Mobile Technology, Maths Education & 21C Learning

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ABSTRACT

Technology in general, and mobile technology in particular, remains under-exploited in secondary school education systems. This paper argues that systemic reform is needed to make the use of mobile technology really meaningful in the classroom. The type of change envisaged falls under what is broadly termed 21st Century Learning which espouses a generally social constructivist pedagogical approach with an emphasis on skills such as collaboration, communication, creativity, problem solving etc. In such a milieu the affordances of mobile technology align seamlessly with classroom practice rather than, as at present, being circumscribed and restricted to use for content consumption, field exercises or one-off customised interventions.

To illustrate the way in which mobile technology could integrate into a 21C classroom a number of lesson plans from the area of math education are described. These are situated in a national second level education system which is undergoing systemic reform and in which teachers, and schools, are looking for exemplars of pragmatic models of 21C Learning which can be used to deliver both 21C skills and traditional curriculum content.

Keywords

21C Learning; mathematics; realistic math education; smartphones; school reform.

INTRODUCTION

There is now a wealth of examples of innovative ways in which mobile technology can be used to enhance learning both within the formal classroom and in informal settings (Ally, 2009). Yet despite over at least 10 years of research in the field, formal classrooms at second level (ages ~12-18) by and large remain immune to the transformative potential of mobile learning. There have been numerous false dawns in the broad field of Technology Enhanced Learning, and in the case of mobile learning both handheld devices and laptops have been heralded as technologies which would help transform classroom learning; the "*anywhere anytime*" mantra has been oft repeated but rarely put into effective practice.

The current pre-occupation in second level schools is with tablet devices but, if past experience is a valid predictor of future behaviour then, they too will at best be assimilated into existing practices and their prime function is likely to be as content delivery devices.

One lens which can be used to help view the way in which technology is used in the classroom is the SAMR model (Puentedura, 2006), see Figure 1.
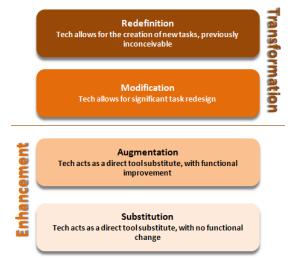

Figure 1: The SAMR Model of Technology Adoption

Tablets, and mobile devices in general, are at best likely to be used as *Enhancement* tools to *Augment* existing practice. *Substitution* of tablets for books may well reduce the weight of school bags but is unlikely to result in a move into the *Transformation* space where the huge potential of mobile technology to be used as *"objects to think with"* (Jonassen, Carr, & Yueh, 1998) could be fully exploited.

This paper argues that reform is needed at the systemic level in order to create the educational context within which the type of *Transformative* learning experiences that mobile can facilitate can be meaningfully implemented in the classroom. These types of experiences fit easily under the framework of 21st Century Learning, which espouses a generally social constructivist pedagogical approach with an emphasis on the development of skills such as collaboration, communication, creativity, and problem solving. (Dede, 2010; Partnership for 21C skills, 2006, 2011; Rychen & Salganik, 2005). In such a milieu much classroom practice will be in the *modification* and *redefinition* layers of the SAMR model and will be structured in a way that is very different from the current didactic (or Victorian) classroom. In settings of this kind the affordances of mobile technology are much more likely to align seamlessly with classroom practice than in the current situation, in which the potential of mobile devices are circumscribed and largely restricted to content consumption, field exercises and occasional (and often one-off) customised interventions; that is, to the levels of *substitution* and *augmentation*.

The 21C learning agenda is not without its critics (Coupal, 2004) and a concern frequently raised by teachers is that it undervalues traditional curriculum content. In this regard the area of mathematics education at second level is of particular interest. On one hand, good performance in the subject is seen as key to the economic wellbeing of a country: policy makers place great emphasis on mathematics rankings in PISA and other international surveys and mastery of curriculum content is seen as crucial. On the other hand it has long been argued that the traditional didactic pedagogy, common in mathematics classrooms, is one of the contributing factors to the lack of interest in the subject at upper second level and as a direct consequence in STEM subjects at 3rd level. If it can be demonstrated that a 21C inspired, (mobile) technology-enhanced learning approach is effective in the mathematics domain then that should go a long way to reassure those who have doubts about its efficacy in general with regard to the delivery of curriculum content.

