An investigation of appropriate new technologies to support interactive teaching in Zambian schools (ANTSIT)

Final report to DfID

A joint report from Aptivate and the Centre for Commonwealth Education (University of Cambridge)

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Executive summary

Our research in Zambia investigated mobile forms of digital technology used to embed interactive forms of teaching and learning into classroom practice. The project explored what kinds of mobile devices and uses can create an environment supportive of learning through active participation and collaborative inquiry within under-resourced and under-privileged school communities. It also examined the constraining factors. The specific focus was on using netbook, tablet and laptop computers, e-Book and wiki readers, digital cameras and mini-projectors along with Open Educational Resources and Open Source software to support students' learning in mathematics and science. We evaluated a variety of educational ICTs in two Zambian primary schools over 30 visits in a period of 6 months. Data collection methods included interviews, post-lesson surveys, classroom observations, and video recordings. The work was carried out by Aptivate in conjunction with the Centre for Commonwealth Education at the University of Cambridge, and with iSchool Zambia.

Our recommendations include:

- ICTs should be procured in sets comprising a teacher laptop and student laptops, as well as provision for storage and transport.
- Continuing professional development opportunities are essential for teachers to become familiar with the mobile technologies and to make creative use of them.
- ICTs should be used in conjunction with non-ICT resources, such as mini blackboards, because these add significant value cheaply.
- Robust and cheap netbooks (e.g. the Classmate netbook) are presently the best candidates for classroom use. Android-based tablets can support interactive, collaborative learning effectively but technically (in version 2.2) they are not yet ready (early 2011). Keyboard-based data entry in Flash games can be particularly difficult. However, devices running Android 3.0 should be considered for future procurements, including an investigation of suitable onscreen keyboard or docking stations.
- We would not recommend mixing devices within a single class, but if more than one class set of computers was procured, it may make sense to purchase a set of netbooks (for tasks requiring a standard operating system), as well as a set of tablets. However, cost and setup/maintenance issues need to be considered.
- Teacher and student laptops need to be configured well so that effort expended in lesson preparation is not prohibitive.
- Resource sharing with student laptops needs to be considered; local wireless networks can be deployed effectively to achieve this.
- Teachers want laptops to allow them to study outside of school. Microfinance could allow teachers to buy laptops which would build their skills and promote successful application of ICTs in schools.

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1 Introduction and background

1.1 Overview and aims of this research project

We looked at new and emerging Information and Communication Technologies (ICTs) in the area of education. In the North, there is increasing understanding of how to deploy technology tools and resources to achieve particular educational objectives, but this can be North-centred; a particular educational technology (be that netbooks, mobile devices, electronics kits, interactive whiteboards) may be used effectively in a UK school. However what works in the UK may fail in a developing country, in the sense of not improving education.

Building on our substantial literature review on developments in using ICT to enhance teaching and learning in Africa (Hennessy, Onguko et al. 2010), as well as experience of the ongoing iSchool[1] and OER4School[2] projects, we investigated how this prior educational technology understanding (North and South) can now be applied to a particular education system in a sub-Saharan country, Zambia, rated one of the lowest developed countries globally (150/169 on the 2010 HDI). We sought to determine what suitable ICTs are currently available or likely to be available in the near future, and what factors need to be considered in making choices for primary education.

The advent of compact devices running Android has led to an open market of affordable and innovative devices, including a slew of touch-based Tablet PCs. This flood of manufacturers releasing new products running Android has driven down the overall cost of the devices and presented a uniform alternative to Windows or Ubuntu. However the merits of competing devices and modes of use are not yet established, and contextual factors operate.

For now, Android-based devices are limited since many do not have access to the Android Market, cannot run Flash, and are not optimised for the device. Because the devices are not operating at their full potential, it is difficult to evaluate their usability and applicability in Zambian primary education. However, Android devices show promise with their low price point, ease of customisation, and ability to upload open-source applications. Future devices with newer versions of Android will hopefully address current issues in usability, be optimised for a touch-based interface, and arrive out-of-the box with access to the Android Market with a wider range of applications.

Apart from technical concerns, we also drew on educational research showing that inquiry-based, interactive and collaborative learning enriches the educational experience for students beyond traditional static learning. Further work has demonstrated that mobile technologies can effectively promote interactive learning in a classroom if the devices and content are appropriate for the environment (e.g. Becta 2004). These devices may include netbooks, mobile phones, calculators as well as other types of educational technologies. Drawing on this literature and our prior studies, we generated predictions about which technology uses were most appropriate for the school contexts (attending to location, class size, etc.) and desired learning objectives of mathematics and

[1] http://www.ischool.zm

[2] http://www.educ.cam.ac.uk/centres/cce/initiatives/projects/ictzambia/

science in the Zambia primary school curriculum. Referring also to published reviews and our own examination and configuration of promising devices, we participatively procured small sets of different portable technologies emerging as most promising.

A student at Chalimbana Basic School presents a maths problem to the class.

We sought to compare how uses of these devices helped create an environment supportive of learning through active participation and collaborative inquiry by evaluating them in two Zambian primary schools. There were two rounds of equipment procurement and classroom trialling; outcomes from Stage 1 in which small numbers of multiple devices were tested, along with further information seeking, informed the Stage 2 procurement of slightly larger sets of two main devices, the Advent Vega tablet and the Lenovo S10-3t tablet/netbook with swivel screen. Measurements of power consumption and notes on battery life and robustness were made.

We worked with the teachers to develop lesson plans around the chosen ICTs, paying particular attention to adopting active, inquiry-based learning approaches that research indicates are most effective. Various forms of qualitative data were then gathered to characterise how the chosen technologies were used in this context and how they were perceived. These included interviews with teachers, students, head-teachers, post-lesson surveys, classroom observations, and video recordings of seven lessons. Analysis of this data allowed us to determine which technology-lesson combinations held up best, logistically and pedagogically. The key design principles underlying this process included:

- **Participatory approach** valuing the voices of practicing teachers and students in the global South in articulating their needs.
- **Triangulation of perspectives** of research team, teachers and learners
- Triangulation of methods.
- Alignment of project and classroom goals.
- **Ongoing assessment** throughout the intervention
- Attention to gender.

- Sustainability.

Ultimately we aimed to produce some initial guidelines for teachers, school administrators, and education ministers for choosing and effectively deploying the most appropriate technologies – those evaluated most positively regarding usability, versatility, availability, power requirements, connectivity, robustness, cost effectiveness and integration with interactive teaching and support for collaborative learning. These need to cover a whole range of education environments, from an empowered teacher in a well-equipped school, to community-based learning with no teacher at all in some rural schools, as well as remote-teaching scenarios. We make some general suggestions but the solution depends on the particular circumstances and goals.

1.2 Demand for research from stakeholders

Education in many developing countries is arriving at a crossroads: There is a very significant disparity between the need for education and the education provided, and at the same time pedagogies (across teaching at all ages) are often outdated, based on passive learning. Heavy investments in ICTs in education will sooner or later be made by any developing country that can afford it, but often this happens without clear understanding of effective uses in an educational context. Instead, there is an expectation that simply providing technology will improve or even transform teaching and learning.

We have reviewed recent research and initiatives into the use of ICT in schools in sub-Saharan Africa (*ibid.)*. There is a clear desire to determine how to introduce ICTs, and clear evidence on the one hand for stakeholders' desire to deploy ICTs in education effectively, but on the other hand demonstration that stakeholders need and want further guidance on choosing the most appropriate technologies. We are working closely with the Ministry of Education in Zambia, as well as various NGOs based in Zambia, who desire further guidance, particularly that directly relevant to concrete implementation. While the present project is conducted in Zambia, it is anticipated to be relevant to a wide range of countries in sub-Saharan Africa.

1.3 Research focus

The overarching goal of the project was to determine how innovative approaches to using emerging and pre-existing ICTs in conjunction with appropriate pedagogies and learning resources can significantly improve teaching and learning in primary schools in Zambia. The key question was:

> ***Based on our understanding of ICT use in schools and of successful pedagogies such as interactive teaching plus collaborative, project- and inquiry-based learning, and given limited resources, what does an effective ICT-enabled Zambian school look like?***

Moreover, how can one bring existing initiatives and stakeholders together in synergy to realise this model in a sustainable way? It is a recognised problem that initiatives often work in isolation, starting from scratch, or are technology-focused, ignoring the crucial role of teacher support in promoting innovation and encouraging experimentation with teaching styles if necessary. Research shows conclusively that if ICT is simply dropped into schools it will be used rarely or poorly. Having recently surveyed numerous initiatives and extracted lessons learnt (Hennessy, Onguko et al. 2010), we explored in this project how to implement an effective solution, working collaboratively with Zambian stakeholders. We worked with and sought outcomes relevant to under-resourced schools serving deprived communities in one of the poorest African countries, where classes may be large. The study directly addressed one of DfID's stated areas for future investigation: "Matching new technologies to suitable low income country environments and opportunities". The emphasis was on capacity building within the existing education system and incremental improvement rather than disruptive change.

A secondary aim of the project was to explore what forms of adaptation (pedagogical and organisational practices) and support were necessary to facilitate the adoption of new technologies and interactive ways of using them, and what constraints operated. We were able to address this to some extent during this small-scale project, and it was hoped that the initial findings could help us to frame the next phase of the work.

1.4 Participant Organisations

Participating teachers

Aptivate (http://www.aptivate.org/) is a not-for-profit organisation specialising in ICT consultancy and services for international development. Since our inception in 2003 we have worked on a range of projects and interest areas including capacity building, software development, research, technical writing, low-bandwidth internet accessibility, network administration support, and in-country project consultancy. We have ongoing experience of working within a rural Zambian school environment to provide ICT training to students with a low previous exposure to technology, through our work with Camfed to support an entrepreneurship program for young women. This has involved technology selection and preparation, creation of sustainable local infrastructure, capacity building of trainers, and lesson support, over projects spanning three years.

The **Centre for Commonwealth Education** (http://www.educ.cam.ac.uk/centres/cce/) within the Faculty of Education receives significant funding from the Commonwealth Education Trust (http://www.cet1886.org/). The overarching principle of the Centre is to build sustainable partnerships which aim to understand and increase young people's and teachers' participation in their own learning, and to further understand how that learning extends beyond schooling, how it connects with prior learning, and with other arenas of learning in informal as well as formal contexts. The ultimate goal is to improve the quality of children's lives and to enrich the quality of learning and teaching. The Centre has developed collaborative partnerships initially in the areas of school leadership, effective pedagogies and initial and continuing teacher education.

iSchool was a participating partner too; see outline of its activities below.

Chalimbana Basic School and Chimwemwe Trust School. The two schools participating in this project were Chalimbana Basic School and Chimwemwe Trust School, further details are provided below.

1.5 Related Projects

iSchool (http://www.ischool.zm) is a project delivering the Zambian National Curriculum online. It seeks to change the pedagogies used in schools and deliver exciting, hands-on learning to students, whatever their age, or ability and wherever they are located. It uses interactive, blended e-learning, with the aim of enhancing the productivity of the Zambian workforce. It is an education project that uses ICTs as its delivery medium. This project has been running for 4 years and has developed from a research project where schools that had some form of computers (22 were chosen in total), were given internet access for free and were left to see what happened to the teaching and learning and the sustainability issues. They were supported by some initial training, but in the main they were left to their own devices. At the same stage a website of over 20,000 external web links was created, these were mapped to the national curriculum by subject and categorised via year groups.

It was soon noted that the teachers needed access to more ‘African content’ and therefore the ‘Total Learning Environment’ was created. This is a learning space for teachers and children; where children go to collect their learning materials that are, in the main, African and have been specifically created for them and their learning context. It is also the place where teachers go to collect the planning for each year, term, half term, weekly overview, daily overviews and lesson plans for every lesson that they teach. In the Total Learning Environment, there is also a space where teachers can learn; teacher training courses are provided. Online support is provided for the teachers. The Total Learning Environment is a work in progress, but the unique African-ness of the content has been noted by many along with the completeness of the content. The project also seeks to find the right ICT requirements for each geographical and socio-economic environment. Therefore there was a real match with the ANTSIT and OER4Schools projects.

