THE HUMAN CATAPULT AND OTHER STORIES – ADVENTURES WITH TECHNOLOGY IN MATHEMATICS EDUCATION

Aibhín Bray, Elizabeth Oldham, Brendan Tangney

Centre for Research in IT in Education (CRITE),

School of Education and School of Computer Science & Statistics,

Trinity College Dublin.

This paper reports on-going research into how the affordances of off-the-shelf technologies can be aligned with relevant mathematics pedagogy, to create transformative learning experiences with the potential to overcome some of the well-known impediments to mathematics teaching and learning. From a systematic analysis of recent literature on digital technologies and mathematics education, a set of guidelines has been formulated by two of the authors for the design of innovative and engaging interventions in mathematics education. In this paper the guidelines are presented, along with results from experiences with two such interventions. An exploratory case study methodology is employed, and the paper reports on an initial pilot study, the results of which suggest that the interventions are pragmatic to implement and may improve affective engagement and motivation.

INTRODUCTION

There is ongoing international debate about the quality of mathematics education at post-primary level. Research suggests that, while the capacity to use mathematics constructively will be fundamental to the economies of the future, many graduates of the secondary-school system have a fragmented and de-contextualised view of the subject, leading to issues with engagement and motivation (Gross, Hudson, & Price, 2009; Grossman, 2001). Digital technologies have the capacity to facilitate realistic, problem-solving and collaborative approaches to teaching and learning, providing coherency and context for the mathematics. However ICT is frequently used in a more traditional manner, with didactic teaching methods, and an emphasis on de-contextualised procedure as an end in itself.

Tools such as Dynamic Graphical Systems (Hoyles & Noss, 2003) (for example, GeoGebra, Cabri and Geometer's Sketchpad), Computer Algebra Systems (for example, Maple and WolframAlpha), tablet/smartphone apps, and educational websites all provide mathematics teachers with readily accessible, and often free, tools to help their students overcome the challenges in becoming mathematically proficient. However, teachers can be overwhelmed when faced with such an array of technologies and pedagogical theories, and may benefit from a framework to guide the integration of technology into their teaching so that it is not used in such a way as merely to re-instantiate aspects of traditional mathematics teaching.

Following a systematic review and analysis of technology interventions in recent literature such a set of guidelines is under development by two of the authors (Bray & Tangney, 2013). In the present paper, a brief background to the development of the guidelines to date is outlined, and the design and delivery of two activities planned in accordance with them are described. The paper reports on an initial pilot study in an out-of-school setting in which 40 mixed-ability students, ranging in age from 15 to 18, took part. An exploratory case study methodology is employed in order to gauge the feasibility of the approach and the potential for further research.

BACKGROUND

The development of the guidelines is based on an ongoing, systematic review of recent literature in which technology interventions in mathematics education are described. The electronic databases in use for the review were chosen for their relevance to education, information technology and mathematics, and include: ERIC (Education Resources Information Center); Science Direct, and Academic Search Complete. To date, 25 papers in which specific interventions are discussed have been classified according to the lenses of technology, learning theory and level of technology adoption (Bray & Tangney, 2013). The review process and subsequent development of the guidelines is ongoing and iterative: while the guidelines and activities are informed by the reviewed literature, the results of the activities along with emerging research will continue to inform and refine their development.

Technology is classified as: Dynamic Graphical Systems (DGSs); Outsourcing of Processing Power (Computer Algebra Systems, Graphics Calculators); Purposefully Collaborative Tools (Google Docs, Knowledge Fora); Simulations/Programming (Microworlds); and Toolkits (technologies designed in accordance with a specific pedagogic approach, with support for student and teacher). The learning theories considered are divided into two main camps - behaviourist and cognitive - with the latter further broken down into constructivist, social constructivist, and constructionist.

The SAMR hierarchy (Puentedura, 2006) is used to describe the levels of technology adoption (Figure 1). This hierarchy classifies interventions according to two main categories – Enhancement and Transformation – with subcategories of substitution and augmentation (enhancement), and modification and redefinition (transformation).

