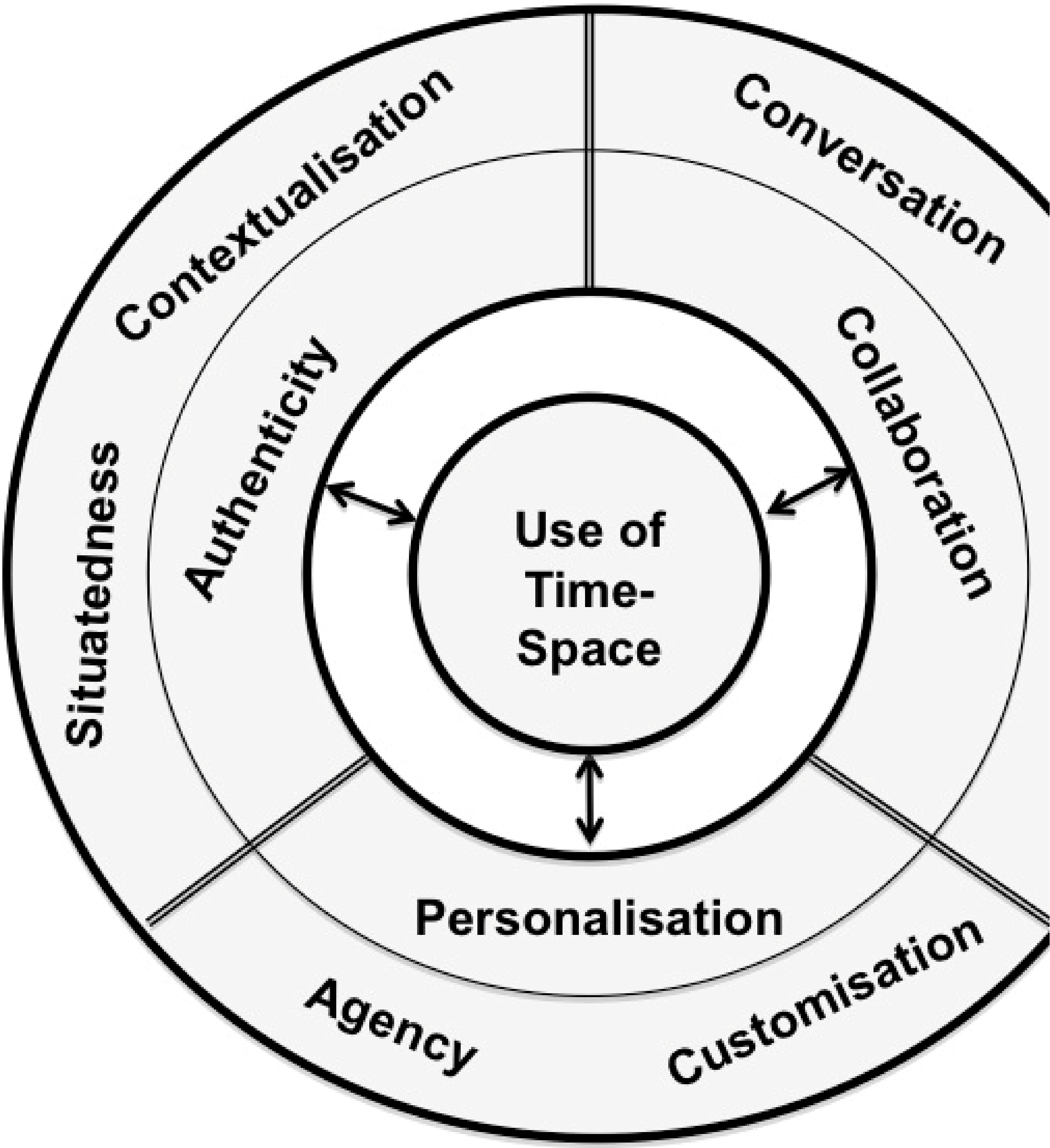

Fig. 11.1 Framework comprising three distinctive characteristics of mobile learning experiences, with sub-scales (from Kearney, Schuck, Burden, & Aubusson, 2012, p. 8)

Firstly, the personalisation feature has strong implications for ownership, agency and autonomous learning. It consists of the sub-themes of agency and customisation. High levels of personalisation would mean the learner is able to enjoy a high degree of agency in appropriately designed m-learning experiences (Pachler, Bachmair, & Cook, 2009) together with the ability to customise and tailor both tools and activities, leading to a strong sense of ownership. Secondly, the collaboration feature captures the oft-reported conversational, connected aspects of mobile learning. It consists of conversation and data sharing sub-themes, as learners engage in negotiating meaning, forging networked connections and interactions with other people and the environment, sharing information and resources across time and space through rich collaborative tasks (Wang & Shen, 2012). Finally, the authenticity feature highlights opportunities for contextualised, participatory, situated learning. Radinsky, Bouillion, Lento and Gomez (2001) espoused two models of authentic learning environments: a *simulation model and participation* model. Tasks that fit a simulation model of authenticity use the learning space (e.g. classroom) as a 'practice field' (separate from the 'real community') but still providing contexts where learners can practise the kind of activities they might encounter outside of formal learning settings. Alternatively, under a *participation* model of authenticity, students participate in the actual work of a professional community, engaging directly in the target community itself. Hence, the sub-themes of contextualisation and situatedness bring to bear the significance of learners' involvement in rich, contextualised tasks (e.g. realistic setting and use of tools), involving participation in real-life, in-situ practices.

This framework has recently been used to inform research on m-learning in school education (Burden, Hopkins, Male, Martin, & Trala, 2012; Kearney, Burden, & Rai, 2015), teacher education (Burden & Kearney, 2017; Kearney & Maher, 2013; Schuck, 2016), and other areas of higher education (Kinash, Brand, & Mathew, 2012). For example, Green, Hechter, Tysinger, and Chassereau (2014) used the framework to inform the development of their own instrument—the 'Mobile App Selection for Science' (MASS) rubric—to aid teachers' rigorous selection and evaluation of K-12 science applications (or 'apps'). In this study, the two constructs of personalisation and collaboration are examined in light of an international survey of teachers, before extrapolating on these results to explore how handheld technologies might influence future STEM learning.

Learning STEM 'seamlessly' across contexts

Mobile learning in STEM education studies have typically focused on informal learning contexts (Aubusson et al., 2012; Schuck, 2016), promoting science and maths 'on the move'. The portable, flexible nature of mobile devices is well suited to these contexts and can facilitate location-based (or place-based) learning (Jones, Scanlon, & Clough, 2013). However, given the ongoing physical realities of formal schooling and higher education, recent studies have focussed on the notion of using handheld devices to provide 'seamless learning' tasks (Rushby, 2012; Toh, So, Seow, Chen, & Looi, 2013), supporting a continuity of learning across contexts and devices, and transitions between episodes of formal and informal learning. For example, connecting learning in/out of class, in/out of school, between curricular/co-curricular, social/personal or academic/ recreational boundaries between physical/virtual contexts and across times and locations (Wong & Looi, 2011). In science education, 'seamless' learning might connect learning in classrooms and science museums; provide a bridge between lab-based inquiry to be continued in a more realistic setting; or connect an 'in-situ' learning episode (possibly personal and informal) to be used a as resource for formal learning at school. In maths education, investigations and calculations required in a project can be completed anywhere of convenience making the learning seamless. Mobile devices might mediate this 'flow of learning' between formal and informal contexts, for example, using microblogging, social networking platforms, specific science tools, mathematical simulations or games (Lai, Khaddage, & Knezek, 2013).

Promoting inquiry across authentic contexts

Digital technologies have typically been promoted in STEM for many purposes, from tools for instructional delivery to student research, communication and presentations. Recent studies have focused on digital learning environments that "emulate the activities of practising scientists" (DeGennaro, 2012, p. 1319), where learners' use of technology becomes an integral part of their task. For example, visualisations, animations, participatory simulations and multi-user virtual environments have been used to actively immerse students in realistic scientist and mathematician roles. In response, m-learning studies in STEM education have advocated a more participatory authenticity (Radinsky et al., 2001), whereby tasks are embedded in real-life, connected, community-based projects (e.g. Jones et al., 2013; Scanlon, Woods, & Clow, 2014). In the same way as real scientists are "connected to a broad community of other scientists who share information and co-construct knowledge and ideas" (DeGennaro 2012, p.1321), such m-learning tasks allow students to participate in authentic ways in real-life, project-based pursuits.