OER4Schools was a pilot project (August 2009 - May 2010) funded by the Centre for Commonwealth Education at University of Cambridge and led by Björn Haßler and Sara Hennessy (http://www.educ.cam.ac.uk/centres/cce/projects/ictzambia). The study assessed the feasibility of providing Open Educational Resources (OER) to ICT- and Internet-equipped primary schools in Zambia, and of supporting interactive forms of subject pedagogy with the new resources. It also identified the needs of school-based professional development adapted to the local context. The project was conducted in a North-South partnership between the CCE and institutions in Zambia, including the National In-Service Teachers College. The chief in-country researcher was Godfrey Mwewa from University of Zambia, Institute of Open and Distance Learning.

We worked with teachers in 3 schools (2 of which were iSchools equipped by Africonnect), developing, supporting and trialling uses of OERs combined with new pedagogical approaches for teaching mathematics. There were opportunities for peer observation and reflective practice. The research element recorded classroom practice and assessed participants' reactions and learning, eliciting messages for embedding basic ICT and OER use in teacher education. Key outputs include insights into OER-Pedagogy-ICT adoption in poorly resourced educational systems, and guidance on implementing better learning environments.

2 ICT Solutions for Contemporary Primary Education in the Developing World

This section reviews the most up-to-date literature on using ICT for education (ICT4E) with a particular focus on the gaps in the current literature where further research is needed on sub-Saharan Africa.

Within the range of available ICTs, we focus on contemporary portable devices that support time, place and learning pace independence (Naidu, 2008), such as laptops, netbooks, tablets, slates and e-readers. The terms ‘tablet’ and ‘slate’ are often used interchangeably. For the purpose of this review, ‘tablet’ will refer to any handheld device where users interact via a touch-responsive screen, and not primarily through a keyboard.

2.1 Overall attitudes toward ICT for education

Programs to leverage ICT for education in the developing world have had mixed reviews in recent years (Derndorfer, 2010; Warschauer & Ames, 2010; Krstić, 2008; Toyama, 2010). In several countries, governmental agencies have increasingly stressed the provision of ICT as an integral part of their development plans, with special emphasis on education.

Plan Ceibal in Uruguay was established in 2007 to provide every school-aged child and every teacher in public school with a laptop computer (Ministerio de Educacion y Cultura, Ministerio de Industria y Energia, and Ministerio de Economia y Finanzas, 2007). In Rwanda, the National Information and Communication Infrastructure plan, now in its third of four stages driving the nation’s vision for development until 2020, promotes the use of ICT in classrooms to support teaching and equip students with the skills necessary to be successful in the 21st century (Republic of Rwanda, 2007 cited in Rubagiza, Were, & Sutherland, 2011). Similarly, Zambia emphasized the establishment of an ICT infrastructure in order to see overall economic and social development, pushing for increased exposure to ICT in early education to address “low levels of ICT literacy” and “’brain drain’ resulting in considerable loss of skilled personnel”, among other issues (Isaacs, 2007). In Zambia as in many other locations, however, practice on the ground has lagged behind the rhetoric of government policy (e.g. Wamakote et al, 2010).

For reasons related to implementing ICT4E initiatives, critics call ICT efforts in developing countries “futile,” arguing that “the potential of ICT will not be realised by the mere introduction of computers and ICT infrastructure in schools” (Toyama, 2010; Rubagiza, Were, & Sutherland, 2011). Critiques highlight the complicated nature of ICT for development projects, where partnering organizations with differing agendas often rely too heavily on singular technological developments to bring about change, ignoring the significant surrounding infrastructure, strategy, and policy contexts that must support an ICT project. Despite this criticism, there is substantial research that ICT can promote a rich educational environment in primary education.

2.2 Interactive, Collaborative, and Mobile Learning

Behind the push for ICT4E lies an inherent goal to use ICT as a tool to create more educationally-rich environments in classrooms. Research has shown that there is increased educational value in interactive and collaborative learning (Cramer, 2009; Nussbaum et al., 2009; Looi, 2010). Pedagogies that take advantage of interactivity and collaboration promote open-ended questioning, discussions in groups, and hands-on activities. Studies have shown that ICT4E initiatives have the most positive impacts when they foster interactive and collaborative environments (Becta, 2004; de Jong, 2006; Barak, 2006; Bebell & O’Dwyer). Despite the overall benefits that ICT can add to education, there can be negative side-effects. For example, laptops can sometimes be a distraction and take away from the learning process (Fried, 2008).

ICT has become an increasingly broad topic, moving beyond traditional static devices like computers to encompass emerging devices such as smartphones or tablets. With such a spectrum of devices, the question facing decision makers is which devices best promote interactivity and improve educational value in the classroom? Recent studies, mostly in the developed world, have shown that mobile ICT devices are favoured by virtue of their mobility (Barak, 2006; Ozok, Benson, Chakraborty, & Norcio, 2008). As portable devices, the ICT encourage students to become more active and engage material, creating new contexts and opportunities to explore beyond traditional classroom exercises (Sharples, Taylor, & Vavoula, 2007).

2.3 Which Mobile ICTs are Best Suited for Interactive Classrooms in Sub-Saharan Africa?

With an expanding market of mobile ICT devices with price points that decrease each year, decision makers have a wealth of options to decide between. Research shows that the benefits from ICT use are often limited by their contexts and environments (Naismith, Lonsdale, Vavoula & Sharples, 2005; Anastopolou et al. 2008). In response to that reality, some programmes have chosen devices to address a specific issue, such as using e-readers to focus on increased literacy (Sundermeyer, Risher, & McElwee, 2010). Other programmes have opted for netbooks as a single, general purpose device to meet the variable needs of a student, including reading, writing, and mathematics and science activities (Gaved et al., 2010). Newer programmes have begun to experiment with Tablet PCs, hoping that the tablet’s innovative method of human-computer interface will result in more natural integration of ICT into the curriculum (Koile, 2006; Berque et al., 2007; Crichton & Onguko, 2010).

2.3.1 E-Readers

A trial study in Ghana showed that e-readers could be an appropriate alternative to paper books for reading learning (Sundermeyer, Risher, & McElwee, 2010). Though the students had only previous experience with cell phones, they learned how to successfully operate Amazon's second generation Kindle with a few hours of instruction and a few days of practice, though there were some usability issues that increased the learning curve. Overall, the impact was positive and students enjoyed reading on the devices, even forgetting they were using ICT. However, there were some challenges that emerged.

Content on e-readers is primarily limited to English at this time. Even in countries where English is spoken, it is often a second language and therefore barriers still prevent seamless learning. The Kindle's built-in dictionary helps address this issue by giving users a ready-to-use resource to look up words which gives students more confidence to read. The Kindles lacked a central way to manage a class set of devices, so there was no easy way to monitor which devices had what material downloaded. While innovations in individual use like keyboards are important, innovations on classroom management are equally important (Cramer, 2009).

2.3.2 Netbooks

In a study conducted by the Open University and University of Nottingham, researchers found that netbooks were the optimum device to support a wide range of activities for mobile learners (Gaved et al., 2010). The study sought to find a singular device that was able to meet a variety of needs for students aged 11-15, including work inside and outside of the classroom. While other devices might work better for specific tasks, the netbook was best used as a general-purpose ICT. An important conclusion was that students learned to use the technology effectively with relative ease. The study found that students were eager to learn about their netbooks and began exploring its functionality. However, it is important to note that the students were from the UK, and are likely to have been exposed to ICT previously. In a developing world setting where most students are unfamiliar with ICT, students may be more timid and uneasy about jumping into a new technology.

Another study compared netbooks and tablets directly, asking students which device they preferred (Ozok, Benson, Chakraborty, & Norcio, 2008). After completing several common computer tasks, the students enjoyed the portability and capabilities of the tablets, but preferred the netbooks for everyday activities, claiming the netbooks were more user-friendly for tasks like typing. As an example, students made more errors on the tablets in writing activities despite the supposedly more natural interface.

2.3.3 Tablet PCs

In contrast to the above findings, a more recent study comparing students' preferences between netbooks and tablets found that "[university] students preferred tablet PCs to netbooks and also indicated greater self-confidence in expressing their ideas with the tablet's digital ink and paper technology than with the netbooks' traditional vertical screen and keyboard arrangement" (Alvarez et al., 2010, p. 834). The study points out that the tablets used in slate format promoted "fluid" discussion amongst students and remove inhibitions about expressing opinions openly (p. 842). In contrast, netbooks seemed to isolate students and inhibit collaboration. However, these results must be viewed in their context. The students observed were educated university students, ages 22-25, studying in computer science and engineering. It is unclear if similar results could be observed with primary-aged students who are unfamiliar with computers and technology.

Ozok, Benson, Chakraborty and Norcio (2008) point out that there is relatively little research on the capacity of tablets in reference to more traditional mobile ICT. There is even less research in tablet use in the developing world. One notable project by Crichton & Onguko (2010) reported successes using a tablet in a project to provide offline digital content in East Africa. In the specific contexts of that study, the capacity and portability of the tablet made it the appropriate ICT for the project.

2.4 What are the Barriers to using Mobile ICTs in Sub-Saharan Africa

There are several barriers to successful ICT use which can be both technical, regarding device usability, and institutional, regarding teacher preferences and school-wide policies. These barriers exist on multiple levels from the individual teachers, to the entire school level, to the overarching school system (Balanskat, 2006).

On the teacher level, teachers are hesitant to use ICT for various reasons: lack of ICT skills themselves, lack of confidence, lack of adequate training on how to integrate ICT into curriculum, etc. (Mumtaz, 2000; Balanskat, 2006; Deaney, Ruthven, & Hennessy, 2006). Moving up the hierarchy, a school might lack sufficient devices, lack educational software, or not have sufficient on-site support. On the highest level, the school system may impose a rigid curriculum or require regimented testing schemes that do not blend naturally with ICT, which can hinder ICT's ability to positively impact on a school (Lim & Chai, 2008).

Some studies show that a teacher's use of ICT in the classroom is directly related to their view of ICT (Jimoyiannis & Komis, 2007). Others contest that view and point out inconsistencies in a teacher's view of ICT and their use (Judson, 2006). Further research needs to seek to understand these inconsistencies and develop a sharper picture relating perception and use of ICT in the classroom.

2.5 Uncertainties and gaps in research

While research investigating the benefits and challenges of using ICT in the Curdeveloped world is expansive (Moseley & Higgins, 1999; Perry, 2003; Warschauer, 2008), comparative studies for emerging mobile technology for the developing world are less available and less certain (Casas, Ochoa, & Puente, J., 2009). It is uncertain, for example, what research findings from ICT4E studies in the North can be applied to new initiatives in sub-Saharan Africa. This disparity, complicated by regional and cultural differences, hinders progress in understanding how ICT might be adapted to developing world contexts. Since ICT4E initiatives vary significantly from program to program, further research needs to evaluate how each device specification, including screen size, robustness, battery life and power requirements, and operating system, affects the ability of the device to support education. The complexity of ICT4E initiatives makes them difficult to measure and assess progress, further impeding the development of thorough and reliable research (Sharples, 2009).

Though initial reports show that ICT can empower interactive learning in the classroom, no cross-platform study has been conducted to analyse the costs and benefits of each in comparison. There are still questions about supplying power to rural environments to support ICT4E as well as the development and distribution of digital content. As an emerging technology, research needs to look at tablets in classrooms to see if their touted benefits outweigh negative aspects such as cost and fragility. Issues of ICT support and the policy context are also important and should be studied.

There is little research on how to overcome the inherent barriers to introducing ICT to schools in the developing world. While the barriers themselves are readily recognised, methods to ease fears, demonstrate the capacity for ICT to improve classroom interactions, and blend ICT activities with existing curriculum have yet to be developed. Research needs to investigate if the barriers seen from previous research exist in developing contexts, and what further role cultural differences may play.