As a concrete example of 21C mathematics lessons that lie in *Transformation* layer of the SAMR hierarchy, and in which mobile technology plays a central role in helping to foster both the delivery of skills and the mastery of curriculum content, this paper describes a number of mathematical learning activities which have been implemented by the authors. They employ a particular model of team-based learning (Lawlor, Conneely, & Tangney, 2010), which adheres to 21C principles. This research is situated within a larger action research initiative in which the authors and colleagues are working with a cohort of (12) early adopter schools at the forefront of a national systemic reform process that aims to move the Junior Cycle (years 1 to 3 [ages 12-15] out of a 6 year cycle) of the national secondary school system away from its traditional didactic, examination focused model, towards one which is based on 21C learning principles. A key challenge of this research is to investigate exemplars of classroom practice which meet the aims of 21C learning while at the same time being pragmatic to implement, and within the realistic confines of day to day operation of schools.

BACKGROUND

There are many barriers to the full exploitation of the potential of (mobile) technology to enhance classroom practice. These range from the focus on summative assessment, to a didactic approach to teaching, issues around teacher professional development and the reliability of technology (Scheuermann & Pedró, 2009).

The situation at second level varies from country to country. The Finnish system for example, with its lack of emphasis on regular state wide assessment, is more amenable to innovative practices than say the UK one. In each country there are of course individual schools, or clusters of schools, which are highly innovative in their pedagogical approach (c.f. www.hightechhigh.org as just one example) but this lack of uptake of (mobile) technology in school systems in general is a manifestation of the deeper issue of a reluctance to engage in systemic change and resistance to technology in particular (McGarr, 2009; Voogt & Pelgrum, 2005).

The academic research community also has a role to play in the process. The research culture lends itself to the development and deployment of innovative interventions but, in many cases, this is also the limit of academic involvement. Exemplars are developed, often relying on the assistance of the research team to deliver them in practice, but when the researchers move on teachers are left to their own devices.

Teachers are most influenced by other teachers and seek pragmatic examples of what they can do with their own resources. Hence many interesting classroom innovations remain at the periphery of practice and do not make their way into the mainstream. Given this inertia in education systems and the lack of sustainable transformative interventions it is not at all surprising that (mobile) technology mediated practice in the classroom falls mostly into the Enhancement level of the SAMR model.

The 21C learning reform movement provides a context in which the issues just described can potentially be addressed. As described in a meta-analysis of the field by (Voogt & Roblin, 2012) most OECD countries are promoting some version of this agenda with "collaboration, communication, ICT literacy....creativity, critical thinking and problem

solving" being common themes across strategy documents. However from the perspective of this paper it is worth noting that the authors go on to comment that many 21C frameworks "leave out a discussion of traditional curriculum competences and their link to 21st century skills." This is the area which this paper seeks to address. What would a learning intervention designed to promote 21C skills and curriculum competences look like and what role could (mobile) technology play in the process?

The National Context

The education system in Ireland is undergoing and extensive systemic reform process. Currently there are two major summative state examinations, one at the end of year 3 and one in year 6. The latter is used as the single determinant for entrance to university for most students and as such is a very 'high-stakes' examination. This has led to many negative effects on the way teaching and learning is carried out in secondary schools and has greatly exacerbated the culture of 'teaching to the test' and all the tendencies which go with that approach to learning. Over the years the exam at the end of the Junior Cycle (year 3) has become more and more a dry run for the Senior exam (year 6).

In the reformed, 21C learning-inspired Junior Cycle now being phased in (and colloquially known as JC 2.0), the number of subjects examined in year 3 is being reduced, responsibility for ~50% of the assessment is being devolved to schools, and assessment for learning within the school context is being strongly promoted. These and other reforms are all devised so that students develop, and can demonstrate their acquisition of, 21C skills while at the same time mastering curriculum competences and curriculum content knowledge. In all, this very ambitious reform process is asking schools to radically rethink the pedagogical models they are using and is strongly encouraging them to move into the Transformative space.

The Bridge21 Model of 21C Learning

Bridge21 (Lawlor et al., 2010; Tangney, Oldham, Conneely, Barrett, & Lawlor, 2010) is a model of collaborative, project-based learning which has been developed at the authors' institution. It embodies many of the aspects associated with 21st century learning including teamwork, extensive use of technology and the teacher as orchestrator rather than director of learning. The model of collaboration used is based on the patrol system of the World Scout Movement (Bénard, 2002). Initially developed for an out-of-school context, as part of the university's outreach agenda, over 4,000 participants have taken part in (week long) workshops over the past 5 years.

Since 2011 we have been working on adapting the model for use in mainstream classrooms to teach the core curriculum as part of an action research project addressing the JC 2.0 reform process (Lawlor et al., 2010). Teachers have adapted the model for the delivery of a variety of subjects ranging from languages through to STEM. Initially teachers tend to adapt the model for use within the conventional 40 minute class periods but as confidence grows teachers are trying more ambitious activities including cross curricular projects with other teachers. Some schools are altering their timetable structure to support a more project-based approach to learning.