The importance of student inquiry and student-driven questions has long been advocated in science education (Krajcik, Blumenfeld, Marx, & Soloway, 2000) and to a slightly lesser extent in mathematics education, where an emphasis on authentic and rich tasks has been suggested (Schuck, 2016). Consequently, there has been a burgeoning interest in exploiting mobile devices to mediate inquiry-based learning, mirroring the types of investigative processes carried out by real scientists. These include support of question generation, planning and implementing investigations, data collection, observation, analysing and interpreting data, constructing evidence-based explanations and arguments (Herodotou, Villasclaras-Fernández, & Sharples, 2014; Wilson, Goodman, Bradbury, & Gross, 2013). Mobile devices are ideal tools for supporting the inquiry process, with their ability to support multimedia access and collection, communication, representation, information sharing, knowledge construction, connectivity, reference and analysis (Song 2014). However, they are not yet used to their full potential in STEM education for inquiry, particularly in support of measuring and investigating real-world phenomena (Herodotou et al., 2014). Also, many STEM students currently carry out inquiry tasks in relative isolation (individual or pairs, small groups) and in a minimal number of locations (classrooms, excursions etc.). Lui et al. (2014) argue a need for expanding these typical inquiry experiences, with less abstract, contrived forms of interactions, for example through digitally augmented physical spaces (mixed-reality environments).

For example, Herodotou et al. (2014) presented a toolkit (the *sense-it* app) to support measuring and investigating real-world phenomena. It combines and customises data from a full range of sensors into new or existing citizen STEM projects. Non-professional members of the public can use these toolkits to collaborate with professional engineers, mathematicians and scientists contributing to observation and measurement data in science projects such as species identification and air/water pollution monitoring. The app allows users to create their own personally relevant STEM investigations and offers instant feedback on how their own sensor recordings relate to other users' data.

Jones et al. (2013) compared two case studies to explore the different ways mobile devices can support inquiry learning in semiformal and formal settings. One study explored the science learning by students aged 14–15 years using web-based software in a semi formal context. The other study looked at informal adult learners using their own devices to learn about landscape. Looking at these studies together allowed the researchers to focus on both the use of mobile devices in situ and how the devices supported choice and learner control. In the first case of semi formal learning, Jones et al. (2013) found that mobile devices with dedicated software supported the science students to choose and take personal responsibility for their inquiries without adult help. These inquiries were engaging and personally relevant. They also discussed their *nQuire* software tool and how it was used to support the inquiry process seamlessly across different contexts (an afterschool club and home). They found the tool used location-based awareness facilities to support the inquiry process, including information sharing and collaborative activities, communication between learners, other observers and experts. They illustrate ways of supporting personal inquiry learning with m-devices (location-based inquiries), accessing resources and information in situ. As *nQuire* is an open software resource, it is also developing a strong community of users.

Scanlon et al. (2014) presented a similar tool, the *iSpot* application, allowing users to participate in location-based activities akin to real scientific pursuits, in informal settings. This UK initiative also uses an inquiry learning approach, and aims to create and inspire a new generation of nature lovers to explore, enjoy and protect their local environment. Members of the public can use this tool to work in combination with science researchers. For example, their (location-based) observations of animals and plants became "shared, social objects amongst associated groups, networks and collectives" (p. 60). Indeed, selected observations are used in biodiversity monitoring and research, essentially enabling learners to actively contribute to knowledge building as a community activity.

Finally, Song (2014) completed a one-year case study in a primary school science inquiry context using BYOD devices. Students developed a positive attitude to science inquiry and demonstrated improved understandings of the topic (the anatomy of a fish). Song (2014) emphasised "affordance networks" (p. 60) as a key aspect to making optimal use of m-devices for knowledge construction across constantly changing contexts such as digital and physical environments at home, school and other spaces. Another example of seamless learning in primary school science contexts was reported by Marty et al. (2013). Their project aimed to develop inquiry skills and digital literacies using an app called *Habitat Tracker*. These m-learning experiences provided a link between formal and informal contexts, including the classroom and excursions to science museums and wildlife centres.

Use of augmented reality and immersive simulations

Augmented reality (AR) is an emerging technology that "utilizes mobile, context-aware devices (e.g., smartphones, tablets), which enable participants to interact with digital information embedded within the physical environment" (Dunleavy & Dede, 2014, p. 735). Cheng and Tsai (2013) distinguish two types of AR: image-based and location-based. Through a scan of existing studies, they found image-based AR was beneficial to students' spatial abilities, practical skills and conceptual understanding; while location-based AR was beneficial to scientific inquiry learning. Location-based AR is usually underpinned by a situated learning perspective, emphasising authentic contexts, inquiry with real-time data and other virtual information in a real context. Students may also communicate with avatars and peers to collaboratively hypothesise, reason, and solve problems.

AR-based tasks typically take the form of participative simulations, using fictional scenarios added to a local setting, allowing learners to connect STEM ideas to community-based experiences. For example, Wong and Looi (2011) report on games played in a physical environment but augmented by virtual artefacts (what they called 'mixed reality learning'). Mobile devices with location-based sensors allowed users in the study to interact with explorations, experiments and challenges for inquiry and games-based learning. Another example is Kamarainen et al.'s (2013) pilot study for the *EcoMobile* (Ecosystems Mobile Outdoor Blended Immersive Learning Environment) project (http://ecomobile.gse.harvard.edu), exploring children's use of a smartphone AR application (*FreshAiR*) for blended learning across virtual and natural (pond) ecosystems. Combining this application with environmental probeware allowed students to take samples of pond water, gain increased understanding of the ecosystem, and interact with each other in student-centred ways that resembled scientific practice.

Immersive and participative simulations have been used as platforms to engage learners in inquiry-based approaches. Lui et al. (2014) described an immersive, cave-like rainforest simulation (called *EvoRoom*) and a mobile inquiry platform (called *Zyeco*) that enabled users to collect and share data. Students are co-located in an immersive and physical digital space, collecting observational data from both the classroom itself (*Evoroom*) and out-of-class settings (such as such as parks or museums), and exploring peers' data using large visualisations displayed at front of room. This arrangement allows students to pose questions, collect observation data, review and share data, and use it to form evidence-based arguments. Foley and Reveles (2014) presented a 'connected classroom' that used online resources to engage students in inquiry, creating authentic science learning experiences. They emphasised the connection between students' handhelds and the Internet to "share information instantly and enable computer supported collaborative learning" (p. 4). Students' data from experiments and simulations was pooled across classes or schools, allowing them to compare and analyse across larger data sets and collaboratively identify trends as a community of science learners. Collaborative tools such as *Google Moderator* then allowed for further discussion and feedback on ideas and consensus building.

Location awareness is an aspect of AR that Zimmerman and Land (2014) use to explore the principles of place-based education (PBE) for teaching science in an era of mobile devices. For a decade, PBE has provided a way of engaging out-of-school students with the issues, artefacts, cultural practices and natural histories of their local communities. To accommodate the location-awareness features of mobile devices in PBE, Zimmerman and Land developed empirically derived guidelines for research and design for outdoor informal mobile computing (p. 82), emphasising participation in disciplinary conversations and practices within personally relevant places; amplification of observations, in liaison with experts, to understand the disciplinary-relevant aspects of a place. Students gain value from experts who can illustrate aspects of a place; and capturing, sharing and reflecting on knowledge artefacts found in local settings to explore new perspectives.

In summary, the contemporary m-learning literature in STEM education mainly comprises case studies of innovative mobile applications exploiting authentic, connected, participative inquiry-based approaches. Research has explored the possibilities for STEM learning across formal and informal contexts, making seamless links between virtual and physical environments, particularly using participatory simulations and augmented reality technologies. Informed by an established framework of mobile learning, and mindful of these current research directions, this chapter focuses on how mobile technologies might influence the future of STEM learning.

Researching STEM Mobile Learning Futures

Firstly, we describe the international survey used to interrogate STEM teachers' exploitation of distinctive m-learning pedagogies, in particular examining aspects of agency and networked collaboration (from items relating to the personalisation and collaboration constructs in Fig. 11.1). Secondly, we extrapolate from the data source to predict and analyse prospective scenarios in STEM education using future scenario thinking as a conceptual framework (Snoek, 2013).