2.6 Moving forward and research questions

The ‘most appropriate’ device depends on the particular classroom circumstances and teaching goals. In developing contexts such as sub-Saharan Africa where this study was located, pedagogies – including teachers’ strategies, goals, beliefs and understanding of their learners’ needs – are often outdated, being based on passive transmission of information. A wealth of educational research indicates that more successful pedagogies are based on interactive teaching (Moyles et al. 2003), collaborative, dialogic, project- and inquiry-based learning. Thus in the reported study, technology choices were constrained through a focus on the most versatile and interactive devices that supported active learning of these kinds – where learners’ own ideas are explored and compared, through open-ended activities and questioning. This focus included consideration of the size and nature of tools that can effectively be used by small groups of learners engaged in collaborative inquiry and led to the choice of portable computer devices as a starting point rather than desktop machines. The subject areas selected were mathematics and science as these are important core subjects and they lend themselves to computer-supported inquiry-based learning.

Therefore, the overall study sought to address the principal questions of:

1. Which technologies are most appropriate for use in primary schools serving deprived communities in developing countries to promote interactive learning?
2. What forms of adaptation and support are necessary to integrate new technologies and what barriers impede the effective use of appropriate technology in the classroom?

The first question encompassed determining which of the available ICT solutions, regarding both hardware and software, are most appropriate to support and improve educational practices in the developing world. The *criteria for evaluation included:*

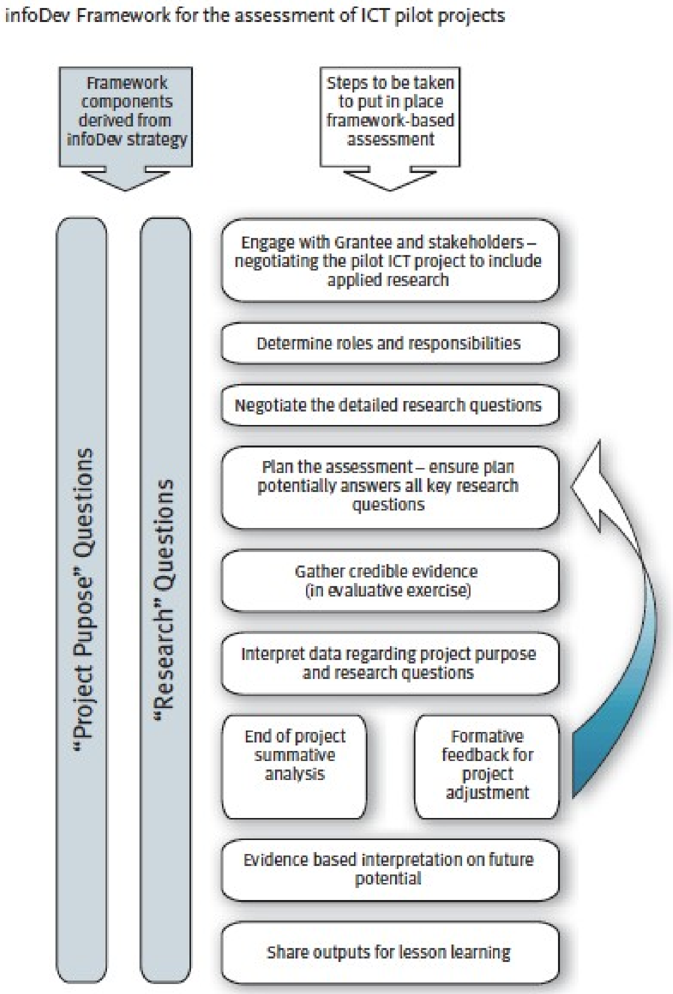
- **Usability;** how quickly can students and teachers learn to use the ICTs?
- **Availability of software and learning resources and match with operating system**; how well can the devices run open source software?
- **Power requirements** and ability to use solar power?

- **Robustness and reliability**?
- **Ability for ICTs to be integrated with interactive teaching styles**? Specifically, to what degree can inquiry-based learning in science and mathematics at primary level be based around these technologies?

The second question sought to understand the best practices and processes for introducing ICT into classrooms with little or no previous ICT experience, and where class sizes may be large.

3 Methodology: procurement and fieldwork

3.1 Design and methods



Our research design was informed by the helpful conceptualisation of the process for assessing ICT pilot projects put forward by Infodev (2005), and roughly followed the steps shown in Figure 1. Our own design was an inductive-deductive research cycle (Teddlie & Tashakkori 2009) that was both exploratory and confirmatory. Abstraction from observations documented in the research literature and our prior studies generated predictions about which technology uses were most appropriate for the school contexts (attending to location, class size, etc.) and desired learning objectives of mathematics and science in the Zambia primary school curriculum. Referring also to published reviews and our own examination and configuration of promising devices, we participatively procured small sets of different portable technologies emerging as most promising.

This procedure and the choices made are detailed below under Procedure. The initiative had two rounds of equipment procurement and classroom trialling; outcomes from Stage 1 in which small numbers of multiple devices were tested, along with further information seeking, informed the second round of procuring slightly larger sets of two main netbook and tablet devices (Stage 2).

We know from our experience with the OER4Schools project that with some support, teachers new to using ICT in lessons are capable of finding suitable resources and integrating them into lesson plans (Hassler, Hennessy & Lubasi, forthcoming), so we worked with the teachers to develop lesson plans around the chosen ICTs. We paid particular attention to adopting active, inquiry-based learning approaches that research indicates are most effective. Various forms of qualitative data were then gathered to characterise how the chosen technologies were used in this context and how they were perceived. Inductive reasoning subsequently illuminated the issues arising and allowed us to determine which technology-lesson combinations held up best, logistically and pedagogically – triangulated from the perspectives of research team, teachers and learners. The key design principles underlying this process are listed below.

3.2 Design principles

An ecological perspective. Davis' (2010) review of the diffusion of IT innovations in education from an ecological perspective construes the teacher's classroom as the central ecosystem within the school (another ecosystem), nested within the region or nation. This view portrays change in the classroom ecosystem as likely to impact related ecologies, and conversely, lack of change in the organisational ecologies may impede change at the classroom level. Change is complex and the ecosystems evolve in unexpected ways (ibid.), with planned innovations likely to have unintended consequences, so needing to be monitored and continuously adjusted as the systems attempt to maintain equilibrium (Somekh, 2010). Recognising this, we focused our lens at least briefly on the teacher and students and the school management. This also served our intention to triangulate.

Triangulation of perspectives. We solicited teacher and learner perspectives and those of the headteacher (investigating any institutional and infrastructure constraints). An in-depth interview was conducted with Mark Bennett, the Director of iSchool and Internet service provider, with 25 years experience of the Zambian education and commercial contexts so as to understand the role of the pilot in this context.

Abel discussing with female students

Triangulation of methods. The design balanced *self-report* (surveys) with direct *observation* and *interviews* along with technical *measurements*.

Participatory approach.
Our experience is that genuine participation is key to ownership, sustainability, and replication. Linda Tillman's (2006) account of culturally

sensitive research (with African-American teachers) additionally informed our investigation and understanding of Zambian classrooms, helpfully elaborating the open-minded and participatory nature of our approach:

> When research is approached from a culturally sensitive perspective the complexity of an ethnic group's culture, as well as its varied historical and contemporary representations, is acknowledged (ibid., p.266) …. Researchers rely on participants' perspectives and cultural understandings of the phenomena under study to establish connections between espoused theory and reality and then to generate theory based on these endarkened perspectives (p.271).

This perspective helped us to explore (in a very modest way within the scope of this small-scale project) the regional ecosystem by gathering some insights from our teacher participants into its culture – namely the shared knowledge, practices, experiences, routines, values, ways of thinking, and behaviours – that were relevant to our interpretation of classroom practices observed. Moreover decision making was collaborative as far as possible, so that for example the subject topics to be targeted were negotiated and the types of technology selected for the second stage were directly informed by teachers' suggestions (the models of equipment within those categories were, however, selected by the research team who were privy to information about the latest models and able to test them out in person). It was also based on a shared vision. Zambian teachers in our studies strongly welcomed a holistic approach that embeds ICT within subject teaching, which the research literature indicates is ultimately most effective for learning, although currently rare in developing contexts (Hennessy, Onguko et al. 2010).

Alignment of project and classroom goals. We stressed to participants the importance of learning from the research programme and the need for systematic, quality data; ongoing discussions between teachers and in-country researchers ensured alignment.

Ongoing assessment throughout the intervention and collection of evidence to demonstrate proof of concept (Infodev, 2005, p.13). Teachers were encouraged to monitor their own progress too and to think of ways that they could enhance what they had been doing through a process of continual self-evaluation and refinement (Unwin & Day 2005). This was captured via the survey forms.

Attention to gender. We sought a gender-balanced team of teachers and also looked at how learners' use and enjoyment of ICT were affected by gender issues.

Sustainability. We aimed for low-cost and low-energy or sustainable energy technology options where possible. The technologies themselves will be maintained by the schools for a few years, but technologies naturally go out of date and this pilot project cannot of course replace them. However it is hoped that project outcomes will become sustainable through the participatory approach and attention paid to environmental and social sustainability. The most sustainable element that we aimed to embed was a culture of knowledge sharing and collaboration around ICT use (by both teachers and students) that is enduring and to some extent replicating; this was maximised through continuing the involvement of the same teachers from the OER4Schools project focusing on professional development – the latter being an important enabling factor in effective use of technology in any context. We had already begun to develop a shared vision of interactive teaching with ICT and were hence able to short-circuit to some extent the process of building rapport and negotiating roles and responsibilities.

We seek to create school-based cultures of technology use that make the *process* of integrating devices an ongoing, self-perpetuating enterprise. This means soliciting participants' views of the important factors and involving them in future planning. In the longer term, we aim to work with the Ministry of Education to make ICT investments in schools sustainable, and also to work with schools towards creating self-funding internet cafes and opening them up to the wider community.

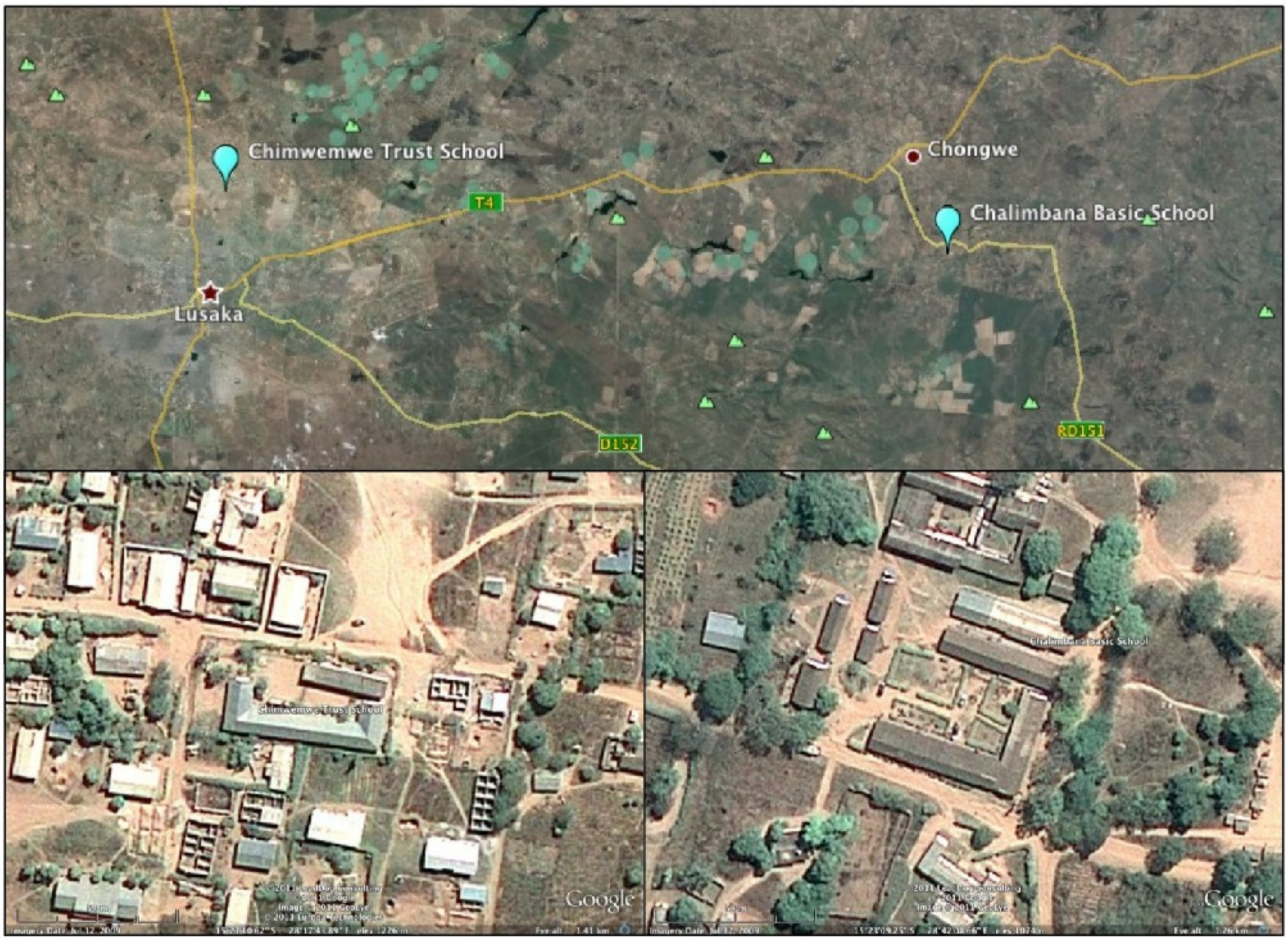
Finally, we see Open Source as an important cornerstone of a replicating, enduring culture (rather than a technology choice), since the social norms embodied in open source communities are durable over time. Wherever possible, lesson plans incorporated open source software and open educational resources freely available via the Internet, both deemed desirable on ethical grounds of cost and fostering a sense of ownership.