MOBILE TECHNOLOGY AND MATHEMATICS EDUCATION

The issues surrounding mathematics education are well documented in the literature. A behaviourist approach to teaching and learning, with an emphasis on formal, abstract mathematics remains dominant in many countries (Conway & Sloane, 2005). In this context, the teacher is frequently viewed as the absolute authority on the subject, their primary purpose being the transmission of information to the students. In conjunction with a strong focus on assessment, this has led to an environment in which mathematics is presented as a "highly fragmented set of rules and procedures rather than a complex highly interrelated conceptual discipline" (Garofalo, 1989). Didactical teaching methods prevail, with an emphasis on procedure rather than understanding. Content is often favoured over mathematical literacy and learners are not encouraged to explore alternative answers or to seek out their own solutions (Conway & Sloane, 2005). The resultant fragmented and de-contextualised view of the subject frequently leads to issues with motivation and engagement (Gross, Hudson, & Price, 2009; Grossman, 2001).

Efforts to address some of these issues have been undertaken, but the result has had limited success. Of particular relevance to this discussion are attempts to introduce a real life context or problem solving dimension into the teaching and learning process but, as Boaler (1993) suggests, this often results in pseudo-real-world problems or "school problems with a thin veneer of real world". Not only are the problems frequently uninteresting from the point of view of the students, but they are also presented in such a way that they are not actually real-world problems but are routine, practice (drill and kill) problems in disguise. Often all of the information to solve the problem, generally without surplus, is provided in the question, and the learner is reduced to following a procedure of putting data into appropriate formulae to get the "right answer".

Based on the arguments outlined previously regarding 21C learning, curriculum skills and the desire on behalf of teachers to have pragmatic exemplars of classroom practice, the challenge is to create truly contextual, collaborative, realistic, problem-solving approaches to mathematics education, thus providing the coherency and context that is sorely lacking in traditional teaching methods. We argue this requires a Transformative approach to the integration of technology into the classroom and that by following such an approach learners can be scaffolded in the acquisition of generic 21C skills, curriculum specific (in this case math) skills and curriculum content knowledge.

SAMPLE ACTIVITIES

This section describes a number of mathematical learning experiences which attempt to overcome the difficulties just described. (Given the strong overlap between the mathematics syllabi in most OECD countries, the activities below can be considered as generic and not tied to any national curriculum in particular). The first two are suitable for students of around 12 years of age while the 3rd one is more challenging and is aimed at 15/16 year olds. Each adheres to a broadly realistic maths education pedagogy (Gardner, 1999) and the problems involve: an environment that is rich in information; performing authentic tasks in ill-structured domains; problem solving in real-life contexts; learning through interactions with others; and an emphasis on learning processes rather than solutions.

Fermi Problems

Named after the Italian physicist Enrico Fermi, Fermi problems are exercises in estimation and approximation and are a good vehicle for teaching problem solving strategies and estimation skills. The classic textbook example of a Fermi problem is "*how many piano tuners are there in Chicago?*", and we have used variations on this theme to underpin a set of learning activities including the following.

- How many tennis or rugby balls could fit into the classroom, school gym or local swimming pool?
- What is the average height of people in the school?
- How many people are on the school corridors at break time?
- How many people are there on the local High Street at a busy period during the day?
- What is the average walking speed of students on the corridors, or pedestrians on the High Street?

These problems can be carried out as desk based activities but are much more interesting when the pupils are required to go out 'into the field' and attempt to make measurements according to whatever plan it is they have devised to solve the problem. There is of course no right answer to the questions. Instead correctness is judged by the reasonableness of the approach followed and the approximate (even order of magnitude) value of their estimation.

Technology offers a number of tools which can be used to assist in tackling these problems. For example in the 'number of people on the High Street and their average walking speed' problem a still camera, video camera, and stopwatch – all available as standard on a smartphone – are of use, as is access to a web browser and Google Earth. A variety of apps are also available to measure distance travelled while walking. The use of these tools in context adds to the realistic nature of the activity and its authenticity.

The Pond Filling Exercise

This problem addresses problem solving, estimation, area and volume. It works best if there is a pond, as shown in Figure 2, within walking distance of the school but any space with an irregular shape can be substituted if needs be. The challenge is to find out how long it would take to fill the pond with water using only buckets filled from a tap in the school. Reasonable assumptions need to be made about the depth of the pond and students can ignore the effect of evaporation and rainfall.