Survey instrument

This study draws upon data collected in an international survey on m-learning identifying how educators use the distinctive mobile pedagogical features (Kearney et al., 2015). One hundred and ninety-five educators from around the world completed the custom designed 30-item online survey instrument. The items were informed by our theoretical framework of mobile learning (Kearney et al., 2012) focusing on the three themes of personalisation, collaboration and authenticity. Participants were asked to identify a specific learning task or activities in which they had recently used mobile technologies and the survey instrument provided opportunities for both closed and open-text responses. A reliability analysis of the entire questionnaire (n=195), and separately for each of the three constructs, was carried out using Cronbach's alpha (Kearney et al. 2015). Internal consistency of the whole questionnaire (with all three scales combined) was excellent (α = 0.828). When considered separately, the internal consistency was in the acceptable range for each of the three constructs, as shown in Table 11.1.

Table 11.1 Internal consistency for each of the three constructs from the theoretical framework

Construct	#items	Cronbach's alpha (n=195)
Collaboration	6	.715
Personalisation	5	.711
Authenticity	3	.775

Although the entire data set in the previous study consisted of 195 participants, this study draws upon only those educators who identified themselves as working in STEM subjects (n=69,) since these discipline areas were considered to be most relevant for our future scenarios development.

Participants and contexts

The 69 teacher participants were mainly from Australasia (51%) and Europe (23%), where the researchers' institutions were located. Of these participants, 22% taught in primary/elementary school contexts, 39% taught in secondary school contexts and 35% in tertiary education; while 45% were Science educators, 30% were Maths educators and 25% were from Engineering/IT contexts. Participation in the survey was voluntary and there was a diverse range of experience levels identified in the participants' background data. Sixty-four percent of the survey participants had been teaching for more than 10 years, while 17% had been teaching for less than two years. Similarly, 46% of participants perceived themselves as experienced users of mobile devices in their teaching—defined as more than two years' experience—while 22% said this was their first attempt at implementing a mobile learning task.

Participants chose a range of task contexts. Ninety percent of the STEM teachers described a formal task that was classroom-based. Only 7% of teachers reported on a task that was situated in an 'extra-mural' context (school playground, excursion site, museum, home) and no tasks were set in a totally informal location such as a cafe or public transport

(3% reported a combination of locations). Most tasks involved use of an iPad (38%), laptop (26%) or mobile phone (12%), with 19% of tasks integrating a mixture of devices. Forty-eight percent of tasks involved use of school-owned devices (33% restricted to on-campus use only) while only 23% of tasks involved student-owned, 'bring-your-own' devices (BYOD).

What Teachers Say They Do: Agency and Collaboration in Mobile Learning

This section is divided into two parts. Firstly, we report on the quantitative data from the online survey relating to the two dimensions, agency and collaborative networking, upon which the scenarios have been constructed. Secondly, we present sample qualitative data from the survey, with a selection of learning tasks from the study to illustrate how STEM educators are currently using mobile technologies. To illustrate the utility of these two dimensions, these examples are then plotted against these two variables of networking and agency. On the basis of this empirical data we then present four scenarios in the form of persuasive narratives or stories.

In selecting the two drivers of student agency and collaborative networking, as explained in the previous section, we returned to those questions in the survey which were most closely aligned with these two constructs. The following data is presented to represent the types of statistical responses made to these questions. Each question usually contained three response options that corresponded to 'low' or 'none', depending on the context of the item, 'medium' and 'high' ratings for a particular construct. Most items offered an 'other' option but this small portion of responses was not included in Tables 11.2 and 11.3.

The flexible, autonomous learning affordances of m-learning environments were not evident in survey responses from STEM teachers, with only one-quarter of tasks giving full control to students for task pacing and only 17% of tasks allowing students full autonomy where and when the activity was implemented (see Table 11.2. Just over one-quarter of teachers perceived their task as lending absolutely no student control over aspects such as the learning context—where and when the activity occurs (35% of teachers), task pacing (26% of teachers), task content and learning goals (28% of teachers).

Table 11.2 Results for sample items relating to student autonomy and agency (n=69)

Sample Items	L	M	H
To what extent does the mobile learning task allow students to control the context (e.g. where and when the activity occurs)?	35%	48%	17%
Who determines the 'pacing' of the mobile learning task	26%	48%	25%
To what extent does the mobile learning task allow students to control the content and learning goals of the activity?	28%	59%	13%

The STEM teachers in the survey did not design learning episodes which grant their students high, or even moderate levels of decision-making with regard to the context of their learning (e.g. where or when it occurs). This lack of opportunities for students to enjoy autonomous learning tasks is particularly surprising given the general commentary around enhanced agency in m-learning environments (see, for example, Burden et al., 2012). Also, given the high level of formal tasks in the data set (90%), these results support the contention that many of the characteristics of m-learning are foreign to traditional classroom-based learning (Mifsud, 2014; Traxler, 2009).

Most activities described by the STEM teachers were highly social and collaborative in nature, albeit within a traditional face-to-face context rather than a remote virtual one (see Table 11.3). The majority of m-learning tasks involved a high level of face-to-face conversation at the device, usually in the classroom. Most teachers prioritised students working in small groups around their device, with 70% ranking their task as 'medium' or 'high' for face-to-face collaboration. Whole-class discussions were frequently mentioned, with teachers using the 'mirroring' feature of the iPad, for example, to display students' work on a large screen. However, levels of online conversation *through* the device (Crooks, 1999) were generally ranked low (68%). In tasks that included online discussion, communications were mainly between class peers (38%) or between students and their teachers (20%). Only 4% of tasks involved 'extra-mural' communications with participants outside their immediate peer/teacher class network.

Table 11.3 Results for sample items relating to collaborative networking (n=69)

Sample Items	L	M	H
Does your task encourage student (peer) face-to-face (f2f) discussion AT the device?	23%	58%	12%
Does your task encourage online discussion THROUGH the device? e.g. email, SMS, Skype, Twitter or Facebook 'conversation'.	68%	7%	20%
To what extent are online interactions (discussions and/or data sharing) THROUGH the mobile device 'networked'?	41%	22%	38%

Indeed, there was a low rate of networked, synchronous interactions in the STEM tasks. Although student generation of digital content was a feature of teachers' chosen tasks, there was a distinct lack of networked interactions. Only 38% of tasks involved a networked exchange of digital data and information, or networked interactions (e.g. via blogosphere, Twitter, multi-layer games etc.). Most online interactions were asynchronous (30%), compared to a much lower rate (17%) of 'live' synchronous communications.

In conclusion, using the two drivers we have selected, the overall picture from STEM participants is one in which students are entrusted or granted relatively limited autonomy or choice when they use mobile technologies and are restricted to largely face-to-face interactions within their own classroom or with their teachers, almost exclusively on an asynchronous basis with limited opportunities to exploit any of the real time benefits afforded by mobile technologies for communication and networking. In light of our pedagogical model and informed by the survey data, we deemed these variables, agency and collaborative networking, as being most useful to form the two dimensions of our scenario forecast

Scenario building

Scenarios have been described as "presentations of multiple possible futures" (Snoek, 2013, p. 311), which are widely used in businesses (e.g. Shell, 2003) and the military (Cann, 2010) but until recently, less common in education. This may be changing with some high profile scenario planning exercises commissioned by organisations like the OECD (2001) and teacher futures special editions in international education journals (e.g. Aubusson & Schuck, 2013). This recent surge of interest amongst educators is not surprising given the complexity and unpredictability of the environments within which they operate, since scenario planning is seen as a more suitable alternative to traditional prediction methods, which depend on greater levels of stability and more predictable contexts (Snoek, 2013). Indeed Snoek identifies this as one of two major problems associated with traditional approaches to planning and predicting the future, pointing out how this has a tendency to produce a single future prediction when in fact there are likely to be many. To compound this tendency, policy-makers and governments are also guilty of believing they can realise a single prediction of the future by mandating change ignoring the 'fundamental unpredictability of the future and the possibility of different futures[that] need to be taken into account." (Snoek, 2013, p. 308).