3.3 Participants

To obtain the widest picture of the role of technology in primary schooling despite such a small sample, we focused on a peri-urban, community school (Chimwemwe, -15° 21' 10.5" S, +28° 17' 44" E) situated in a high density housing compound on the outskirts of Lusaka, with on-site access to electricity and the Internet, and a rural, government school (Chalimbana Basic School, -15° 23' 9" S, +28° 42' 8" E) with electricity but no Internet and much larger classes. Both are mixed sex, are poorly resourced and serve disadvantaged communities; the majority of parents are unemployed (although "piecework" – casual labour with an income of around $50 / month – is common) and many children are orphaned or otherwise vulnerable. Within these schools we worked in collaboration with 6 basically ICT-literate teachers (3 male and 3 female, 3 from each school) who are involved with our parallel OER4Schools project (one school was also an iSchool), and their respective classes in Grades 1-9 (the fieldwork spanned two school years and teachers in one school taught another cohort in the afternoons): see Table 1. One teacher was ill for some weeks and thus unable to participate fully.

Table 1. Participating teachers

School	Name of Teacher	Sex	Grade(s) Taught	Qualifications and Teaching Experience
Chimwemwe	Ivy Phiri Eness Chileshe Brian Machiko	F F M	Grade 1,2 Grade 3,4 Grade 6,9	ECCED; 1 year ECCED; 2 years Teachers Certificate; 6 years
Chalimbana	Abel Makonga Agness Tembo Sydney Mukonda	M F M	Grade 6,7 Grade 2 Grade 8,9	Diploma, Teaching cert; 6 years Diploma, Teaching cert; years Diploma; 13 years



Chimwemwe and Chalimbana schools

Together with the teachers we identified suitable curriculum topics within primary mathematics and science that fit within their teaching plans at the time of the study. We trialled each set of technologies in the two different school contexts.

3.4 Procedure

Table 2: Overview of research process

1	Perusing available information about the relative merits of different potential technologies, referring to technical user forums and reviews
2	Ordering sample machines (on loan where possible) and testing them, reconfiguring them, etc
3	Informed decision on a shortlist for bulk purchase
4	Equipment procurement and deployment
5	Classroom trials in Stage 1 in Zambia (Oct-Nov. 2010)
6	Observation of lessons by in-country Zambian researcher; collection of survey forms after each lesson

7	Dec.-Jan.: Consideration of outcomes from Stage 1 and further information seeking about new technologies
8	Stage 2 classroom trials in Zambia (Feb.-March 2011)
9	Data analysis and assessment of how well the intervention served teachers and learners, obstacles arising, lessons learned and implications for scaling up.
10	Reporting

Table 2 summarises the overall research process, including the equipment procurement and the fieldwork trials. In the following sections we describe the procedures for these in more detail.

3.5 Fieldwork

3.5.1 Stages

The research work was conducted in close collaboration with the two schools involved, including students, teachers, and headteachers. The field work was undertaken in two stages, as detailed above.

In the first stage, we conducted visits schools to the schools, to introduce teachers to the project, equipment, and the evaluation methodology. The 6 visits and a 1-day workshop were conducted jointly between a member of the UK team, as well as a member of iSchool, a seconded Zambian teacher. Following the initial visit, the iSchool research assistant made another 14 school visits to continue to support the teachers, through developing lesson plans, observing and feeding back on lessons. During this period the teachers reported back through post-lesson survey forms.

The second visit (conducted in February / March 2011 by two members of the UK team) for Stage 2 continued school visits, with direct lesson observation and video recording of 7 lessons, as well as interviews with participants and further post-lesson surveys.

A typical day at school consisted of observing lessons in the morning with one of the teachers, a joint lunch, followed by joint lesson planning and preparations for the next visit.

Impact on the whole school. The majority of the 40 teachers at Chalimbana expressed strong interest in the project, and were keen to acquire personal laptops. While personal laptops do not necessarily help with ICT use in lessons (or interactive teaching), they certainly are useful in enabling teachers to acquire ICT skills. While most teachers can not afford laptops, they do have some disposable income. We conducted a simple study at Chalimbana, regarding microfinance for purchasing computers. The monthly disposable income available towards computers ranged between £25 and £60 per month. Currently, there are no microfinance opportunities in Zambia, though at least one company is hoping to introduce a scheme within 2011.

Sample lessons and activities are detailed below in Key Findings under “Supporting interactive classroom teaching”.

3.5.2 Data collection

The underpinning research strategy was to assess the impact of introducing new technology tools on the learners, the teacher and the interaction between them. To this end we collected the following data:

1. **Interviews** (14 semi-structured) in Stage 2:
   - *teacher interviews* (6 individual interviews, one group interview with 3 teachers at Chalimbana) concerning experiences with the devices, ease of use, constraints, support needed, perceived change, support for collaborative learning;[3]
   - group interviews with *students* after 4 lessons (one half class of boys, one half class of girls, one equally mixed group of 8, 3 small groups of 2-4 students); the first 3 interviews asked about how the equipment helped to support learning; the fourth short interview asked each small group in turn to compare two devices;
   - interviews with the 2 *head-teachers* focusing on their experiences and perceived outcomes of the project;
   - interview with *Mark Bennett, Director of iSchool* concerning technical challenges, bandwidth, factors for integrating equipment smoothly, issues in scaling up.

   See Appendix 1 for interview questions.

2. **Surveys** (post-lesson, written/electronic): 58 forms in total (see Appendix 2 for an example of a reasonably informative completed survey)

3. **Classroom observations** (31 in total), collecting field notes, photographs; lessons lasted 1hr. 18 mins on average (see Appendix 3 for observation focus)

4. **Video recordings** of all 7 of the lessons observed in Stage 2

5. **Measurements** of power consumption, notes on battery life and robustness

In the next two sections we report our decision-making process for the procurement of equipment to be trialled, and the considerations taken into account. These included features of the hardware and the operating systems.

3.6 Review of ICT Hardware

3.6.1 Introduction

Hardware solutions for ICT in education come in two forms: specifically designed solutions for educational contexts, or consumer electronics designed for traditional markets. The One Laptop per Child (OLPC) XO, a “rugged, low-cost, low-power, connected laptop,” is a notable example of a device designed specifically for educational use in the developing world. To address issues of

[3] Note that the timescale was too short to measure student learning outcomes, however informal teacher perspectives on this were solicited.

robustness, power, and simplicity, OLPC reduced the form-factor and power requirements for a laptop and built the XO specifically for use in the developing world. Other examples are Intel's Learning Series PCs, with similar design specs for robustness and power, RM's set of netbooks and tablets designed for educational use, or larger-scale designs like SMART Boards. With specific education focuses, these products focus on scale, interactivity, durability, and ease of use.

Outside of the educational context, the wider consumer market for laptops, netbooks, and recently tablets can also be applied to education. Different from educational designs, these ICT solutions push for better performance, graphics, and user-interface.

The educational computer market has increased dramatically in recent years, where many traditional computer manufacturers now have entire lines of devices for education. Similarly, the push for increased ICT in schools in the developed world has resulted in a wider variety of applicable designs. The selection of devices to review is meant to be a cross-section of what is currently available and is by no means an exhaustive list given the uncertainty and competitiveness of the current market.

3.6.2 1-to-1 vs multiple students per device

Providing each child with a mobile device is the aim of many education schemes involving technology in the developed world. However 1-to-1 initiatives in developing countries are generally smaller in scale and spread out due to resource constraint and costs. Notable exceptions are Plan Ceibal in Uruguay using the OLPC XO, along with several other OLPC-assisted deployments in countries like Peru or Rwanda. Plan Ceibal is unique in that each public school child and teacher in the country now has a laptop computer. The first phase of the project concluded with the distribution of the last of 369,727 laptops in October of 2009, two years after the project's inception in 2007 (Hirschfeld, 2009).

The program reports some positive initial results. An internal review shows that over 37% of mothers say their children are more likely to look up information for a homework assignment (Martínez, Alonso, & Díaz, 2009). The review similarly states that over 75% of school heads say the arrival of the ICT has had a positive impact on student motivation, has stimulated the students' work outside of school, and has improved their self-esteem.

Statistics on 1-to-1 programs are difficult to come by, and even more difficult to properly interpret. As Bebell and O'Dwyer point out, despite a growing interest in 1-to-1 ICT programs, finding empirical evidence to guide decision making is difficult (2010). Their study in American schools using 1-to-1 ICT programs highlight the difficulties in measuring success even in developed contexts, but overall promisingly point to the potential for 1-to-1 initiatives to transform classroom education.

In contrast to some 1-to-1 initiatives in the developed world, nationwide 1-to-1 computer programs are more feasible in locations with fewer resources and less infrastructure. In those cases, programs and schools opt to have students share computers. The issue is then to decide how many students can reasonably share a computer and still maximise it as a resource. Having multiple students working on an activity on the same computer increases collaboration and allows the students to discuss the issues productively as a group. However, crowding too large a group around a single computer breeds confusion and impedes the collaborative process.

Questions of screen size and how many computers can be effectively used are linked. Netbooks have smaller screens than laptops or desktops, and therefore can accommodate fewer students and still yield equal participation. So, given that resources are scant and a 1-to-1 ICT program is unlikely in many circumstances, it would be valuable to qualitatively understand how many students can reasonably use the same device at once. The question measures trade-offs between cost, number of devices, and screen size, recognizing the educational benefits of collaborative learning and difficulties of ensuring equal participation with limited resources.

3.6.3 Screen size and visibility

The recent explosion in netbooks, tablets, and smaller ICT devices has given rise to a large variation of screen sizes and types, including traditional touch-pads, fully-interactive touch-screens, or even combinations of the two. The OLPC XO-1.5, the upgrade from the XO, has a 7.5” (19.1 cm) liquid-crystal display with a special monochromatic mode for power savings and readability in full sunlight. The Intel Learning Series Convertible Quanta NL1 and NL2, touted as “netbooks designed for learning and collaboration”, have a 10.1” (25.7 cm) convertible swivel screen functioning as both a traditional visual screen and a touch-optimised tablet. Intel’s Clamshell Classmate PCs come in 7” (17.8 cm), 8.9” (22.6 cm), or 10.1” (25.7 cm) models. Screen sizes can even be as large as the RM One, a more robust but less portable computer designed for the classroom, at 19” (48.3 cm).

Amazon’s Kindle, which uses electronic ink technology to make the screen more readable in full sunlight and reduce power consumption, has a 6” (15.2 cm) screen. The Barnes & Noble Nook B&W, which also uses electronic ink, has a slightly larger 7” (17.8 cm) screen.

