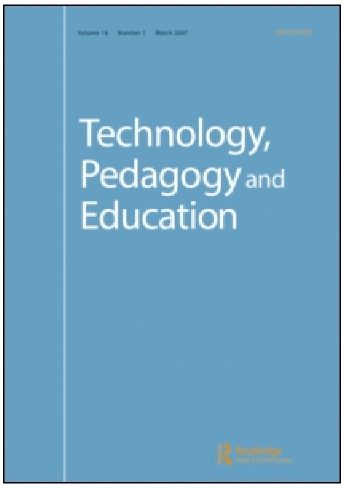

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David Wright[a]
[a] Research Centre for Learning and Teaching, Newcastle University, UK

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Orchestrating the instruments: integrating ICT in the secondary mathematics classroom through handheld technology networks

David Wright*

Research Centre for Learning and Teaching, Newcastle University, UK

This article reports on a study into the integration of ICT for students' personal use in the secondary mathematics classroom through using small software applications on handheld computing devices (graphical calculators). The handhelds were networked through wireless hubs so that data, software and output can be shared and an interactive space created for whole-class interaction and discussion. It argues that personal access to ICT tools within the traditional classroom environment is vital to support and enhance learners' mathematical development and that integration is effectively initiated through the use of 'microworlds'. The initial outcomes of this study and a review of research carried out in the USA and Europe reveal the transformative potential of this technology for the mathematics classroom and other educational settings.

Keywords: handheld technology networks; mathematics; ICT

Introduction

Evolution in the use of ICT in mathematics classrooms

The introduction of projective technologies into classrooms in England has seen an increasing use of Information and Communication Technology (ICT) by teachers. Sinclair and Jackiw (2005) suggest that this is part of a 'second wave' of ICT technologies in education in which the focus of ICT has expanded from the learner's relationship to mathematics to include the teacher and curriculum. However, these technologies can limit the access of learners to the use of ICT individually or in small groups (Smith, Hardman, & Higgins, 2006). The UK Office for Standards in Education (2008) for example, reports that:

> mathematics makes a relatively limited contribution to developing pupils' ICT skills. Moreover, despite technological advances, the potential of ICT to enhance the learning of mathematics is too rarely realised. (p. 17)

In contrast, Sinclair and Jackiw (2005) identify the characteristics of the 'third wave' of ICT technologies into the classroom to be a further expansion of the pedagogic focus which will include: 'relationships among individual learners, groups of learners, the teacher, the classroom, classroom practices and the world outside the classroom' (p. 244). This 'connected classroom' can be situated within the context of

*Email: d.g.wright@newcastle.ac.uk

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a programme to 'democratise' the benefits of ICT for learners of mathematics (Hegedus & Lesh, 2008).

The enquiry

The study (Wright & Woolner, 2009), supported by a grant from the National Centre for Excellence in Teaching Mathematics (NCETM, G21) and Texas Instruments, was a two-year enquiry which began in June 2007 with the delivery of graphical calculators[1] (GCs) and was completed in March 2009.

It was thought that GCs, as handheld computing devices, could be useful ICT tools which can be put into the hands of every student in a mathematics lesson without having to take the class to the ICT suite. This appealed because the GCs are also able to run versions of small software, sharply focused on specific topics, which is established as a useful resource to support learning in mathematics. Examples used in the study were the *SMILE* mathematics application (http://education.ti.com) and a suite of programs from *Calculator Software* (http://www.calculatorsoftware.co.uk/).

This approach was chosen since it was hypothesised that the adoption of new technology by teachers and learners is most successful where it does not involve a big commitment initially in learning about its functionality, where the application fits in well to teachers' existing practice and where there is an immediate gain in 'value added' to the learning of the students. However, it is possible that this approach may lack challenge and fail to have an impact on classroom practice, thus some episodes of outside training were also offered.