Scenario planning is positioned as a viable alternative to the traditional 'rational-central-rule' approach (Gunsteren, 1976) since it accepts the inherent unpredictability and complexity of modern society and seeks to identify multiple possible futures enabling greater scope for discussion and alternative perspectives. Put another way, traditional approaches are akin to 'forecasting', which leads to future predictions, compared to 'foresighting', which leads to alternative scenarios for the future (Codd et al., 2002).

What are scenarios and how are they produced?

Scenarios are often described as narratives or stories about multiple futures which help their creators to consider and conceptualise alternatives along with the choices associated with them. Rather than rushing forwards into foreshortened perspectives, scenarios encourage a longer-term outlook (Schwartz, 1997). The first stage in the production of scenarios involves the identification of key trends or 'drivers', which shape the development of society such as environmental change, social inequality, demographic shifts and technology itself, which is the focus of this study. Although these trends are recognised as important drivers of change it is only those defined as 'unpredictable' which are selected since these serve as vectors inviting debate, discussion, difference and ultimately polarities. Technology meets these criteria well as it generates considerable debate and difference at both the micro and macro level.

However this study is not primarily driven by an exploration of technology *per se* as we have pointed out in previous papers (Kearney et al., 2012) but rather by a socio-cultural investigation of the signature pedagogical affordances associated with the use of mobile technologies and their particular relevance for STEM educators in the future. Therefore our first task was to re-examine our existing data set from our international survey to identify sub-drivers within the field of mobile learning which meet the criteria for scenarios. Table 11.4 identifies the main themes which were investigated and validated through the online survey (Kearney et al., 2015). All of them are capable of generating dichotomous positions, as illustrated below, but some of are more unpredictable in the sense that the educational community is divided or unclear about how these themes might be applied in practice.

Table 11.4 Potential 'drivers' identified in a previous study of m-learning (Kearney et al., 2015)

Constructs / Drivers	Dichotomous positions	
Personalisation		
Agency/student autonomy	External control (teacher directed)	Internal control (negotiated by student)
Customisation	'One size fits all'	Tailored fit ('customised to me')

Authenticity		
Contextualisation	Contrived	Realistic
Situated	Simulated	Embedded in real practice
Collaborative networking		
Conversational	Solitary (disconnected)	Rich (networked)
Data sharing	Content consumption (alone - no sharing)	Content / context building (in communities)

We therefore followed the recommendations in the literature on working with scenarios to scrutinise the data set in order to identify those drivers considered to be amongst the most impactful and unpredictable (Van der Heijden, 2005). The sub-elements of ‘conversational’ and ‘data sharing’ were originally part of a broader category termed ‘collaboration’ which described those pedagogical affordances which enable individuals to engage in greater levels of networked sharing, exchange and collaborative discussion mediated through the mobile technologies. This notion of networking is similar to what Park (2011) refers to as the ‘social nature of learning’, which measures the degrees to which learning is an entirely independent or entirely social enterprise. Although participants described tasks or activities that were ranked relatively high for face-to-face conversations and discussion they ranked online networking and data sharing as relatively low. We therefore identified this as one of the drivers to adopt in this exercise, since it offered considerable scope for alternative practices and thinking in science education around virtual and multiple conversations and collaborative data exchange.

We selected student autonomy/agency as a second driver or variable, since this had also emerged as a significant finding from the previous study, where participants reported surprisingly low levels of student autonomy and choice (goals, content etc.) given the dominant discourse in the literature which portray digital technologies as vehicles for greater learner agency (Burden et al., 2012; Pachler, Bachmair, & Cook, 2009). Since the purpose of the scenario building methodology (for details see Chapter 6) is to stimulate discussion and thinking about possible futures in STEM education, we identified these two drivers as ideal candidates and followed the recommendations of others who have adopted this approach (Schuck & Aubusson, 2010) to generate a two-dimensional model with four separate quadrants (see Fig. 11.2).

For each of the four quadrants, we generate distinct narratives paying particular attention to ground them in the concrete data generated by participants in both the closed and open text responses collected in our study. The scenarios (see Findings section) are deliberately written in a compelling and persuasive fashion and all four are written with a positive perspective since scenario building is designed to encourage consideration of alternatives that might not otherwise appeal. For purposes of transparency and trustworthiness a selection of these data are illustrated in Fig. 11.2 and Tables 11.3 and 11.4. In this sense our methodology is firmly grounded in the existing data set we have collected and validated in previous studies, and we use it to extrapolate four equally valid alternative futures, rather than a single future prediction. It is acknowledged that this methodology has its limitations and is not particularly valuable in explaining how to mobilise change towards any of these possible futures. However this is beyond the scope of the chapter, although it is further examined in some of the more recent literature on boundary objects and activity theory (see Snoek, 2013).

We conclude this section by identifying the research questions that form the focus for the chapter:

1. What possible futures might present themselves to STEM educators interested in harnessing the potential of mobile technologies?
2. What are the implications of these possible futures for STEM educators?

Harnessing the Potential of Mobile Technologies: Producing Alternative Futures

To demonstrate the utility of the two chosen dimensions of agency and collaborative networking, sample qualitative data were analysed according to their match with the polarities of these two variables. The online survey did not mandate participants to provide an actual example of their m-learning task but 43 of the 69 STEM participants did so in the optional open-ended survey questions. Table 11.5 illustrates a selection of these tasks, providing a snapshot of qualitative data relating to the following questions:

- What was the topic of your learning task/activity?
- What were the objectives of the topic associated with the task you have described?
- What did the students do during the task using mobile technologies?
- What was your role as the teacher during the task?

Table 11.5 Sample m-learning tasks from study: Snapshot of responses to open-ended questions

	Background	Student / Teacher roles
1	Objective: *To apply knowledge on everyday items using mind maps.* Video cameras were used to take notes of mind maps drawn on the whiteboard of content (about programming) from both the classroom and real-world contexts, then discussed amongst themselves on *Edmodo*. *(Engineering/Technology*)	Students asked to use mind map and apply terms. Students and teachers walked around the school and applied these terms. Teacher as guide.
2	Objective: *To explain a concept in elementary science through video. Also, to learn skills such as storyboarding and animation.* Elementary science education concepts. The students used mobile phones and digital cameras to take pictures to create *Slowmation* movies. (*Science teacher education*)	Students used their phones and digital cameras to take pictures. Teacher helped with technical issues, and helped students to think about the science concepts they had chosen and how to represent them.
3	Objective: *To enhance engagement/ownership of the laboratory practical. Placing the practical in a larger scientific context. Network building.* Students use mobile phones to live tweet findings of their laboratory practicals. *(Secondary school science*)	Students took pictures, provided advice and responded to others' examples. Teacher leads by example and occasionally moderates.

4	Objective: *To display appropriate stages of dissection Identification of various specified parts of the kidney / brain.* Laboratory-based session dissecting kidneys / brains. Students used their phone cameras to record various stages in the dissection processes. Photos became an integral part of their notes and provided evidence of exploratory investigation of structures, as decided by the students. (*Secondary school science*)	Students dissected kidneys and brains (from sheep) in groups. Teacher acted as demonstrator, supervisor, observer.
5	Objective: *To understand the causes and effects of global warming, and identify ways of controlling it.* Global warming. (*Secondary school science*)	Students watched and listened to lectures and photos via skype. Teacher introduced the lesson, setup laptop and internet connectivity and mediated Skype call with expert.
6	Objective: *To plan and write a script; create a storyboard and edit and present the multimedia presentation.* The life and habitat of an animal. Students used their device to make a movie to help explain their chosen animal. (*Primary/elementary school science*)	Students created short videos, including sound. Teacher helped to facilitate use of device, allowing students to explore and learn as they created their short video clip.
7	Objective: *To identify real-life acute, obtuse and right angles.* The Year 4 Maths class was learning about angles. The students used their iPad devices to take photos of angles in the playground. (*Primary/elementary school maths)*	Students included all the photos that they had taken in the playground to produce a collage. They used functions of the iPad to crop, colour, add text and amend layouts. Teacher assisted students in finding the angles in the playground and encouraged them to present their photos to the class.