Tablet screen sizes also vary widely, and though they have not been specifically marketed as education tools, still have classroom application. The RM Slate has an HD GLARE 11.6” (29.5 cm) LCD screen. Apple’s iPad2, released in March 2011, has a 9.7” (24.6cm) LED-backlit screen. Other, lesser known tablets, have also hit markets with lower price points, such as the SmartQ7 with a 7” (17.8 cm) resistive touch-screen or the Advent Vega multi-touch 10.1” (25.7 cm) HD screen. The Nook Colour, the touch-based follow up to the Nook, has a 7” (17.8 cm) screen.

These examples were chosen to show the variability in screen sizes and types. As a growing market, especially with tablets since the arrival of the Apple iPad, there are many options and no clear leader. The question for ICT4E implementers is a design tradeoff between size, functionality, and cost. Further research is needed to explore the relationship between the various size options and how they affect the classroom experience.

3.6.4 Battery life

Battery life is an important issue for schools operating in regions with unreliable power or lack of mains power, a typical scenario in sub-Saharan Africa. While prolonged battery life does not circumvent power issues, it can help in situations with limited availability or with shared primary power sources.

Mounting emphasis has been placed on increasing battery life for devices, while the actual battery performance of course depends on the device and its usage. For the devices mentioned above, manufacturer-stated battery life ranges from 4 hours to 7.5 hours for netbooks, 3 hours for the RM

Slate, and up to 10 hours for the iPad2. Devices like the Kindle or Nook B&W claim battery life of up to a month due to their power-saving electronic ink technology. As with other issues, because of variation in needs and use there is no prescribed figure for the optimum battery life.

3.6.5 Human Computer Interaction – touch pad vs mouse vs touch screen

The array of new tablets has introduced a new form of human-computer interface, the touch screen, moving away from the traditional mouse or touch pad that accompanies laptops and netbooks. Some environments make working with touch-based devices difficult since dirt or dust can inhibit use. Tablets are generally more fragile and difficult to repair because of the materials of which they are made. As a developing technology, some tablets have usability issues with precision of touch, depending on the application (Kendrick, 2009).

The traditional mouse is simple enough, but necessitates an external device which can break or hinder portability. Touch pads are convenient since they are built into the keyboard surface of laptops and netbooks, but can have usability issues, especially for children. Touch-based devices promote a different kind of interaction than using a traditional touch pad or mouse, however they come with their own difficulties. The development of more interactive interfaces, such as multi-touch, will make their use more valuable, but may not outweigh the obstacles to use (Mediati, 2010). It is not well understood how these different forms of interaction affect children's user experiences and this merits further research.

3.6.6 Products designed for educational use vs wider-market devices

Devices specifically designed for educational use have advantages in their robustness and a form factor targeted at use in the classroom environment. They prioritise portability and ease of use over power and size. They are scalable by design and come ready-made with suites of educational software. Their power and hardware have been pared down to reduce unnecessary features and lower the price.

However, the overall consumer demand for ICT devices has created vast competition between these educationally-focused devices and wider-market products. This competition has lowered prices overall, but has made wider-market devices competitive with devices like the XO or Classmate PC.

3.6.7 Emerging market technologies

Technologies like tablets are relatively new, even in developed world markets, and therefore a thorough understanding of their applicability to education has yet to be developed. Devices that prove successful in consumer markets will eventually trickle into the educational sphere, and it is yet to be determined if tablets have a place in classrooms of the developing world. Further research should be conducted exploring their potential for use in the classroom.

3.7 Operating systems

The software landscape differs slightly from the diversity of competition between hardware manufacturers. Regarding the operating system (OS), the four largest competitors are Windows, Mac OS, Android, and Linux. Devices often are able to to have multiple OS installations, either as primary operating systems or in some form of virtualisation. Other issues include the open source model vs purchased software, customization of the devices beyond default factory settings, and scalability of deployment.

Most laptops and netbooks come pre-installed with a version of Windows, however netbooks may also be available with Linux or, rarely, with an Android release. Additionally, users can of course install one of the many free Linux versions available after purchase. So, there is a range of operating systems to choose between.

Windows has the advantage that it can support most programs or applications, while Android is more customizable and supports a powerful application market where users can instantly download and install applications. At present, Windows 7 and Android have established their own niche within the wider ICT market. Linux, as an open-source and free option, is always a viable option. However, very few come with Linux as the primary operating system. Instead, netbooks can be set up as dual boot devices where users can run Linux as a secondary option to another more prominent OS. All three platforms have developed special versions for netbooks and are working on versions optimised for tablets. These designs take into account the smaller screen real estate, lower processing and graphics power, and touch-based interface for tablets.

While Windows XP initially dominated the netbook market, Windows 7 has now taken over as the default OS on most netbooks (NetBooks 2011, 2011). In some user reports, Windows 7 Starter performs better than XP and Ubuntu 10.10 Netbook Edition on start-up and application opening times, and comparable on other tasks such as suspending to RAM, waking from suspend, and web performance (Graham-Smith, 2010). On the flip side, Windows 7 is less customizable since it has been scaled down for optimum running times. There are netbooks with a version of Android on them, but most reviews feel that Android is not optimised for netbooks yet and should be limited to smaller devices (Westaway, 2010). Since Android can boot faster than operating systems intended for desktops, it can offer a nice alternative for quick internet access (Lu, 2011). However, running Android does not mean the device will come with the Android Market. Google has strict hardware requirements for devices that are allowed to run the Market to ensure the device can properly run the Market applications. So, for many of the emerging netbooks and tablets that prioritise cost over robust hardware, Google has not allowed them to run the Market which limits the number of available applications and thus consumer appeal.

However, in the tablet space, the roles are reversed (Marshall, 2011). Android is the leader and gaining popularity, whilst Windows lags behind, though is rumoured to be working on an OS optimised for tablets (Emigh, 2011). Android is highly customizable which is convenient for the variety of tablet manufacturers. They can give their device a unique look and feel. The NookColor OS is built atop an Android platform, but has been optimised as an e-reader and the user would never know it was powered by Android (Topolsky, 2010).

Advertisement for Huawei u8230 outside the Airtel store at Arcades, Lusaka, Zambia

With each revision Android becomes faster and more powerful. FroYo, or Android 2.2, improved speed and performance and enabled Flash, an important asset to many online educational resources. Gingerbread, or Android 2.3, was released in February 2011 for use on smart phones, and tablet releases are forthcoming, though are not currently available (TechRadar News, 2011; Sovy, 2010). Honeycomb, or Android 3.0, is the Android OS specifically designed for tablets. Honeycomb boasts a range of improvements, including a 3D user interface, an improved virtual keyboard, and overall improved performance (Krill, 2011). It debuted on the Motorola Xoom as the first tablet with an Android operating system specifically designed for the large touch-screen tablet.

We also note that Android-based phones are starting to become available in Africa[4], including Zambia.

Regarding desktops and laptops, Windows 7 comes as standard on most laptops, though Linux is widely available. Which OS to use on a standard PC is mostly open for user preference based on user experience, since the devices are generally more powerful and performance issues between operating systems are less pronounced.

Another OS worth mentioning, if only as an example of an OS specifically designed for education and collaborative learning, is the Sugar OS that comes as standard on OLPC's XOs, but is also available to the wider market. Sugar is a Linux Fedora-based OS with built-in basic applications geared towards children such as Paint, Write, Read, or more innovative and complex programs like Scratch, a visual programming language application. Recently, Sugar on a Stick was launched so that users could run the OS directly from a USB drive (Lawton, 2010). Another Linux-derived operating system is MeeGo[5].

Further research could look at the use of each of these operating systems through the lens of a developing country school, evaluating the positive and negative aspects of each.

3.8 Equipment procurement

The hardware procurement for this project took place in two parts, matching the two visits made to the Zambian schools during the project. In Stage 1, small numbers of a large range of technologies were evaluated and purchased for initial evaluation by the teachers and students. Based on the outcomes of Stage 1, Stage 2 focussed on fewer types of technology, but in larger numbers, to allow larger class trials while limiting the complication of using several technologies at once. Stage 2 procurement also focused on specific items to address issues that had been reported and observed. Table 3 lists all the equipment purchased, along with numbers of devices used in the project.

4 See this item http://www.ictworks.org/news/2010/09/07/100-huawei-android-mobile-phone-bringing-netbook-revolution-smartphones.

5 http://meego.com/, list of tested platforms http://meego.com/devices/netbook/supported-hardware-platforms

Table 3. Equipment for first and second rounds of trialling (number of units in brackets)

Non-digital devices:
• Calculators (20) • Stop watches (10) • Measuring tapes (paper, ~ 100) • Mini whiteboards (100) and mini blackboards (15)
Book readers:
• Kindle (2) • Nook Color (1) • Nook B&W (1) • WikiReaders (5)
Accessories:
• Wifi hubs (2) • Web cams as document projectors (5) • Projectors (4 different models)
Laptop, netbooks, and tablets:
• Lenovo X61 (3) • Lenovo Edge (3) • Lenovo S10-3t (9) • ClassMate, JP Sá Couto, MP PUPIL 101 (150), MG Tutor 1001 (10) • Advent Vega (8) • Advent Amico (1) • SmartQ V7 (2) • Toshiba AC100 (1) • Toshiba Folio (1)

3.9 Stage 1: September-December 2010

In Stage 1, we sought to provide devices showcasing a range of variables for comparison, in order to be able to choose a class set for the second stage. These variables included operating system, screen size, input devices, use mode, and battery life.

For Stage 1 we also selected a range of supporting equipment to support a more holistic and resource-rich participatory learning environment, e.g. projectors, both battery-powered and mains-powered; blackboards and chalks; whiteboards and pens; measuring equipment for open-ended research project work e.g. stopwatches and tape measures; digital still and video cameras. These devices are described in detail in the Key Findings section.

3.9.1 Operating System (OS)

The primary effects of the operating system on the experience in the classroom include the levels of operating system support for the hardware (e.g. how well do touchscreen devices work under Linux?); the overall user interface experience for teachers and students; and the level of software availability and associated software user interfaces for each operating system (OS). At a secondary level, the nature of the operating system in terms of free open source, or paid-for proprietary software, has implications for large-scale roll out of such technologies, such as initial and ongoing costs, and customisability. It is worth noting that some educational software is designed to run on multiple operating systems and is in theory independent from this variable.

At this point in the project (last quarter of 2010), the available Android-based hardware seemed not well developed enough for large scale testing (significant user interface issues reported, and no Flash support), making some educational applications unavailable, and limiting web browsing. Also, some devices did not have access to the official Android Market, which severely limited software availability.

As such, we focused on providing free, open-source software (FOSS) environments in the form of Ubunutu, a Linux distribution, with some machines also providing a Windows option. The choice of Ubuntu was based around its relatively widespread usage, and design for usability for less technical users. Table 4 shows the equipment we used in this stage of the project.

Table 4. Equipment used in Stage 1

Device	*Operating System*
Lenovo S10-3t laptops	Windows 7
Lenovo X61 laptops	Ubuntu 10.4
Lenovo Thinkpad Edge 15 laptops	Ubuntu 10.4

We also used devices running customised or proprietary operating systems such as Wikipedia browsers and e-book / document readers.

3.9.2 Screen size

Screen size would intuitively be a major factor for the collaboration potential of various devices, and we were interested to see how well students were able to share on a variety of screens. Table 5 shows the screen sizes of devices we used in this stage of the project.

Table 5. Screen sizes of equipment used in Stage 1

Device	*Screen Size (inches)*
Wikireader	3.7
Kindle e-book reader	6
Nook e-book reader	7
Lenovo S10-3t netbook / tablet	10
Lenovo X61 laptop / tablet	12
Lenovo Thinkpad	15

3.9.3 Types of input device

We were interested to see how easily the students were able to work with various types of input device without prior experience. In this stage, we used touchscreens, pen-based touchscreens, trackpads, trackpoints, and different sized laptop keyboards, as shown in Table 6.

Table 6. Types of input device in Stage 1

Device	*Input*
Lenovo S10-3t	touchscreen, smaller keyboard and trackpad
Lenovo X61	pen-based touchscreen, larger keyboard and trackpoint
Lenovo Thinkpad	trackpad, larger keyboard
Kindle	keyboard with four-way switch
SmartQ	touchscreen

3.9.4 Mode of use

We wanted to investigate any difference in individual and collaborative use between tablet usage (e.g. screen can lie flat on desk) with standard laptop / netbook usage. Table 7 shows the modes of use in this stage of the project.