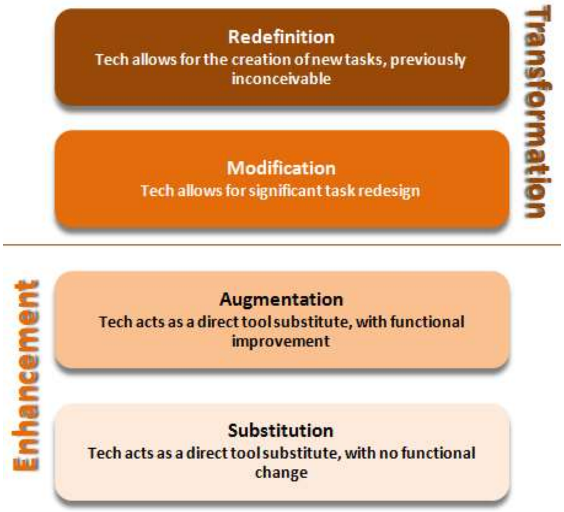

Figure 1 : The SAMR hierarchy

To date, the review has revealed a marked prevalence in the literature of studies that involve DGSs and Outsourcing of Processing Power. Some collaborative technologies, programming/simulation tools, and toolkits are also in evidence. There is a strong socially constructivist direction evident in the interventions that have been considered. This pedagogical theory has its foundations in the learning theories of Kolb, Vygotsky and Bruner. The interventions deemed most successful, according to the review, are those that are classified as being within the transformation space in the SAMR hierarchy, that is, those that achieve significant task redesign or the creation of new, previously inconceivable tasks, through appropriate use of technology.

Many of the empirical studies reviewed are somewhat limited in that they concentrate on the implementation of a single technology without focusing on the more pragmatic issues around technology interventions that teachers may desire. These areas of consideration however, are addressed in a number of papers that do not examine specific interventions, but rather consider the circumstances under which learning has the potential to be enhanced by the use of technology (Means, 2010). These papers highlight the necessity for the use of a variety of appropriate technologies, implemented in meaningful, interesting and realistic scenarios.

THE GUIDELINES

The literature review and subsequent classification of papers has informed the development of a set of guiding principles resonant with a view both of mathematics as a problem-solving activity and of mathematics education as involving students in constructing their knowledge via the formulation and solution of problems. Moreover, it seeks to counteract beliefs – unfortunately prevalent – that mathematics is a collection of unrelated facts, rules, and 'tricks', and that mathematics education is about memorisation and execution of procedures that should lead to unique and unquestioned right answers (Ernest, 1997). The guidelines describe an approach to the design of learning experiences that aim to combine the educational potential of off-the-shelf technology with appropriate pedagogy. According to these principles, an appropriate and innovative technology intervention in mathematics education should exhibit the following properties (Bray & Tangney, 2013):

1. *Be collaborative and team-based in accordance with a socially constructivist approach to learning;*
2. *Exploit the transformative as well as the computational capabilities of the technology;*
3. *Involve problem solving, investigation and sense-making, moving from concrete to abstract concepts;*
4. *Make the learning experience interesting and immersive/real wherever possible, adapting the environment and class routine as appropriate;*
5. *Use a variety of technologies (digital and traditional) suited to the task, in particular, non-specialist technology such as mobile phones and digital cameras that students have to hand;*
6. *Utilise the formative and/or summative assessment potential of the technology intervention.*

TWO INTERVENTIONS

In order to refine the guidelines and validate their usefulness, the authors are using them to create and evaluate a suite of technology-mediated learning experiences that aim to address some of the issues in mathematics education. These learning experiences are being initially piloted in an experimental learning space in the authors' institution before being evaluated in mainstream classrooms. The design and delivery of two such interventions are described below. The longer term goal of this research is to create a community of teachers who are using the guidelines as part of their own classroom practice, and to determine if the learning activities so designed do in fact help address some of the concerns associated with the teaching and learning of mathematics.

Scale Activity

In this activity, the students work collaboratively, in groups of 3 or 4, to develop a presentation about scale, orders of magnitude and scientific notation. The learning objectives include developing an understanding of how to recognise appropriate technological and mathematical techniques for measuring and estimating. The students, working actively and collaboratively, are required to select objects to measure and to make sense of their information, figuring out how to measure objects of diverse size, and to present their results.