The seven examples from Table 11.5 (shown with small numbered boxes in Fig. 11.2) were analysed by the two researchers using the two scales of agency and collaborative networking to rate these critical features of the m-learning activities. They were then plotted according to their rankings along each axis, with lower ratings at the bottom of the vertical axis or left-hand side of horizontal axis, and higher ratings towards the top or right-hand side of each axis. When researchers' ratings differed, differences were resolved through group consensus. From this analysis, each of the seven examples was plotted into one of the four quadrants (see Fig. 11.2), labelled according to their agency and collaborative networking characteristics: Quadrant A: guided and scaffolded; quadrant B: simulatory and autonomous; quadrant C: connective and directed; quadrant D: participative.

Most of the data captured in this exercise is contained and can be described by a relatively small footprint (illustrated with the dotted rectangle) in the lower two quadrants of the diagram. Despite two outliers (examples 3 and 5), the other qualitative examples (2, 4, 6 and 7) were plotted within a consistent pattern, showing limited interactions beyond the physical boundaries of the classroom and essentially solitary in nature, with little opportunity for students to share data or engage in conversations.

In what follows we describe four narrative scenarios developed for STEM education, as depicted in the quadrants of Fig. 11.2. These present alternative possible futures for mobile technology-enhanced STEM learning. Each scenario is rooted and grounded in the data we have described previously but these are not intended to be merely descriptions of the data. Rather they use the data as starting points to extrapolate possible futures. Each scenario has been developed in a way that is consistent and recognisable with the data set to ensure it is plausible yet sufficiently challenging to encourage new patterns of thinking. Following the methodology recommended by Snoek (2005) each scenario is described in an extreme manner in order to differentiate them.

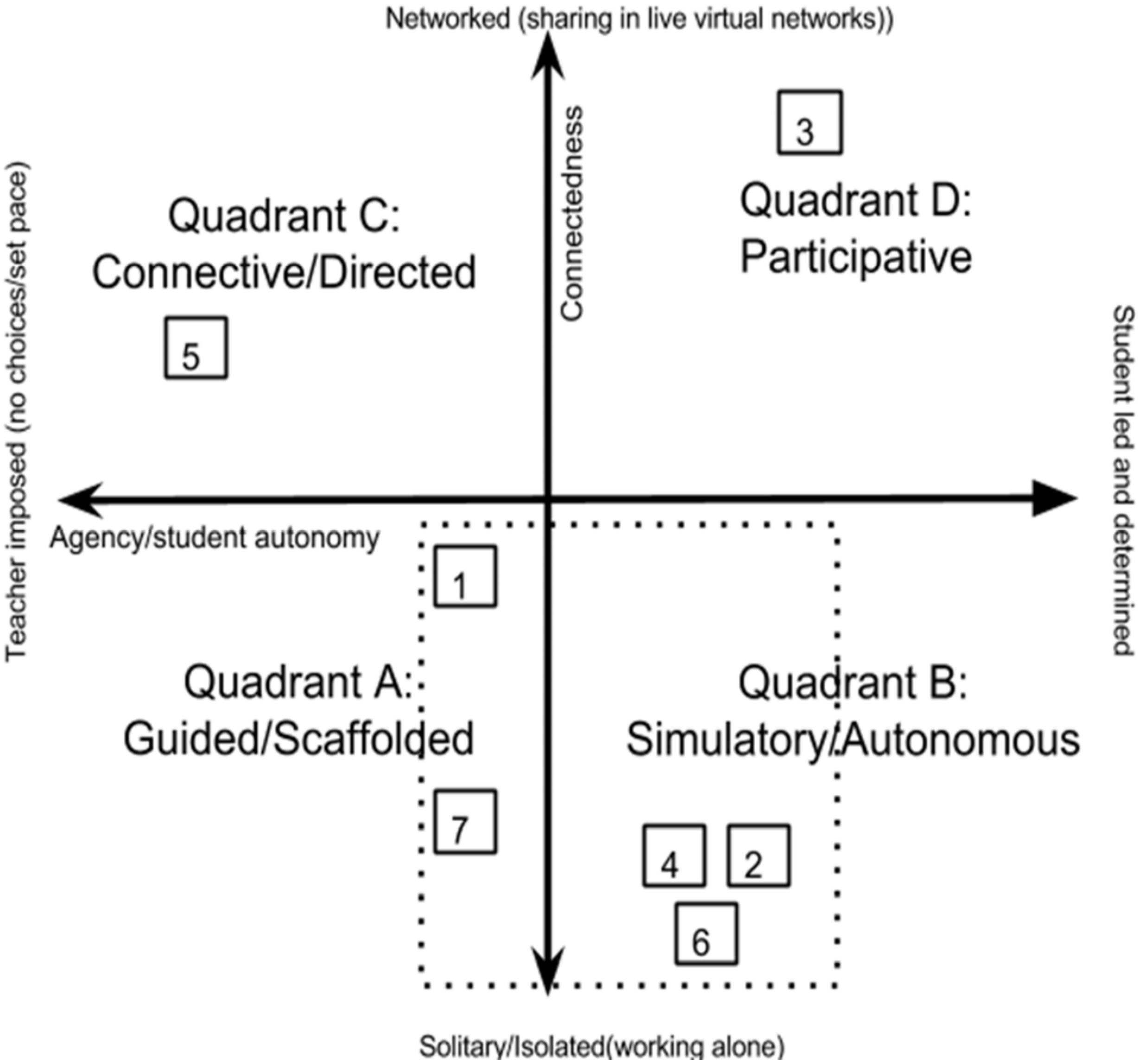

Fig. 11.2 Qualitative data plotted against twin variables

Scenario A: Guided and scaffolded STEM learning

In this scenario, mobile technologies are used by STEM educators to underpin and reinforce traditional practices of STEM education (i.e. the status quo) where STEM subjects are taught as formal, curriculum-based subjects and technology is employed to make teaching and learning more effective and efficient. The main emphasis lies with the transmission of accepted STEM principles and knowledge and this is undertaken most effectively through teacher-directed access to information sources such as *YouTube* video demonstrations, podcasts, e-textbooks and the use of 'skill and drill' apps such as science quiz apps. Mobile devices are used extensively in the classroom and laboratory to free students from traditional note-taking and drawing exercises and these are replaced by digital annotation tools, usually used individually or in pairs, such as stand-alone mind-maps, electronic worksheets and e-books. Teachers control the content, objective and pace of lessons, including tightly scaffolded, recipe-style investigations. They administer live polls to students to test their immediate understanding of a concept (e.g. through an app like *Socrative*) and to gain feedback about what students know or need to know better. Teachers present and explain key ideas and principles using whole-class presentation apps such as *ShowMe*, *Explain Everything* and *Nearpod* which enables them to scaffold the content delivery, ensuring all of the class are working at the same pace. Students work mainly with the teacher and their classroom peers, only using the Internet to access information or to e-mail the teacher their work. Mobile technologies are seen as a highly effective and efficient way to better prepare students for high-stake testing. In class, students are encouraged to use their mobile device to capture and annotate notes made by the teacher on the interactive whiteboard or examples of experiments or demonstrations which cannot be undertaken by the students for reasons of efficiencies of time, or health and safety. In this way students can return to their personal store of notes for revision purposes after the lesson is complete.

Scenario B: Simulatory and autonomous STEM learning

In this scenario, mobile technologies are appropriated by STEM educators to mediate autonomous but largely isolated learning by students whereby the device acts as an 'intellectual partner' and cognitive tool for the students (Jonassen, Carr, & Yueh, 1998). Students typically use mobile technologies to mediate relevant STEM processes and tasks, depicting a simulation model of authenticity (Radinsky et al., 2001), making use of class-based investigations and fieldwork as a 'practice field', albeit separate from the real STEM community. Use of the mobile device gives students the ability to control tools such as the ability to manipulate a range of scientific variables and make predictions, thus encouraging them to think and behave like real scientists. Students are given varying degrees of freedom and choice to explore a STEM related problem or issue, and the teacher adopts the role of facilitator or guide. Rather than scaffolding the learning of STEM to the entire class, the teacher allows students to use their mobile device to explore simulations and other resources (depending on the problem), such as animal dissection apps to 3D views of the periodic table. In this way, students work more at their own pace on a challenging, self-selected problem or issue. They use a wide range of apps and tools to observe phenomena and collect and analyse data in and outside of the classroom, for example, to measure sunlight, gauge sound levels, observe the night sky using location-based AR apps such as *Skyview* (http://tinyurl.com/lonln3j). Many experiments and processes which cannot be undertaken physically are simulated using mobile apps such as *Wind Tunnel Pro* in engineering (http://tinyurl.com/p3ohqmh), to gain a more accurate understanding of how engineers think and behave. Students typically work in small groups to tackle a STEM-based problem and are encouraged to use a range of generic media capture and editing tools such as the camera, the audio recorder and the video editing and animation apps to produce high quality representations of their current understandings. Assessment is based on these authentic demonstrations, rather than simple tests.