Table 7. Modes of use in Stage 1

Device	*Usage format*
Lenovo S10-3t	notebook / tablet
Lenovo X61	laptop / tablet
Lenovo Thinkpad Edge 15	laptop
Kindle	tablet
SmartQ	tablet
Wikireader	tablet

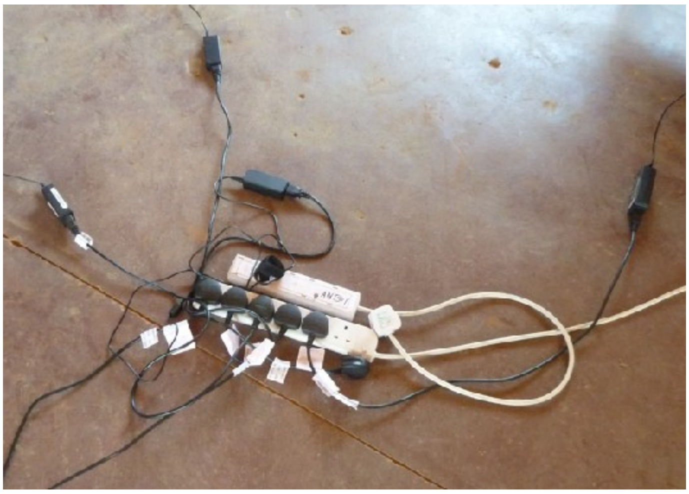
We were also interested to see how or whether devices intended for a specific use such as calculators, Wikireaders and Kindles integrated with other lessons using technologies, and also whether specific devices could be repurposed to other uses, e.g. is the inclusion of a web browser on newer book reader models useful for teachers or students?

3.10 Power sources for ICT

In this project, we selected equipment with a range of battery life, from several hours or even days, to a couple of hours. This obviously has implications for the viability of classroom environments in which power cannot necessarily be relied upon, and for lesson timings.

3.10.1 Solar power

A consequence of using ICT for education in rural areas is finding cost-effective and reliable ways to power or charge the devices. Alternatives vary from grid connections to gas-powered generators to renewable technology like photovoltaic (PV) solar panels. If a school is not connected to mains power supply, PV systems can offer an alternative way to power the devices, but this is an expensive operation.



In Zambia, mains power supply rates are subsidised by the government and are an attractive options in regions where mains is available. However, an initial survey in 1999 estimated that extending the grid to provide mains power would cost approximately 50,000 US$/km, and it cost as much as US$244 for individual connections (Chandi; Lemaire, 2009). For more remote regions, connection to the grid is expensive and therefore unlikely and so PV systems become more viable.

Costs on PV systems can vary based on region and availability. The Africa Renewable Energy Program published a document on installing stand-alone PV systems for the World Bank which estimates that a PV system costs around US$14-19/Wp in capital costs, and an additional 10-15% of capital costs each year on maintenance, repairs, and replacements (2010). Similarly, estimates for the price of stand-alone PV systems in Kenya were similar at 12,000 US$/kW for capital costs and another 2,000 US$/kW for operating and maintenance (KMOE, 2008).

To understand the power needs of schools using the ICT, power consumption was measured for three devices: two laptops, the Lenovo x61 ThinkPad and the Lenovo ThinkPad Edge, as well as a touch-screen netbook with swivel screen, the Lenovo S10-3t. Table 8 lists the devices we tested for power consumption in Watts over 5.5 hours of charging.

Table 8. Power consumption (Watts) while charging for the three devices

Device	*x61*	*Edge*	*S10-3t*
At the start	53	36	30
After 30 minutes	35	30	30
After 1.5 hours	34	30	29
After 3.5 hours	34	34	30
After 5.5 hours	21	21	30

To calculate the size of PV array needed to charge the laptops, we multiply the number of devices by the power consumption, and then multiply that by how many hours per day they charge to get the total number of Wh/day. Then, we divide the Wh/day our system needs to provide by the peak sun hours (PSH) which is a reflection of how much sun the region gets. For Zambia, the PSH is between 5 and 6 hours, according to the Joint Research Centre of the European Commission. We will use a conservative estimate of 5 hours.

For a class set of 40 laptops, a potential PV system would therefore need to provide around 2.2kW to charge the system directly during the day for the Lenovo x61, or around 1.5kW for the other two devices. Assuming the cheapest rate of US$14/Wp, a sufficient PV system to charge the Lenovo x61s would cost around US$30,000 in capital costs and around US$20,000 for the Edge or S10-3t. Annual operating and maintenance costs would be around US$ 3,000 for the x61s and $2,000 for the other two devices, again assuming minimum for costs. Even when using the cheaper rates, PV systems are expensive and would require significant outside funding to install.

3.10.2 A potential model for using a Photovoltaic (PV) system

For the two schools we worked in, we envision a PV system that charges batteries during the day which in turn can charge the devices at night or at the weekend. Such a system would need to be specifically designed for the ICT devices at the school for efficiency. Ideally, the devices could be loaded onto a mobile cart that is stored in a safe location in the school. Certain design concerns would need to be accounted for, such as durable wheels for uneven ground and the safety of the charging location. Since a mobile cart means all of the ICT is in one location, extra precaution should be taken to secure the room. However, these concerns are also present for a computer lab scenario where all the ICT is in one room.

3.10.3 Fee-for-service programs: ESCO

In other parts of Zambia, an innovative fee-for-service programme for PV systems is in place called the Rural Energy Service Companies (ESCOs) project. The project installs basic solar home systems (SHS) with customers and charges a monthly fee for services, rather than an upfront purchase and installation cost. The SHS include a 50Wp PV panel, a battery, charge controller, 12V DC socket, and all the other components needed to set up a system. While these installations are geared toward home use, they could be scaled up for the schools' ICT power needs.

Customers demonstrate willingness to pay through a down payment, and then pay an estimated monthly fee of $5 in 1998 USD spread out over 10 years. The service fee covers all the system components and includes the cost of technicians to maintain the system. A detailed study was conducted by Lemaire in 2009 and discusses the broader issues at length, but overall shows that a PV scheme based on monthly fees is feasible and perhaps a more likely scenario for the schools.

3.10.4 Conclusions for schools

The overall conclusion is that a PV system to charge the ICT devices would be an expensive operation, but a necessary addition for schools without consistent mains supply. The system would need to be designed with the school's particular needs in mind with specific attention to security and maintenance. Though an expensive investment, a PV system could potentially be funded as a fee-for-service scheme like the ESCO project.

3.11 Stage 2 - January-March 2011

In Stage 2, we decided to focus on two netbook and tablet devices to be evaluated in more depth in the context of whole class use. This choice was based on outcomes from Stage 1, and the detailed findings can be found in the Key Findings section below. Classroom sets of the same devices allow us to test technologies with a larger number of students at once, without increasing the management overheads inherent in introducing too many different technologies and interfaces. Our decision-making process including viewing some of the latest devices (some unreleased) at the annual British Educational Technology and Training show, leading to another round of shortlisting, testing sample machines and procuring sets to test.

It was clear to us that one of the devices tested should be have a laptop / notebook use mode, following positive feedback from teachers in using these in class. Feedback from teachers after Stage 1 showed that in general terms there was a preference for larger laptops because of a perception that it was easier for students to share them. However, when teachers considered the comparable prices of laptops and netbooks, they preferred to have more netbooks instead of fewer laptops. Based on this feedback, we decided to purchase more Lenovo S10-3t tablet-laptops, as they had become more affordable in the time between the two stages, and having three models already in country meant that we could combine the new purchases with the existing kit for larger class trials.

The S10-3t is a low-power netbook, and thus akin to all low-power netbooks, however it also includes a swivel screen / tablet use mode. The idea was not that such a device may be ideal for actual use in the classroom, but to make it easier for us to test both modes of interaction, and give students the instant choice between the two modes.

We purchased five additional units of the S10-3t for Stage 2, making eight units in total for in-class testing. The S10-3t allowed us to test established operating systems (both Windows and Ubuntu, following installation of a dual-boot system) with both a laptop and tablet mode of use. We wanted to complement this choice with a device using a “new” operating system.

As remarked above, the choice of Android-based devices (with a Flash-enabled version of Android, and reasonable screen size) was very limited in the last quarter of 2010. However, towards the end of 2010 and the start of 2011, towards the second stage of the project, we saw a surge in the release of Android-based devices, mainly tablets. This is likely to continue to be driven by companies trying to obtain a market share in this Apple iPad-dominated sector. Interestingly the Samsung Galaxy Tab is available in Zambia.

Advertisement for the Samsung Galaxy Tab at the Samsung store at Arcades, Lusaka, Zambia

The Android operating system has already become the most popular platform for smart phones in the US, and seems likely to continue to become increasingly popular for mobile devices including phones and tablets, and also possibly for laptop / netbooks given recent releases. The open Android platform has attracted a developer community, which has been able to contribute changes and features, providing an impressive range of functionality. At the same time, Android is freely available and thereby more attractive to manufacturers than costly proprietary systems. The large Android user-base provides its own incentive for the developer community to provide applications. There are also few barriers to entry for developers of Android applications: cheap or freely available tools are readily available; the language used, Java, is very well established; and releasing applications is a relatively easy process, without the initial approval that blocks access to, for example, the Apple App Store. According to the February report from the App Genome Project[6], which monitors US app usage:

> "The number of apps available on the Android Market increased by approximately 127% since August 2010, while the Apple App Store grew at a relative rate of 44%.
> If each market continues to grow at the same rate, the Android Market will have more apps than the Apple App Store by mid-2012."

As well as the popularity and seeming long-term viability of the Android platform, it is worth noting that the proportion of freely available to paid-for apps on the Android platform is much higher at the moment than Apple apps. This may reflect the general ethos of the open source software community, or may reflect lack of maturity of this market, or both. If this trend continues, this has good implications for the ease of access to, and sustainability of Android-based technological interventions.

Another interesting feature of the Android platform is that it is designed as a low-power operating system to be used on battery-based devices. This is very relevant in a context where power availability can be limited, and the interactivity expected of the students requires mobility unfettered by power leads.

As such, it seemed prudent to investigate Android-based devices alongside more traditional operating systems. In order to make a purchase decision, we trialled a number of Android devices, including phones, netbooks, tablets, book readers. We specifically focussed on lower end devices that are likely to applicable for our scenario, and excluded high end devices (such as the Motorola Xoom, or the Apple iPad, running iOS rather than Android).

Two main sticking points continued to affect the Android systems - the versions of Android shipping with the the devices considered often did not support Flash officially, and some devices still did not come with access to the Android Market, in both cases limiting the functionality of the devices. However, in the weeks leading up to the Stage 2 visit to Zambia, the availability of devices that seemed able to support the Android Marketplace as well as Flash, was changing on a weekly or daily basis. It seems likely in the future that these teething issues with access to applications will affect fewer new Android devices.

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[6] https://www.mylookout.com/appgenome

We also included two Nook book readers in the evaluation phase of Stage 2, partly for comparison against the Kindle book reader, and partly because the Nook book readers are based on a custom version of Android, which can be restored to the standard version of Android. It seemed possible that this relatively cheap device might also offer all the benefits of a standard Android tablet as well as a book reader, if the Android platform underlying the technology can be accessed.

While the standard version of Android could not be accessed on the Nook B&W, it was possible to do so on the Nook Color. The Nook Color enjoys a vibrant user community with promising work underway on using the new Android 3.0 release. We decided to not test the Nook Color more widely, simply because much of this work is at an early stage, and would have required too much customisation, beyond the scope of this pilot. The Nook Color (marketed as a book reader) lacks a number of features (such as a camera, or bluetooth). However, overall the Nook Color is a very interesting device, and is a promising platform for future investigations.

The Toshiba AC100 is an Android-based netbook. The cost is similar to a standard netbook, but it promises to be more robust, due to the lack of moving parts, such as hard drive or fan, and the good build quality, while being lighter than a standard netbook. We did not choose this device for our classroom trials because of the lack of “root access” and access to the Android Market, which meant we could not trial the applications we wanted to trial. While it remains to be see whether Android will give good usability on a device with this form factor, it would certainly merit further investigation.