Figure 2: The Pond Filling Problem

This problem ticks many of the boxes outlined earlier in terms of it being rich in information, an ill-structured domain etc. As for the Fermi problems, the 'pond filling' exercise can be attempted as a desk-based activity, but it really only comes to life when tackled by actually filling buckets and carrying them to the pond. The problem challenges the learners' powers of estimation and approximation, their understanding of area and volume, and their approach to problem solving. It also lends itself to cross-curricular learning in that it can be used as an entry point into discussions on rainfall, evaporation or as one teacher suggested, human rights. (The question of what percentage of the world's population lives more than 1km from a clean water supply, and what are the implications of this, takes on extra meaning when one has just carried a full bucket 500m!)

A variety of technology based tools need to be used to help tackle this problem including those listed in the previous section. At the core of the solution is approximating the area of the pond as a number of small squares. One way to do this is by overlaying a grid on the Google Earth image of the pond. In our case participants were given access to a

smartphone-based maths learning toolkit (Tangney, Weber, et al., 2010), which included functionality to overlay a resizable grid on an image – see Figure 2. A distance measuring tool on the phone was then used to calibrate the size of the squares and hence work out the area of the pond.

The Human Catapult

In this activity, learners investigate the properties of projectile motion, angles, functions and velocity using a variety of tools – see Figure 3.
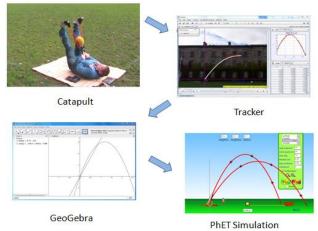

Figure 3: Tools for Catapult Activity

Full-body catapults are used to launch foam balls at a target and the flight path of the projectile is captured on video using a smartphone. A free software tool (Tracker[1]) enables learners to do a frame-by-fame analysis of the video, tracing the trajectory of the ball and generating a variety of interesting functions - height with respect to time, horizontal distance with respect to time, and height with respect to horizontal distance. These can be further analysed using GeoGebra[2] which allows the learner to conduct investigations by overlaying tangents and calculating angles and distances. Hence, learners are provided with the instruments to investigate and estimate angles of projection, horizontal and vertical distance, and the effects of initial velocity.

In the final phase of the exercise, learners use a projectile motion simulation[3] to compare values they calculated for initial velocity etc., with those determined by the simulator. Thus learners move from the concrete, physical activity, to its abstract analysis and back to the use of concrete data in the simulator. This provides a powerful structure within which students and the teacher can engage with the mathematical content in a highly innovative way and dynamically probe the depth of understanding that has been accomplished.

Anatomy of a Lesson

In delivering the activities just described teaching is carried out using the Bridge21 model of collaborative learning and all exercises are team-based. Lessons follow a Polya style cycle (Polya, 2008). The problem is introduced in a whole-class setting, and the teacher leads a discussion to ensure that learners understand what is being asked and to encourage them to think about similar problems they may have encountered before. Working in teams, learners then devise a plan to solve the problem and, where appropriate, record an initial estimate of their answer and the value of any key items they will need to measure. The teacher moves between teams prompting and assisting as required, but letting teams devise their own plans. (Restraint is needed to allow students to fail if appropriate.) Teams then carry out their plans and perform any necessary calculations. Finally, a whole-class plenary session hears presentations from each team on how they approached the problem, a view on whether or not their results are sensible and what they learned from the experience. This whole-class activity allows the teacher to lead a discussion which can further probe the learners' understanding of the underlying mathematical content and the mathematical skills that were exercised.

DISCUSSION

Versions of the activities described above have been carried out in 3 second level schools with cohorts ranging in size from 20 to 120. The activities have also been used within our 3rd level institution in both teacher continuous professional development workshops and workshops for students as part of the university outreach program. The exercises to date are exploratory in nature and it is too early to make definitive statements about either student learning or sustained uptake by teachers. Initial results however, are very positive and a number of themes are emerging from the work to date.

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1 www.cabrillo.edu/~dbrown/tracker
2 www.geogebra.org
3 phet.colorado.edu/en/simulation/projectile-motion

There are an increasing amount of technological tools available to assist in learning activities of this type. Built in functionality in smartphones provide a range of useful tools which would have required specialised equipment a few years ago – c.f. video. Furthermore there are an increasing number of apps becoming available, many of them free, which are either designed for maths education, or can be used in such activities. For example one teacher, on a professional development workshop had a hill walking app on her phone that she used for measuring distance in the 'number of people on the High Street' problem. In fact across the range of activities described we have found participants tend to use a mash-up of traditional, mobile and desktop tools to assist in different aspects of an activity, and teachers find this helpful because it shows there are different ways of doing things. As one teacher commented "by using both techniques – the phone and the traditional trundle wheel, metre stick techniques and the clinometer – it showed them that there are many ways of solving the same problem."