Scenario C: Connective and directed STEM learning

In this scenario teachers use mobile technologies to liberate students from the physical confines of the formal classroom, enabling them to work and interact with peers and experts beyond the classroom, using teacher controlled sites such as class blogs and wikis, discussion forums and microblogging services such as *Todaysmeet*, to ask questions, receive responses and exchange ideas. The teacher uses the technology as a starter to carefully scaffold and monitor realistic explorations, often based outside of the classroom. Students use their devices to collect data and to analyse it, often in situ and under the careful guidance of the teacher or an expert. Students behave like STEM practitioners to the extent that they are working collaboratively, undertaking problem solving activities and real-time data exercises, such as the use of Bluetooth enabled data collection tools to undertake a beach survey. Data and findings are shared with peers and teachers in externally controlled cloud-based documents. However, projects are carefully selected and externally designed to ensure students cover curriculum content. Although collected data may be shared beyond the class, it does not contribute to any wider STEM community projects. Most of the activities undertaken are likely to be highly scaffolded inquiry projects, or tightly controlled multi-player games or simulations, making greater use of the networking features of mobiles and the ability to tap into real time data.

Scenario D: Participatory STEM learning

In this scenario, mobile technologies are a dynamic and reciprocal conduit to live time data, expertise and a community of real STEM practitioners, which enable students to think and behave as part of the real STEM community (e.g. as citizen scientists). This is not simulated and the students are seen as equal status and co-constructors with their teachers in the process of producing new STEM knowledge, akin to the notion of participative authenticity espoused by Radinsky et al. (2001). STEM subjects are unlikely to be taught as separate subjects in this scenario and indeed formal school curricula may not be recognisable. Students are immersed in real STEM areas of interest (e.g. a nature reserve) where they undertake an extended work experience using the technology to share, analyse and interpret their own and others' data, maintain contacts with their peers and with experts in the real world, who validate and credential the learning. Students are asked to think and behave as STEM practitioners and their findings are used and valued by the scientific community (e.g. in collecting real time data as citizen scientists). Students in this scenario use networking tools and social media apps like *FaceBook*, *Instagram* and *Twitter* to pose questions and share their predictions and interpretations with peers (in and beyond their own cohort) and with other STEM experts. Teachers may use data analytics to monitor students' activities in these spaces and assess their progress and development in real-time. Connective, augmented reality apps, multi-player games and immersive learning tools enable students to understand complex ideas and concepts at their own pace and in many cases these act to mediate students' learning, independently of the teacher. Examples include use of the previously discussed *sense-it* app (Herodotou et al., 2014), *nQuire* app (Jones et al., 2013) and *iSpot* app (Scanlon et al., 2014).

Implications of these Alternative Futures for STEM Educators

The previous section presented four radically different alternatives for the use of mobile technologies in STEM education and therefore addressed the first of our two research questions: *What futures might present themselves to STEM educators interested in harnessing the potential of mobile technologies?* In this final part of the chapter we return to the second of our research questions: *What are the implications of these possible futures for STEM educators?*

The low rates of networked data collected from STEM teachers in this study (n=69) follow the same pattern as the entire data set (n=195) (Kearney et al., 2015), which run contrary to much of the m-learning literature around 'real-time' spontaneity and extensive connections (or 'hyperconnectivity') enabled by m-learning environments (Norris & Soloway, 2011; Parry, 2011; Peluso, 2012). Only two of the exemplars cited from the STEM data set appear to have been deliberately designed by teachers to engage students in STEM learning tasks that connected them more widely with peers or subject experts, despite many of the obvious benefits associated with this approach in terms of inquiry-based learning. In these cases, students exploited the affordances of their mobile devices to tweet live findings from their experimental work to other students and experts outside of the classroom and to receive the assistance of an external science expert via Skype (cases 3 and 5). Many more networked and collaborative examples might have been expected in the survey, and with relatively simple adjustments to the learning design of their lessons teachers might have 'brokered' more opportunities for students to cross the boundary between their digital worlds and the (analogue) arena and physical realities of formal education (Royle & Hadfield, 2012). This point also picks up on the 'seamless' learning theme covered in the literature which indicates how mobile technologies have the potential to assist teachers and students in crossing boundaries between various settings and contexts to extend and continue their STEM learning beyond the formal, physical classroom (Toh et al., 2013). For example, by empowering the students to use an interactive app or social media tool, in example 5, students would enter the more collaborative Quadrant D by posting real questions and problems for real scientists to respond to, rather than simply consuming their expertise in a passive manner. Indeed, many of the examples from the STEM data set had a similar potentiality to be shifted from the lower two quadrants to the upper two quadrants (i.e. the boundaries are permeable), usually by considering opportunities to collaborate and network, and by thinking about learning tasks as multi-staged events to be completed in more than one place or time (for example, 'seamlessly' linking an in-situ field investigation with networked sharing of data and follow-up learning conversations).

There was an identified trend of STEM teachers in the study designing relatively solitary m-learning STEM activities. This raises the question of how educators can better leverage 'massive social networking' (UNESCO, 2011), for example via social media, to allow learners to better connect with and participate in communities outside their immediate class context (Parry, 2011). In this way, teachers can extend the inquiry model of STEM teaching, allowing students to more widely share predictions, data and findings, encourage collaborative analysis and interpretations, and promote more diverse feedback and exchange of ideas within a legitimate and diverse community of learners. Furthermore, the rich networking and strong digital footprints characteristic of quadrants C and D scenarios, brings to bear the possibility of using learning analytics to assess learners' needs and development. For example, participation in *iSpot* activities (Scanlon et al., 2014) enabled the use of learning analytics to gauge participants' identification knowledge and proficiency using the *iSpot* app (p. 69).

The flexible, negotiated nature of learners' use of time and space is a well-documented feature of mobile learning environments (Traxler, 2009), particularly in the malleable spatial-temporal contexts of less formal learning spaces. However, 90% of the m-learning tasks reported in the survey by STEM teachers were based in formal institutional contexts, making use of traditional, rigid configurations of time and place. We know that mobile technologies enable learning to occur in a multiplicity of more informal (physical and virtual) settings situated in the context about which the learning is occurring. For example, the opportunities for in-situ inquiry projects, in learner-generated contexts using real-time data and immediate feedback mechanisms, are well reported, with documented benefits for learning science (Zhang et al., 2010). We trust that whatever features of the four scenarios eventuate in the future, more teachers will exploit the affordances of mobile technologies to leverage more diverse, inquiry-based pedagogies in these less formal 'test-beds' for STEM learning.

This study did not explore causal relationships between time/space configurations and the twin dimensions of agency and networking. Indeed, we propose that flexible time/space configurations could be applied to *any* of the four scenarios, particularly multi-staged tasks across a blend of contexts. For example, teachers following a flipped learning pedagogy (Herreid & Schiller, 2013) might encourage students to view their instructional podcast (Quadrants A features) using a negotiated time/space configuration, 'at their own time, pace and place' before class. The rationale for this type of pre-class task is to reduce the need for instruction in subsequent classes, allowing for precious, formalised 'class time' to be used for more active, autonomous, inquiry-based work (e.g. Quadrants B or D). In other words, a higher rating of agency and networking does not necessarily align with flexible, negotiated use of time and space, nor do low ratings of these dimensions correlate with more traditional formal arrangements.