The teachers were supplied with a GC emulator (*TI Smartview*), which allowed them to model the GC on their PC and project the image on to a whole-class display, facilitating explanations and the modelling of procedures. A later addition to the project was a networking system, the *TI Navigator*, which allowed the GCs to be linked to each other and to the teacher's PC so that data and images could be shared and 'screen shots' from the GCs projected on to the whole-class display. There are a range of functions supplied with this system to support and enhance social interaction and investigation. For example, assessment of learners' understanding can be obtained through sending a variety of questions to the learners (called 'quick poll') where all the students respond and their responses are aggregated and displayed. A particularly interesting facility is a function where all the learners' inputs of points or graphs are aggregated anonymously and displayed so that the class are sharing an interactive space and creating participatory mathematics.

The two mathematics teachers centrally involved in the project were interested in the potential of the GCs, but had no previous experience of using such technology in their teaching. They were given GCs and some initial training (mainly focused on how to load and run small software on the GC) in the summer term 2007 and used them in class from September 2007. The *Navigator* networking device was delivered to them during this first term and they received training on it in February 2008 and began to use it in their lessons from that date. The pupils using the devices were in Year 8 (ages 13–14).

Throughout the project, data were gathered from teachers and pupils through informal interviews and meetings, classroom observation, teacher diaries and pupil questionnaires in order to investigate their experiences of using the handheld technology for mathematics teaching and learning. Further details of the methodology and empirical evidence can be found in the full study report (Wright & Woolner, 2009);

owing to space limitations this article focuses more on discussing than reporting the findings.

Learners' perspective

Observation of lessons by the researchers and the recording of informal comments made by the students supplied evidence that GCs were a popular resource in the classes. These observations also supported the frequently reported impact of the effectiveness of ICT in promoting conjecturing and experimentation, yet here they are taking place in the context of the normal mathematics classroom and lesson, not in the ICT suite.

Teachers' perspective

The teachers' reactions were favourable and the potential for students to progress at their own pace was noted:

> I feel [the] motivation of [the] class and overall pupil enjoyment of maths has increased dramatically using the calculators. Especially effective for engaging boys who sometimes do little work in the lesson!

However, teachers quickly noted that there was a need for another style of pedagogy in using this facility:

> I found the program is good for testing understanding, but I found it hard to assess pupils' understanding during the lesson due to pupils' being asked different questions.

The network

Teachers found the technical burden in setting up and getting to understand the wide range of functionality in the system onerous and this prevented their using it frequently enough for students and themselves to become fluent in their use of the system. However, there were some lessons where the system was used extensively. For example, it was observed that during lessons which involved investigating linear graphs and used the network, learners were able to look at and share the graphs they had managed to produce through inputting equations, in the context of results from others. The display of screen shots allowed them to see how others were rising to such challenges as the teacher's request to produce a horizontal line and facilitated discoveries through discussion, such as about the quadratic curve that one student had accidentally produced.

It was observed that the network was also used to aggregate points entered by the students, according to a given rule, to produce the loci of a line on a single set of axes on the IWB. This clearly appealed to the learners, who responded quickly and made comments such as 'There's mine!' This introduction to the relationship between equations and graphic representations resulted in engaged discussion between the teacher and individual learners, as learners tried to describe what the results of varying the equation would be. One girl was observed to criticise her own contribution and provide a correction without having to acknowledge her ownership of it – here the system removed the barrier of embarrassment from students in making contributions.

Students commented:

> I think it's good because the teacher can see everyone's work
> It's great finding who's right and wrong
> Allows everyone to participate in activities
> You could see what we're doing
> It gets everyone involved

However, there were also issues arising from students inputting erroneous points, initially by accident, but then on purpose. The teacher found this disconcerting and curtailed the activity. Thus the most engaging and interactive use of this technology also makes it possible for learners to 'derail' the lesson, since the genuine collaboration depends on their cooperation. This is an area of pedagogy where teachers were essentially on new ground and could be a key issue on which to focus further professional development. For example, some researchers have found that this is a stage students need to encounter and explore in order to 'own' the system (Hivon, Pean, & Trouche, 2008).