We also tested the SmartQ v7. This inexpensive device has a resistive screen, and an early version of Android (1.6), as well as a version of Linux, and Windows (i.e. a triple boot). Devices like this are quite promising, as they may offer value-for-money solutions. Overall the 7” resistive screen, the early version of Android, and issues with supply to the UK meant that we decided to not test this device further.

Overall, we identified one of the few Android devices available at the time that combined both access to Flash and the Android Marketplace as being the Advent Vega tablet, and decided to take eight devices out for evaluation in Stage 2.

For Stage 2 we also trialled some wireless broadcast access points to allow teachers to provide resources from their own machines, acting as a local web server, which could address situations where the school cannot provide local networking or servers, or access to the internet is not available.

All devices were pre-configured to make start-up as painless as possible; to install and make lesson tools accessible in the user interface; and to reduce the likelihood of users re-arranging or deleting elements of the initial user interface (see Key Findings below).

Through the iSchool trials, we also had access to 150 Classmate-platform PCs (manufactured by JP Sá Couto), as well as the JP Sá Couto teacher laptop, and a Soekris low power server.

4 Key findings

The study, whilst directed towards specific technology use at the student and classroom level, further raises issues that relate to the classroom environment, methods of teaching, and also to the broader level of the school and wider educational context.

4.1 Technical findings

This section discusses findings relevant to procurement of equipment.

4.1.1 Device evaluation and specific challenges

Non-digital devices

The primary role of trialling the non-digital devices (calculators, stop watches, measuring tapes, white boards and blackboards) was to answer questions about the respective use of (and interaction between) specific and generic devices below. The mini white/blackboards stood out as being very effective and intuitively usable. Blackboards used to be used in the Zambian classroom, and the students enjoy using them for writing. They lend themselves to discussion, as writing can easily be erased and overwritten. They are intuitively used for holding up and sharing results with the whole class, but this pattern of usage is easily introduced. In terms of blackboards vs. whiteboards, it may be possible to manufacture blackboards locally (e.g. using blackboard paint), and chalk can be supplied locally. The whiteboards (as supplied in the UK) are cheaper, lighter, and are more easily wiped using the supplied sponges. The white surfaces scratch more easily, especially in the often dusty environment found in the schools we worked in.

Student using whiteboard for writing

Stop watches and calculators can be sourced locally in Zambia. The calculators are hard for teachers to integrate creatively, and they are mainly used to substitute for mental arithmetic, rather than to enable exploratory project work. Stop watches tend to be used for sports, however teachers also used them for data gathering in the context of maths lessons. The measuring tapes were also useful; it is also possible to make measuring sticks in other ways.

Sometimes, the simple, single-purpose devices like stop watches hindered lessons. The teachers thought the stop watches were difficult to use, saying the “learners face a lot of difficulties in stopping and starting them in the lesson” (Sydney). Overall, the teachers said they were “not effective” and that they “did not have much of a purpose” (Brian).

eBook readers

Generally speaking, the eBook readers (Kindle, Nook B&W, WikiReader, Nook Color) were not that successful at stimulating interactive activities in class. This is not that surprising as they are mainly a source of information. Teachers found it difficult to bring e.g. the WikiReader into the lesson fairly dynamically whenever a definition needed looking up. Moreover, the devices can be quite idiosyncratic to use (small keyboard/four-way switch on the Kindle, the touch area on the Nook B&W), and the students did not find this easy.

There may be a role for book readers in learning and teaching as a text book replacement, and there are projects exploring this, such as the WorldReader project using Kindles in Ghana discussed in Section 2.3 (Sundermeyer, Risher, & McElwee, 2010). One can imagine a scenario where a whole set of text books is made available through book readers. Potentially, a single book reader could hold an entire curriculum. In the case of standard book readers, books are formatted in the ePub format, while for a WikiReader the books would need to be prepared in a suitable format.[7] One would then have to evaluate whether this is more cost-effective and sustainable than getting paper-based books, and how the environmental footprint compares, taking into account how many books could be replaced by an eBook, bearing in mind that each book in a paper library can be accessed independently at any time (i.e. by more than one student), while access to an eBook library is limited by the number of eBook devices available (where only one student can use the entire collection at a time). We refer the reader to emerging work in this area (Sundermeyer, Risher, & McElwee, 2010; WorldReader.org report, 2010).

eBook readers have a number of properties that would make them suitable for deployment in scenarios with poor infrastructure, including small power consumption (due to digital ink) and daylight readability. However, our teachers did not report these as key advantages, and the lack of lighting can also be a disadvantage. Regarding power consumption, all of our schools had power for some part of the day on most days, meaning that battery life beyond a few days is irrelevant. The teachers did like that the devices were small, and one teacher enjoyed taking the Kindle online. The small form factor may also make it easier for a teacher to carry a device covertly without attracting too much attention. It may be that a low-power book reader could be supportive for professional development, and we will be exploring this in the future (see below).

[7] The WikiReader can in principle be updated with any texts. It currently does not display images, but this could be overcome.

The WikiReader had some usability issues, and despite being relatively simple in function, some teachers judged it to be too complex for lower grades. The batteries needed changing after a few months, but unfortunately we were not able to get comprehensive data on this.

Most standard book readers are fairly non-extensible, i.e. they are a proprietary platform that allows no user modifications. The exception to his are the Nooks, and in particular the Nook Colour. These are essentially locked-down Android-based devices, and for some devices (early Nook B&W and the Nook Color) the restrictions can be reversed, turning the book reader into a full Android device. We tested this with the Nook Color, and as commented above, the Nook Color is a very interesting device, and is a promising platform for future investigations.

Webcams as document cameras

The webcams that we had hoped to use as document cameras did not produce a sufficiently sharp image. Also, the concept of using a document camera is fairly extraneous to current Zambian teaching, so it was hard to introduce this idea.

Projectors

The battery-powered Optoma projectors (PK201, PK301 both 20 lumens on battery, PK301 50 lumens on mains) are not bright enough for use in Zambian classrooms. While use of battery power is attractive, currently it seems that projectors are not bright enough to support this. The mains-powered projectors generally worked well, and were bright enough, but there were some issues with over-heating for bulb-based projectors (Acer P3251, 2100 lumens). Projectors like the Acer K11 may be a good compromise (with LED at 200 lumens), and we were able to run it for a short period of time with an extra battery pack from one of the Optoma projectors. With a larger battery pack, this could be a viable solution, and it warrants further investigation.

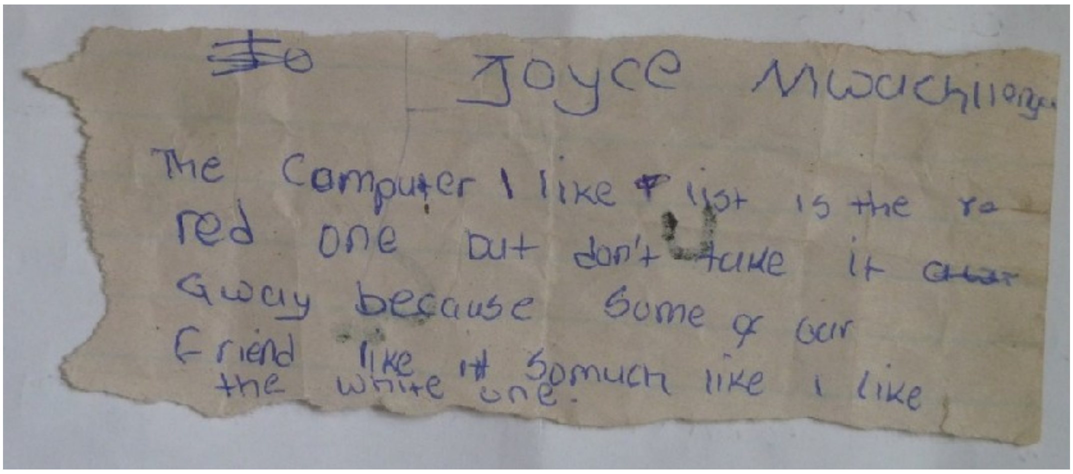
Robustness

Overall, there was relatively little breakage. The flaps on the micro-SD card compartments of the Kodak cameras broke on both cameras. While the cameras themselves are waterproof, the compartments do not have particularly robust hinges, and need to be left open while charging.

One laptop screen of a Lenovo S10-3t broke in transit, as the laptop had not been stored for transport. One Kindle was dropped from a table, landing on a corner of the device, breaking the screen. One pen from an X61 was lost.

The projector overheating was already mentioned, and the issues with the Advent Vega tablets are discussed elsewhere.

4.1.2 Laptop, netbooks, and tablets



In this study, we have opted to use mobile computing equipment, opposed to a fixed installation, such as desktop computers in a computer lab, as this is well documented to support classroom learning effectively (e.g. Becta 2004). Generally speaking, there appears to be little awareness and experience of the benefit of mobile equipment in Zambian schools. When ICT in schools is discussed, for instance within government or within schools, there is generally a push towards putting equipment into computer rooms. Educationally speaking we consider this to be outdated, and within the current project (as well as within iSchool) we are emphasising portable equipment. There are benefits to computer labs (such as security in some circumstances, but mobile equipment can also be made secure). A very significant benefit of mobile equipment is that it is meant to be battery-powered, which means that devices can be used irrespective of whether there is power during the lesson itself, and that equipment can be integrated into teaching without taking the children out of class, saving time and avoiding upheaval.

The full list of equipment explored was presented in Table 3. A number of devices were only evaluated through direct testing (Advent Amico, SmartQ V7, Toshiba AC100 and Toshiba Folio), while some devices were evaluated through classroom trials (Lenovo ThinkPad X61, ThinkPad Edge 15, Lenovo S10-3t, Advent Vega) as well as the ClassMate (through the iSchool trial).
The Lenovo ThinkPad X61, ThinkPad Edge 15, and Lenovo S10-3t were all trialled in stage 1 in order to make a decision for Stage 2. Initially the Edge netbooks seemed to be popular, due to the large screen size. Teachers thought that the large screen would help to demonstrate things clearly. However, they also commented that they were quite bulky and possibly difficult for the students to carry around. When the teachers were presented with a scenario where the cost of the laptop was factored in, teachers thought that a netbook shared between two students was better than a larger laptop shared between four. So while the large screen is advantageous, when the cost is taken into account, a larger number of smaller netbooks is preferred by the teachers. More equipment also provides more resilience against equipment failure. In terms of screen readability, in a range of conditions the Edge has best screen due to the matt finish and consistent brightness. Gloss screens reflect a lot. Least popular were the X61s, due to the track point input device.

Overall, like other Android devices tested, the Advent Vega stays cool, and has a relatively low power consumption. The most significant issue was that three out of the eight Vegas developed an issue with the touch screen. The touch screen became irresponsive, rendering the device useless. When those Vegas were taken back to the UK, the problem disappeared again. The source of the problem is unclear, but may be due to the higher ambient temperature. A similar failure was observed on one of the mobile phones tested, and the issue requires further investigation.

At the present moment in time, a netbook form factor device, such as the Classmate PCs in use by iSchool seems like a good choice, that both teachers and students are comfortable with. In the future, Android-based devices should be considered.

Teacher use vs. student use

We should also consider that the ICT requirements of a teacher differ from those of the students. In other words, a teacher laptop is not the same as a student laptop. A teacher laptop needs to be much more versatile, as it may be used for content preparation, content remixing, as well as personal tasks, and thus offer reasonable security feature. Also, as discussed below, a teacher laptop might also run a web server. Contrary to this, as discussed below, a student laptop above all needs to be simple, and allow the students to access activities as quickly as possible. The laptops and netbooks that were tested are all suitable for teacher use, as they are reasonably powerful and run a general-purpose operating system. Current Android-based tablets do not offer sufficiently comprehensive features for teacher use, for instance for content preparation.

In terms of the other devices tested, some devices may be more useful for teachers, rather than to directly support interactive teaching. For instance, the e-book readers may have interesting uses as part of professional development programs, but less so for students. While the students found the devices hard to use (and indeed the controls are not that straightforward), for the teachers however, this did not present a problem. Teachers found the devices small and easy to carry around, which for student use is a disadvantage in terms of security, while for a teacher it means they can be used without attracting too much attention.