Conclusion

We acknowledge that other emerging technologies may well have a profound influence on STEM learning in the future, for example, learning analytics (see Chapters 4 and 10), 3D printing, games-based learning and wearable technologies (Johnson et al., 2013). However, given the current interest and investment in mobile technologies, it is timely to explore the future of STEM learning in light of the distinctive features of mobile-intensive pedagogies. Previous research demonstrates how teachers have a strong tendency to design tasks that use mobile technologies to 'fit' into traditional notions of formal, scheduled, institution-based learning (Rushby, 2012; Kearney et al., 2015), and recent studies undertaken by the authors of this volume suggest that teacher educators adopt broadly similar approaches (Burden & Kearney, 2017). In some ways, this default position has been influenced by the large majority of educational apps that are underpinned by an information transmission model of learning, or behaviourist, drill and practice approaches (Murray & Olcese, 2011). Indeed, Mifsud (2014) and Traxler (2009) argue that many of the features of m-learning are in conflict with traditional classroom-based learning, making the effective use of m-learning a challenge for educators and teacher educators in particular.

In this study, we meet this challenge by rationalising and developing four future scenarios that help STEM educators project how they might choose to exploit two distinctive pedagogical aspects of m-learning: student agency and collaborative networking. Unlike some macro-level driving forces that cannot be easily influenced by teachers or teacher educators (e.g. national policy or global trends), each of these two micro-level variables falls within the locus of control of individual teachers and teacher educators. The scenarios reveal a range of pedagogical affordances for STEM education, highlighting connection between peers and the STEM community, participative authenticity and student autonomy.

If, as this study suggests, the current generation of STEM teachers are not yet exploiting the authentic and collaborative affordances of mobile learning that have been shown to align so well with many of the principles underpinning the current drive for STEM learning, it will be incumbent on teacher education and individual teacher educators to grasp this opportunity in order to ensure the next generation of teachers are better prepared and more disposed to do so. No single action alone is likely to achieve this but role modelling the use of mobile technologies to join, network and work in partnership with real life STEM practitioners must be considered amongst the top priorities for teacher educators if they are to engage their trainee students in the same kind of work. This study has revealed how few teachers set their students tasks located outside of formal classrooms and seldom grant them freedom to select their own activities or negotiate their own learning objectives, despite the wealth of research literature that illustrates how effective mobile technologies can be in supporting these activities. Therefore, if teacher educators are to model the effective use of mobile technologies in STEM related contexts it is imperative that they review the current contexts they set students to work within and the degrees of agency that grant them to negotiate their own learning outcomes. This may involve teacher educators moving beyond the safety and security of their university based teaching contexts to sometimes work in other settings such as museums, real life laboratories, heritage centres, engineering workplaces and field-sites. Additionally, they will need to demonstrates the seamless affordances of mobile technologies by designing tasks and settings that enable their trainees to work across boundaries, both virtual and physical, such as a virtual laboratory or a 3-D immersive setting where they can learn how to undertake a task as a simulation before undertaking it in a physical setting. By modelling these mixed settings and offering students opportunities to cross boundaries between them seamlessly, it is more likely they will encourage their trainees to use these same techniques and affordances when they start work in schools.

However, possibly the most powerful and effective lever that teacher educators could use to accelerate these shifts in schools, and encourage both their pre-service and in-service teachers to buy into these approaches, would be to establish authentic and meaningful partnerships with different STEM practitioners that mirror the way citizen science projects currently work, often through a mobile app. In these projects members of the public can participate in authentic science inquiries and projects, collecting and analysing scientific data alongside real scientists and other experts. In the best of these projects there is little in the way of power imbalance that has blighted some projects, and both parties benefit equally, though in different ways. The challenge for teacher educators is to conceptualise similar projects that would work across the STEM disciplines, enabling their trainee teachers, and ultimately school students, to benefit in the same way as members of the public enjoy in citizen science. Citizen science projects probably work well because there is a mutual benefit to both parties (the public and science experts) in participating in these projects. In particular, the professionals (in this case scientists) benefit by gaining access in real-time to vast quantities of data collected by volunteers they could not expect to access by themselves. Are there comparable benefits to be had for technologists, engineers and mathematicians that would induce them to take a more active role in the networks we are proposing here? We are not currently in a position to answer this question in a definitive manner, but we suggest it would be a fruitful one for teacher educators to discuss alongside STEM practitioners and see this as an urgent priority in order to make progress in this respect. NASA has demonstrated how to harness public interest in space and astronomy to help them discover new planetary systems hidden amongst the data they have collected through the Wide-field Infrared Survey Explorer (WISE) (see www.DiskDetective.org). Similar challenges and problems might be identified by mathematicians, engineers and technology specialists, and be precipitated with the encouragement and partnership of teacher educators. It requires a proactive stance on their part and a recognition that they need to develop symbiotic relationships outside of the university that could facilitate the benefits we have outlined above. This chapter advocates further studies into how informal STEM-based learning can complement formal STEM learning, the changing nature of teacher roles in these blended environments, and use of emerging mobile technologies to engender agency and networking of STEM learners.

References

Aubusson, P., Griffin, J., & Kearney, M. (2012). Learning beyond the classroom: Implications for school science. In Fraser, B., Tobin, K., & McRobbie, C. (Eds.), *The second international handbook of science education* (pp. 1123-1134). Netherlands: Springer.

Aubusson, P., & Schuck, S. (2013). Teacher education futures: Today's trends, tomorrow's expectations. *Teacher Development, 17*(3), 322-333. doi: 10.1080/13664530.2013.813768

Burden, K., Hopkins, P., Male, T., Martin, S., & Trala, C. (2012). *iPad Scotland evaluation*. Faculty of Education, The University of Hull, UK. Retrieved from http://www2.hull.ac.uk/ifl/ipadresearchinschools.aspx

Burden, K., & Kearney, M. (2016). Future scenarios for mobile science learning. *Research in Science Education. 1-22*

Burden, K., & Kearney, M. (2017). Investigating and critiquing teacher educators' mobile learning practices. *Interactive Technology and Smart Education, 14*(2), 110-125.

Cann, A. (2010). *Scenario based strategic planning in the U.S. Army Corps of Engineers Civil Works Program*. IWR White Paper. Retrieved from http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/Scenario-BasedStrategicPlanning.pdf

Cheng, K. H., & Tsai, C. C. (2013). Affordances of augmented reality in science learning: suggestions for future research. *Journal of Science Education and Technology*, *22*(4), 449-462

Codd, J. A., Brown, M., Clark, J., Mcpherson, H., O'Neill, J., O'Neill, H., Waitere-Ang, & Zepke, N. (2002). *Review of future-focused research on teaching and learning.* Wellington: Ministry of Education New Zealand.

Crooks, C. (1999). Computers in the community of classrooms. In K. Littleton & P. Light (Eds.), *Learning with computers. Analysing productive interaction* (pp. 102-117). London: Routledge.

DeGennaro, D. (2012). Evolving learning designs and emerging technologies. In Fraser, B., Tobin, K., & McRobbie, C. (Eds.), *The second international handbook of science education* (pp. 1319-1331). Netherlands: Springer.

Dunleavy, M., & Dede, C. (2014). Augmented reality teaching and learning. In J. M. Spector, M. D. Merrill, J. Elen, & M. J. Bishop (Eds.), *Handbook of research on educational communications and technology* (4th ed.) (pp. 735–745). New York: Springer.

Foley, B. J., & Reveles, J. M. (2014). Pedagogy for the connected science classroom: Computer supported collaborative science and the next generation science standards. *Contemporary Issues in Technology and Teacher Education*, *14*(4). Retrieved from http://www.citejournal.org/vol14/iss4/science/article1.cfm

Green, L., Hechter, R., Tysinger, P., & Chassereau, K. (2014). Mobile app selection for 5th through 12th grade science: The development of the MASS rubric. *Computers and Education, 75*, 65-71. doi:10.1016/j.compedu.2014.02.007

Gunsteren, H. R. Van. (1976). *The quest for control exemplar scenarios from science, engineering and maths*. London: Wiley.

Herodotou, C., Villasclaras-Fernández, E., & Sharples, M. (2014). The design and evaluation of a sensor-based mobile application for citizen inquiry science investigations. In *Open Learning and Teaching in Educational Communities* (pp. 434-439). Springer International Publishing.

Herreid, C. F., & Schiller, N. A. (2013). Case studies and the flipped classroom. *Journal of College Science Teaching*, *42*(5), 62-66.