The network also has the facility for providing instantaneous assessment feedback through a 'quick poll' where students respond to a variety of multi-choice or free-text entries. This has the potential for the greatest impact on pedagogy through supporting formative assessment. The use of this facility was not well developed by these teachers within the scope of the project. Whether this was due to unfamiliarity with the technology or some other issue, for example a lack of development of an understanding of formative assessment, is not clear. Although these particular teachers did not use this function effectively, it was observed that other teachers in the department did see its potential and were quick to take up this facility and develop its use in their classrooms.

Discussion

ICT tools support an entitlement to opportunities for learning mathematics to which all learners should have access during their schooling (Becta, 2009). Through feedback from ICT learners notice patterns and see connections and explore, making mistakes and seeing the consequences of their decisions. Moreover, it is clear that *personal* access to an ICT tool is particularly important in supporting learning (Guin, Ruthven, & Trouche, 2005; Hennessy, 1999).

> One of the key findings from reading the many meta-analyses on computer aided instruction was that when the student is in 'control' over his or her learning […] then the effects were greater than when the teacher was in 'control' over these dimensions of learning. (Hattie, 2009, p. 225)

Personal access to powerful computing tools has the potential to alter the way in which the learner interacts with the subject; researchers have called this process 'instrumentation' (Guin et al., 2005). Current handheld technology such as the graphical calculator affords access to all of these opportunities within the 'normal' classroom situation, without too much extra organisation or negotiation over access to computer facilities.

The additional facility of the network which has been specifically designed to support and foster interaction within the classroom leads some researchers to believe that there are now opportunities for transforming pedagogy within the traditional classroom (Stroup et al., 2002). The development of these networks in creating a connected classroom brings new possibilities and new challenges to mathematical educators:

> The highly interactive and group-centered capabilities of a new generation of classroom-based networks are helping both to support and to provoke the development of new theoretical, methodological and design frameworks for engaging classroom learning. (Stroup et al., 2002, p. 1)

There appear to be at least two stages of pedagogical development involved in the introduction of networked handheld technologies into the mathematics classroom. In the first stage both learners and teachers become familiar with the technology and the teacher develops ways of working with a class of learners, all of whom can be progressing at their own rate. Researchers have referred to this as learning to 'orchestrate' the class (Hivon et al., 2008).

However, this experience is mainly individual – there is little use made of the social space of the classroom. Also, where the handhelds are being used to run small software, albeit motivating and educational, the trajectory of learning is largely owned by someone who is not a member of the classroom – the programmer of the software. This is an issue for both the students and the teacher, since the teacher will find it difficult to mediate in the learning of the students unless requested to intervene by a student in difficulties. The students may also find the 'microworld' limiting or too challenging and become bored or disengaged. Hence the trajectory of development needs to include activities where the learners and teacher are using the functionality of the handhelds as problem-solving tools which support a community of enquiry, characterised by joint ownership and construction of understanding (Stroup et al., 2002).

In the second stage, the networking of the handhelds introduces a new dimension in which the technology actively supports social interaction in a range of ways. It allows much more effective intervention and mediation even where learners are working in individual microworlds since the teacher can 'grab' individual, group or whole-class screen shots at will in order to assess the learners' progress. These can be displayed either on the teacher's PC or on the large-scale projector so the screens can be shared by the class. It can also support powerful 'assessment for learning' strategies by supporting the teacher's questions and accumulating feedback from the learners in a range of ways. This function can be used to support activities which have no other connection with ICT. A powerful psychological aspect of this system is the way in which learners' contributions are anonymous – hence all the class can participate without the fear of embarrassment because of an incorrect answer. However, extensive exploitation of this facility needs the teachers to have expanded their own understanding of the pedagogies afforded here.