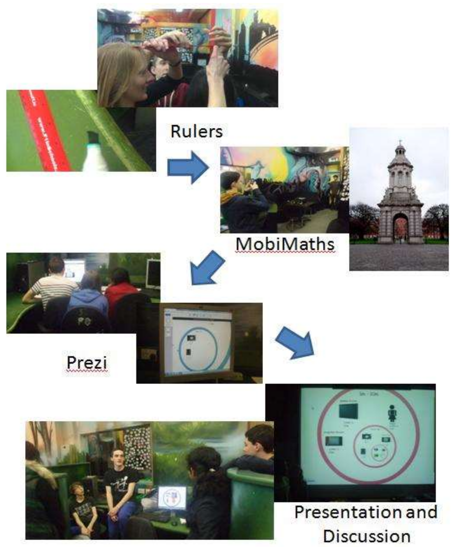

Figure 2 : Steps in the "scale" activity

In our implementation, smartphones are used to gather information, take measurements and perform some trigonometric calculations. Instruments utilised include tools for measuring distance and angles of elevation from the MobiMaths app (Tangney et al., 2010). The students are required to determine into which 'Power of 10' each measurement fits and have the option of further populating their collection using Google Earth, Google Maps, and research on the internet. The target for each group is to have two or three objects within each band of measurement and to cover at least five consecutive orders of magnitude. Prezi (www.prezi.com) is suggested as appropriate for creating the presentations, as it is straightforward to use and facilitates a zooming effect to simulate a perception of increasing and decreasing size.

The adoption of technology to mediate this activity has permitted significant task redesign, placing it in the level of 'modification' within the SAMR hierarchy. The students use smartphones for scientific calculation, capturing images, and a variety of measurements. Online mapping tools permit the measurement of greater distances than would be practical to calculate by traditional means.

This activity is designed to help students develop a sense of when and why different mathematical approaches and notations are required, and to acquire a realistic idea of scale and estimation, based on concrete examples. The final presentations and discussion allow for formative assessment of these learning goals, and for the scaffolding of deeper engagement with the topic.

Slingshot Activity

Once again, a collaborative approach is adopted for this activity, in which students work in groups of 4 or 5 to investigate the properties of projectile motion. Particular emphasis is placed on functions relating height, horizontal distance and time; angles; rates of change; and velocity. Students use an oversized slingshot along with readily available, free software to conduct their investigations, moving from a concrete exploration of trajectory, to mathematical modelling of the activity, with verification of the results using a projectile motion simulation.

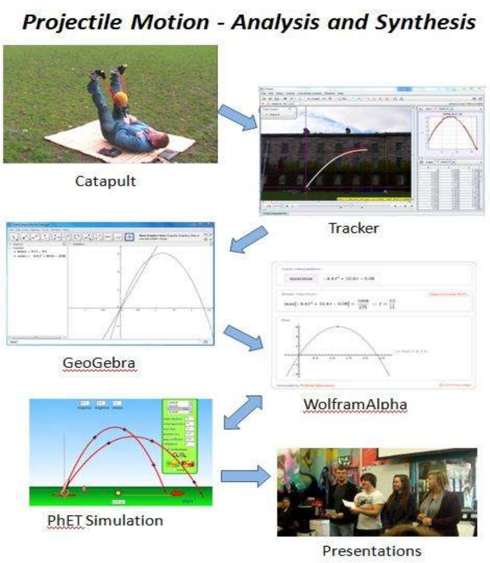

Figure 3 : Steps in the "slingshot" activity

Initially the students record videos of their team using the catapult to fire a foam ball. The trajectory of the ball is analysed using the free software Tracker (http://www.cabrillo.edu/~dbrown/tracker/) to trace the flight path, and also to generate functions relating height to time, horizontal distance to time, and height to horizontal distance. GeoGebra (www.geogebra.org) is used for further analysis of the functions, enabling the students to estimate the angle of projection and initial velocity of the projectile. The investigations are guided and scaffolded by an instruction sheet, with suggested explorations provided. The computational website www.wolframalpha.com can be used for routine calculations and for checking answers. Once the students have calculated the data required, they can use the simulation on phet.colorado.edu to check the validity of their results. Group presentations and whole class discussion conclude the activity, providing scope for formative assessment as well as an opportunity for the students to consolidate and demonstrate their learning (Figure 3).

The tasks involved in this exercise would not have been possible without the use of technology, leading to its classification as 'redefinition' in terms of the SAMR hierarchy. The students are required to make extensive use of the computational facility afforded by the technology in a task that is designed to be engaging and immersive.