The attitudes of the students to the experiences are positive and they report finding them both interesting and engaging. They particularly like the immersive aspect of the activities, and the fact that the use of off-the-shelf technology juxtaposed with specialist software permits a genuinely realistic experience of problems, with the generation of real-world data. Quotes such as: "Playing with catapults was enjoyable and using technology was a better way of learning and teaching maths", "I found myself trying stuff and exploring lots of different things…. Very fun!", and "I enjoyed the use of technology in maths. It makes maths fun and interesting", are representative of the attitudes of the students, and paint an encouraging picture of the approach to integrating mobile technology in mathematics education proposed in this paper.

Collaborative learning is an under-exploited resource in second level classrooms in the Irish education system – and indeed beyond. In Vygotskian terms collaborative learning increases the number of 'more able others' in the classroom from one (i.e. the teacher) to many (the students themselves) and this has been shown to have significant impact on student attainment (Baines, Blatchford, & Kutnick, 2008; Maurice Galton & Hargreaves, 2009). As expressed by one of the teachers: "You're not aware you're teaching. It's great because to be honest with you it makes the class more active and there's more chance of engaging everybody."

Furthermore collaboration is one of the key skills that the 21C Learning agenda is trying to promote, so is of value in and of itself. In keeping with the recommendations of Galton, Steward, Hargreaves, Page, & Pell (2009) pupils are not expected to just pick up team working skills as they go along but need to be provided with a set of induction activities which help equip them to work productively in teams. To this end, in the schools participating in our research, students engage in a number of workshops which introduce them to the Bridge21 model of learning and scaffold them in gaining confidence in the processes involved in teamwork and project-based learning. Thus when they come to tackling the maths activities described they are already adept in the methodology and can concentrate on the task in hand.

A concern for a number of teachers relates to the amount of time required to invest in training students about working and learning effectively in teams. However, these fears were allayed when they recognised that the students made faster progress in this kind of environment, with greatly increased levels of engagement and motivation as well as greater depth of understanding and recall of the topics. Teachers also acknowledged a shift in the student-teacher relationship, with an increasing level of trust and respect on both sides.

A similar argument regarding prior training, applies to students' presentation skills. If it is to become an integral part of their learning then appropriate instruction and support needs to be put in place to help them develop that skill over a period of time.

30 or 40 minute class periods are a challenge to the type of learning activities described here and different teachers have adopted different approaches. For the "pond exercise" one school cleared the timetable for an entire morning so that the activity was carried out over one long session. Another teacher did it within the confines of the existing timetable by devoting successive classes over a week to different aspects of the task. Lesson 1 introduced the problem and did initial planning. Lessons 2 and 3 were a double period in which students went outside to take measurements and lesson 4 was devoted to team presentations and a whole class discussion of what had been learned.

The role of the teacher in activities such as these is much more one of orchestration of learning, as opposed to delivery of content. Careful planning is needed to set up the activity and an appropriate level of scaffolding needs to be provided. However for the most part, while the activity is on-going the teacher needs to adopt a stand back approach and encourage learners by asking questions or helping out those experiencing difficulties, rather than directing learning in the traditional sense. The whole class discussion at the end of the activity is key: here the role of the teacher is to encourage learners to reflect upon the experience and to tease out how their understanding of the topic in hand has developed throughout the process.

CONCLUSION

This paper puts forward the argument that the potential of mobile technology to enhance learning in our second level institutions will only be fully exploited when the schools embrace a 21C model of learning. That is, when classroom practice is transformed from its current didactic model into one in which teaching and learning is carried out in an open, collaborative and technology-mediated environment. This has the potential to shift the focus of learning away from a

narrow view of the instruction of individual, isolated subjects, to a broader goal of teaching key competencies and skills through engagement with curriculum material.

By way of exploring what such an alternative model might look like, the paper has described 3 sample learning activities, which we contend have the following properties:

1. They provide a fruitful and meaningful way in which learners can engage with (mathematical) curriculum content.

2. They allow learners to develop key curriculum skills – in this case mathematical skills such as measurement, estimation and mathematical problem solving. (Together these two points go some way to addressing the issues in mathematics education that were raised in section 3).

3. They promote the development of generic 21C skills such as collaboration, communication, creativity and problem solving.

4. They fall within the *Transformation* space in the SAMR model (Puentedura, 2006) – a variety of technologies and tools are used in tandem to support both "significant task redesign" and the "creation of new tasks, previously inconceivable". It is only by moving into this space that the advantages described in points 1, 2 and 3 truly accrue.

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