Some developers are exploiting this technology to create new ways of learning which have opened up – where the subject content is starting to structure the social sphere of the classroom. 'If mathematical ideas participate fully in the social space, they are not just *organised by* the social space, they are also *organising of* this social space' (Stroup et al., 2002, p. 6; emphasis in original). Examples include activities where individual learners are given different parameters for linear graphs and submit their solutions to a public display (Roschelle, Vahey, Tatar, Kaput, & Hegedus, 2003); where proof becomes enacted through the interaction between the teacher and learners as learners display and justify their solutions (Mack, 2002); where learners come to understand how complex, dynamic systems develop through participating in simulations (Levy & Wilensky, 2008).

Conclusion

The diagram in Figure 1 provides a way of comparing the power of an application (mathematical expressivity) with its location within the mathematics curriculum (curricular specificity). The arrow is intended to demonstrate that the more powerful and generally applicable the application, the greater the 'learning curve' needed to be traversed in order to use it effectively. It is possible that the same sort of trajectory also applies to the use of technology 'tools', that is, the more powerful and functionally complex a tool, the longer it takes to learn how to use it effectively. Hence potentially powerful pedagogical systems will not be used in classrooms by teachers unless an immediately effective but simple application is found.

The conclusion is that successful integration of technology into mainstream classrooms with mainstream teachers and learners depends on choosing the appropriate entry point into the learning curve and building in professional development to sustain progress through an understanding of the pedagogical challenges and trajectory of development of the technology in the subject.

Early adoption of technical innovations by 'mainstream' teachers depends on:

- a relatively undemanding commitment initially in learning about its functionality
- the application fitting in well to teachers' existing practice
- a perceived immediate gain in 'value added' to the learning of the students
- readily available technical support to sort out any 'hitches'
- including an 'outside' influence to provide an initial 'boost' and to sustain the promotion of innovative activities.

Although the underlying technology used in this study has developed within a particular domain – graphical calculators in mathematics classrooms – it is possible to

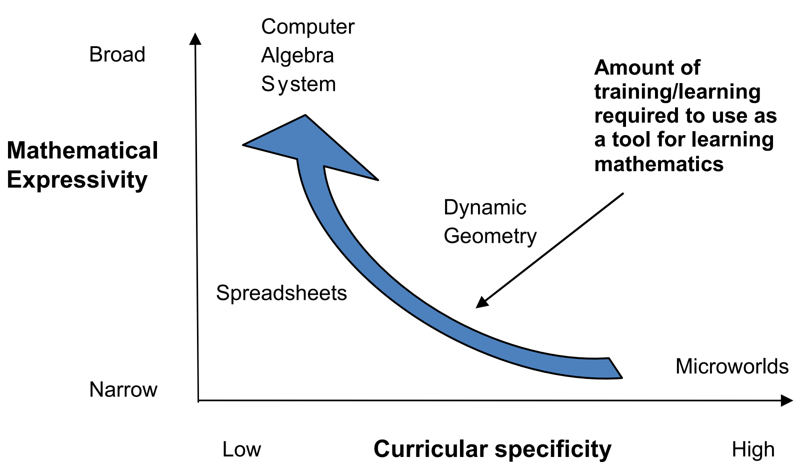

Figure 1. The learning curve for mathematical software. Adapted from Sinclair and Jackiw (2005).

see through these particulars to the potential for future applications in a wide range of educational settings. In these examples we can see the possibility of both new ways of learning and new access to knowledge through the affordances created by these connected classrooms.

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Note

1. Graphical calculators are handheld computing devices which can display graphical images such as graphs or provide multiple representations of functions, for example. Some have large memories which allow them to run software packages like a conventional computer.

Notes on contributor

David Wright is programme leader for secondary mathematics initial teacher education at Newcastle University and an Associate of the Research Centre for Learning and Teaching (CfLaT) (http://www.ncl.ac.uk/cflat/). He taught in secondary schools and further education for 15 years before joining the British Educational Communications and Technology Agency (Becta) as subject officer for mathematics. He is particularly interested in the transformative potential of ICT for mathematics education when integrated into the mathematics classroom through the use of connected portable technology to form an interactive social space for doing mathematics.

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