METHODOLOGY & RESULTS

Our initial research is employing an exploratory case study approach, with use of direct observation, semi-structured interviews and questionnaires to gather data. This methodology was chosen to address issues around feasibility of the approach and the suitability of the instruments. The Mathematics and Technology Attitudes Scale (MTAS) (Pierce, Stacey, & Barkatsas, 2007) is utilised to measure confidence, behavioural engagement, affective engagement, and attitude to using technology in mathematics.

In the pilot phase described here, three day-long sessions have been conducted with groups of students drawn from various schools. The setting is an experimental classroom environment in the authors' institution. A total of 40 boys and girls of mixed ability and socio-economic background took part in the trials. All the participants had previously taken part in group-based learning activities in the authors' institution.

Scale Activity

Two day-long sessions were conducted based on the scale activity described above, with 13 participants on day one and 11 on day two. The participants were aged between 15 and 16. The day was broken down into an initial plenary session in which the main concepts were introduced; a planning phase, which gave the groups time to decide what to measure, estimate the sizes of the objects, and decide how to go about collecting the measurements with the tools available to them; an indoor and outdoor measuring session, which included estimation, generalisation and trigonometry; and a phase in which the students prepared their presentations. Each group was required to present their Prezi in a final plenary session, commenting on the accuracy of their estimates and measurements, and giving a short explanation of scientific notation, its relevance and how to manipulate it. Further questions, comments and corrections were posed by the coordinator.

The duration of the intervention is too short and the sample size too small for statistical significance to be of interest, but on each day the overall mean scores on the MTAS inventory rose, going from 73.9 to 79.4 out of 100 on the first day and from 68.8 to 74.8 on the second. Cognitive engagement with the material is suggested from student comments collected during the two activities. Quotes such as: "I found it a little bit hard to understand, but by the end of it, I sort of understood it"; "I learned how to look at maths in a different way"; "I would love to learn about other areas of mathematics using the things I did today"; and "I enjoyed the use of technology in maths. It makes maths fun and interesting", all go to paint a positive picture of the approach to integrating technology in mathematics education proposed in this research.

Slingshot Activity

Sixteen upper second level students, aged between 16 and 18, working in groups of 4, engaged with the "catapult" activity which took place over a five-hour period, on a single day. This included an initial group session in which the tasks were discussed; an outdoor data gathering session; analysis using the various tools; and a plenary session at the end of the day, in which each team presented their findings. The day was punctuated with 'breakout' sessions in which one member from each team and the activity coordinator collaborated to discuss emerging difficulties with the tasks.

Once again, although the duration of the activity is too short to draw any substantive conclusions, informal interviews reveal that the students found the experience interesting and engaging; they particularly enjoyed the collaborative aspect and the immersive experience of the initial experiment. The use of readily available technology juxtaposed with the specialist software allowed them to experience mathematics at a realistic level, with numbers generated from the data they collected. Again, quotes such as the following suggest that the majority of students enjoyed this approach to mathematics education, believing it helped them to engage with the subject in a meaningful way: "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."

CONCLUSIONS AND FUTURE WORK

The purpose of this study is to assess the potential and feasibility of the design and implementation of activities in accordance with a set of guidelines under iterative development by two of the authors. The guidelines aim to assist in the generation of transformative activities that facilitate appropriate learning of mathematics at post-primary level, aided by technology. The present paper describes an exploratory case study examining two interventions designed in accordance with these guidelines. While the results of the pilot are limited in scope, they do suggest that the two initial activities are pragmatic, and warrant further investigation in real classroom settings. The results indicate that they may have the potential to engage learners cognitively, increase motivation and help contextualise mathematics. It bears noting however, that the participants' prior experience of working in groups, the small numbers of participants, and the novelty of the experience will have impacted positively on the results.

Running the interventions in the experimental setting has helped us refine the learning activities and has highlighted issues that may arise in a classroom setting. In particular, the duration of the activities extends over many single class periods, which is not usually feasible in traditional classrooms. In the next phase of our research we intend to cooperate with a network of schools that are currently engaged with our institution on an associated research project aiming to implement 21st century learning practices in mainstream classrooms (Tangney, Oldham, Conneely, Barrett, & Lawlor, 2010). These schools are already favourably disposed towards a collaborative, technology-mediated approach. In the longer term we also aim to engage with more traditional schools.

Further learning activities based on our guidelines are under development. The underlying literature review will continue to be expanded and reviewed on an ongoing basis in order to refine the results, keep the system of classification up to date, and further inform the guiding principles.

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