Johnson, L., Adams Becker, S., Estrada, V., & Martín, S. (2013). *Technology outlook for STEM+ education 2013-2018: An NMC Horizon project sector analysis*. Austin, Texas: The New Media Consortium.
Jonassen, D.H., Carr, C., & Yueh, H.P. (1998). Computers as mindtools for engaging learners in critical thinking. *TechTrends, 43*(2), 24-32.
Jones, A. C., Scanlon, E., & Clough, G. (2013). Mobile learning: Two case studies of supporting inquiry learning in informal and semiformal settings. *Computers & Education*, *61*, 21-32.
Kamarainen, A. M., Metcalf, S., Grotzer, T., Browne, A., Mazzuca, D., Tutwiler, M. S., & Dede, C. (2013). EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips. *Computers & Education*, *68*, 545–556.
Kearney, M., Burden, K., & Rai, T. (2015). Investigating teachers' adoption of signature mobile pedagogies. *Computers & Education*, *80*, 48-57.
Kearney, M., & Maher, D. (2013). Mobile learning in maths teacher education: Driving pre-service teachers' professional development. *Australian Educational Computing, 27*(3), 76-84.
Kearney, M., Schuck, S., Burden, K., & Aubusson, P. (2012). Viewing mobile learning from a pedagogical perspective. *Research in Learning Technology, 2.* doi: 10.3402/rlt.v20i0/14406
Kinash, S., Brand, J., & Mathew, T. (2012). Challenging mobile learning discourse through research: Student perceptions of Blackboard Mobile Learn and iPads. *Australasian Journal of Educational Technology*, *28*(4). https://doi.org/10.14742/ajet.832
Krajcik, J.S., Blumenfeld, P., Marx, R.W., & Soloway, E. (2000). Instructional, curricular, and technological supports for inquiry in science classrooms. In J. Minstrell & E.H.v. Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 283–315). Washington, DC: American Association for the Advancement of Science.
Lai, K. W., Khaddage, F., & Knezek, G. (2013). Blending student technology experiences in formal and informal learning. *Journal of Computer Assisted Learning*, *29*(5), 414-425.
Ling, R., & Donner, J. (2009) *Mobile communications*. London: Polity.
Lui, M., Kuhn, A., Acosta, A., Niño-Soto, M. I., Quintana, C., & Slotta, J. D. (2014). Using mobile tools in immersive environments to support science inquiry. In *CHI'14 Extended Abstracts on Human Factors in Computing Systems* (pp. 403-406). ACM.
Marty, P. F., Alemanne, N. D., Mendenhall, A., Maurya, M., Southerland, S. A., Sampson, V., & Schellinger, J. (2013). Scientific inquiry, digital literacy, and mobile computing in informal learning environments. *Learning, Media and Technology*, *38*(4), 407-428.
Mifsud, L. (2014). Mobile learning and the socio-materiality of classroom practices. *Learning, Media and Technology*, *39*(1), 142-149.
Murray, O., & Olcese, N. (2011). Teaching and learning with iPads: Ready or not? *TechTrends, 55*(6), 42-48
Norris, C. A., & Soloway, E. (2011). Learning and schooling in the age of mobilism. *Educational Technology, 51*(6), 3-12.
OECD. (2001). *Schooling for Tomorrow, What schools for the future*, Paris, OECD).
Pachler, N., Bachmair, B., & Cook. J. (2009). *Mobile learning: Structures, agency, practices.* New York: Springer.
Park, Y. (2011). A pedagogical framework for mobile learning: Categorizing educational applications of mobile technologies into four types. *International Review of Research in Open and Distance Learning* 12 (2), 78-102.

Parry, D. (2011). Mobile perspectives: On teaching mobile literacy. *Educause Review*, 46, 14-18.

Peluso, D. (2012). The fast-paced iPad revolution: Can educators stay up to date and relevant about these ubiquitous devices? *British Journal of Educational Technology, 43.* doi: 10.1111/j.1467-8535.2012.01310.x

Radinsky, J., Bouillion, L., Lento, E., & Gomez, L. (2001). Mutual benefit partnership: A curricular design for authenticity. *Journal of Curriculum Studies, 33*(4), 405-430.

Royle, K., & Hadfield, M. (2012). From 'posh pen & pad' to participatory pedagogies: One story of a netbook implementation project with 108 pupils in two primary schools. *International Journal of Mobile and Blended Learning, 4*(1), 1-17,

Rushby, N. (2012). Editorial: An agenda for mobile learning. *British Journal of Educational Technology, 43*(3), 355-356. doi: 10.1111/j.1467-8535.2012.01313.x

Scanlon, E., Woods, W., & Clow, D. (2014). Informal participation in science in the UK: Identification, location and mobility with iSpot. *Journal of Educational Technology & Society*, *17*(2), 58-71.

Schuck, S., & Aubusson, P. (2010). Educational scenarios for digital futures. *Learning, Media and Technology* 35, (3): 293–305. doi:10.1080/17439884.2010.509351

Schuck, S. (2016). Enhancing teacher education in primary mathematics with mobile technologies. Au*stralian Journal of Teacher Education,* 41(3), 126-139.

Schuler, C., Winters, N., & West, M. (2012). *The future of mobile learning: Implications for policy makers and planners*. Paris: UNESCO.

Schwartz, P. (1997). *The art of the long vie.* Chichester: Wiley.

Sharples, M. (2013). Mobile learning: Research, practice and challenges. *Distance Education in China*, *3*(5), 5–11.

Sharples, M., Taylor, J., & Vavoula, G. (2007). A theory of learning for the mobile age. In R. Andrews & C. Haythornthwaite (Eds.), *The SAGE handbook of e-learning research*. (pp. 221–224). London: Sage.

Shell (2003). *Scenarios: An explorer's guide*. London: Shell.

Snoek, M. (2005). *Scenario writing in education: Teaching guidelines for an in-service course for teachers and teacher educators.* Brussels/Amsterdam: Association for Teacher Education in Europe.

Snoek, M. (2013). From splendid isolation to crossed boundaries? The futures of teacher education in the light of activity theory. *Teacher Development, 17*(3), 307-321. doi: 10.1080/13664530.2013.813758

Snoek, M., Baldwin, G., Cautreels, P., Enemaerke, T., Halstead, V., Hilton, G., Klemp, T., et al. (2003). Scenarios for the future of teacher education in Europe. *European Journal of Teacher Education*, *26*(1), 21-36.

Song, Y. (2014). "Bring Your Own Device (BYOD)" for seamless science inquiry in a primary school. *Computers & Education*, *74*, 50-60.

Toh, Y., So, H. J., Seow, P., Chen, W., & Looi, C. K. (2013). Seamless learning in the mobile age: a theoretical and methodological discussion on using cooperative inquiry to study digital kids on-the-move. *Learning, Media and Technology*, *38*(3), 301-318.

Traxler, J. (2008). *Current state of mobile learning.* In M. Ally (Ed.), Mobile learning transforming the delivery of education and training. Athabasca: University of Athabasca Press.

Traxler, J. (2009). Learning in a mobile age. *International Journal of Mobile and Blended Learning, 1*(1), 1-12.

UNESCO. (2011). *UNESCO mobile learning week report.* Retrieved from http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/ED/ICT/pdf/UNESCO%20MLW%20report%20final%2019jan.pdf

Van Der Heijden, K. (2005). *Scenarios: The art of strategic conversation*. London: Wiley.

Wang, M., & Shen, R. (2012). Message design for mobile learning: Learning theories, human cognition and design principles. *British Journal of Educational Technology*, *43*(4), 561-575.

Wilson, R., Goodman, J., Bradbury, L., & Gross, L. (2013). Exploring the use of iPads to investigate forces and motion in an elementary science methods course. *Contemporary Issues in Technology and Teacher Education*, *13*(2). Retrieved from http://www.citejournal.org/vol13/iss2/science/article1.cfm

Wong, L. H., & Looi, C. K. (2011). What seams do we remove in mobile-assisted seamless learning? A critical review of the literature. *Computers & Education*, *57*(4), 2364-2381.

Zhang, B. H., Looi, C. K., Seow, P., Chia, G., Wong, L. H., Chen, W., So, H. J., Soloway, E., & Norris, C. (2010). Deconstructing and reconstructing: Transforming primary science learning via a mobilized curriculum. *Computers & Education, 55*(4), 1504-1523. http://dx.doi.org/10.1016/j.compedu.2010.06.016

Zimmerman, H. T., & Land, S. M. (2014). Facilitating place-based learning in outdoor informal environments with mobile computers. *TechTrends*, *58*(1), 77-83.