Power requirements and consumption

The circumstances of Zambian schools regarding power are very variable. Some schools (particularly in urban and peri-urban areas) will have power for a number of hours each day, some schools may only have power for a number of days each week, while other schools (particularly in rural or deep rural areas) will only sporadically have power or will have no power at all. The degree to which devices can be provisioned depends on those different scenarios.

The schools we worked in during this pilot do have power for a number of hours on most days, allowing equipment to be recharged. Assuming that devices are only used at the school during the day, and can be charged at night, a sufficient battery life is of the order of one day. The laptops and netbooks trialled do not approach this, but Android-based devices such as the Advent Vega are coming close, although have not quite reached this yet. For a school that has a reasonable provision of power, Android-based devices could be a good solution, allowing maximum use of the equipment to be made.

For a deep-rural school, with very little or no electricity, it may be possible to develop an appropriate charging regime using a fairly large solar power installation, used in conjunction with low-power devices (such as Android tablets). Current technologies may not yet allow for this to happen cost-effectively, but further investigation is necessary. A possible future scenario might be to use very low-power devices (similar to book readers with electronic ink, like the Amazon Kindle), that last for such long periods of time that even class sets could be charged in turn, vastly reducing the need for solar power. However, at present, such devices do not allow for a sufficient degree of interactivity (see discussion of eBook readers).

One possible avenue for reducing power is through low-power screens, such as the Pixel QI screen, which we experimentally fitted to a Samsung netbook. The netbook already had an efficient LED backlight (consuming about 2.5W), which was was reduced the 0.5W (with PixelQI screen without backlight). The PixelQI screen is also daylight readable, which could have advantage in some scenarios.

Power consumption of the various devices used is detailed in Table 9.

> “During the first part of the lesson we experienced an electricity power shut down so we reverted to using the whiteboards and chalkboard” (Brian).

Table 9: Power consumption (Watts) while charging

Device	*X61*	*Edge*	*S10-3t*
At the start	53	36	30
After 30 minutes	35	30	30
After 1.5 hours	34	30	29
After 3.5 hours	34	34	30
After 5.5 hours	21	21	30

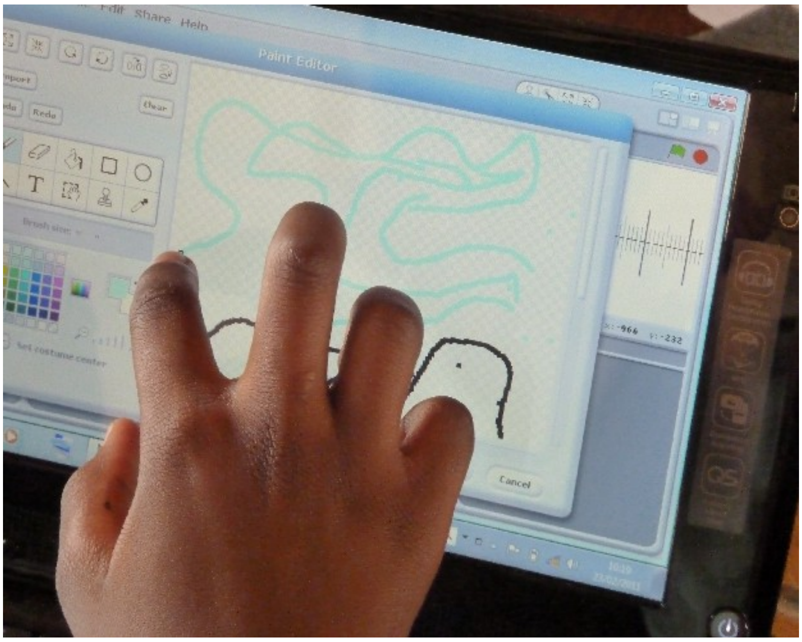
Input devices: Trackpoint, trackpad, mouse and haptics (touchscreen)

Generally speaking students learnt to use whatever technology they were exposed to, and different input devices did lend themselves to different tasks and grouping scenarios. A device that seems to be more difficult than others is the “trackpoint”: On some Lenovo laptops, such as the X61, the mouse controller is red rubber button located within the the keyboard. This was found to be hard for the students to operate and generally disliked.

Although the trackpads on netbooks are small, students soon got used to using the trackpad. This is a good general device, although on smaller netbooks it is given limited space and this presents problems for use in groups.

Mathematical tasks in particular benefit from accuracy. For example, identifying particular co-ordinate points, or cleanly identifying and linking points in a co-ordinate field take some precision. This could be solved easily by using a stylus (on resistive devices), however the pen is easily lost or broken and not found to be a reliable tool. The touchscreen does offer a workable solution to this problem, but again is somewhat dependent on the size of the finger using the screen.

Where the touchscreen really does show benefit is in the sharing and collaborative engagement that it fosters. Given a reasonable screen size (such as 10”), the touchscreen lets users work together, with no one student necessarily being in control.



A student drawing with their finger in scratch

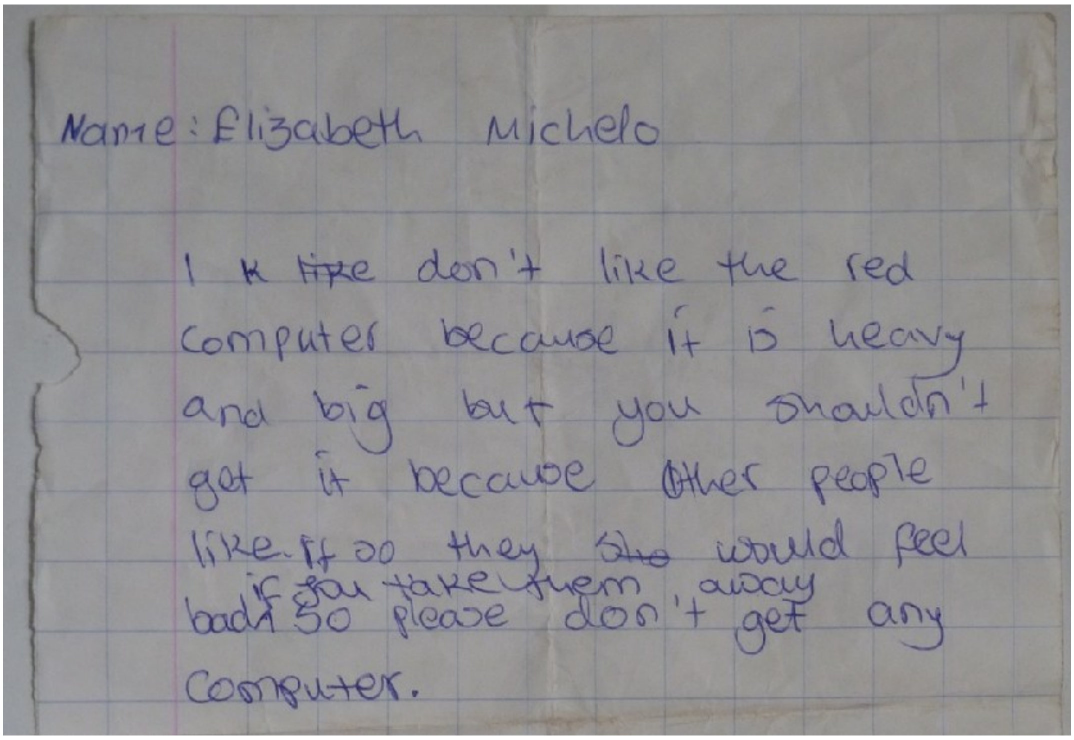
This worked extremely well on group problem-solving tasks, although the results observed were somewhat dependent on the size and age group of the class. Particularly where an application can be used from any angle, students can sit around the device to collaborate, and control is “decentralised”. After having made a move, you need to relinquish control by pulling your hand back, allowing different students to come in. This rapid swapping of control is hard to achieve otherwise.


Students reflecting on input devices (trackpad vs. touchscreen) when working in groups of 4

The students reflected on the use of touch screens vs. using a trackpad, and one student suggested that a trackpad, which gives students access one at a time, might help weaker students by giving them a chance to use the computer. This supports our research findings regarding “decentralised control” vs. a single point of access, and highlights that teachers need to ensure that students can access devices fairly.

Different groups have different attitudes to sharing, and perhaps older students tended to share less openly and at times seemed to be more concerned with asserting a dominance within the group.

The mouse does allows a certain amount of individual control over a task, and as a single input device allows a user to monopolise control of that task. Mice are easy to operate, but do require a flat surface next to the laptop. Desks are often sloping with little spare space. Initially students did find the mice difficult. For example, some used them rotated 180 degrees so that the pointer movements are mirror images on the screen, but again, these problems resolved after some use.



Name: Elizabeth Michelo

I ~~k like~~ don't like the red computer because it is heavy and big but you shouldn't get it because other people like. if so they ~~she~~ would feel bad if you take them away so please don't get any computer.

A student states their preference: "I don't like the red computer because it is heavy and big but you should't take it (away) because other people like (it). ... They would feel bad if you take them away, so please don't (take) any computer."

Form factor, device size, screen size, and group size

One important question is how device and screen size relates to the effective group size to be used with this device. Clearly there are situations where one device per student is preferable, but in many scenarios, particularly for project-based work, groups of two to four are actually preferable.

Teachers reported that groups of two to four can work well. In larger groups, students start to be left out. A larger screen helps with groups of four, but in practice groups of four managed to work even with smaller screens. A good scenario that was also trialled is to work in groups of four, but with two devices per group.

Students also self-reported that groups of three to four are best for discussion. Students in principle say that larger screens are better for sharing, but in practice are happy to collaborate up to four.

We concluded that in a range of scenarios groups of four would be workable, while groups of two to three are more desirable for some tasks. If a school owned say 40 devices, they could be used either in groups of two in a class of 80, or in groups of four in two classes of 80, depending on the task at hand.

"Groups of three .... it is easier to do it in a group of 3 or 4 so that you can be easier to share ideas. Each one can have ideas. 3 or 4 is better than two. 6 in a group is too much people... When we are in a group of 4, it is easier to see properly." (Rebecca)

Children at Chimwemwe sharing tablet

4.1.3 Blend of equipment: General purpose vs. specific devices

Zambian schools may lack very basic resources, such as furniture, but in particular may also lack teaching resources, such as books. Having more resources (of varied kinds) is useful for schools, and enables teachers to create more varied learning experiences.

In this project, we were concerned with inquiry-based approaches, and we needed to consider that for engaging with project work, students need more resources than just computers. For instance, to do a digital project using measurement, measuring tapes are needed. Moreover, some resources facilitate a more interactive learning experience per se, such as mini whiteboards or mini chalkboards. Among all the equipment used, the wipe-clean mini whiteboards probably had the most positive impact, and at the same time are the cheapest. They also allow sharing, and (e.g. see picture of Richard with his peers) drawing to explain processes shown on the laptop screen. Mini whiteboards (or mini blackboards), as a supportive device, cheap, can be used in any lesson, and are intuitive to use. We recommend these as a must.

Richard interacts with group

Students holding up whiteboards

Another device that was very useful was the cameras. Extended project work can be built with this. In principle computers have got cameras too, but actual cameras are easier to use. One of the head teachers spoke about impact on community, when children go into the local community with cameras, through which interactive learning becomes visible to the community, and the school standing is improved. It is interesting to note that the use of the cameras never turned into lessons about how to use cameras, unlike the use of laptops, where teachers definitely thought that students needed instruction first. Of course there are arguments for and against formal instruction in both cases, but generally the exploration of the cameras was left to the students.

Calculators are generally welcome, but use tends to be as substitution for mental arithmetic. When this was challenged, one of the teachers pointed out the multiplication tables on the backs of some exercise books, stating that such traditional practises were equally non-interactive. So while calculators are cheap, they do need to be introduced with some care.

We also point out that different technologies are appropriate for different ages, and that some of the simpler technologies were more successful in lower grades. However, with suitable care, netbooks can also be used efficiently in lower grades, as the work of iSchool shows.

4.1.4 School-based wireless networks and Internet availability

Interactive teaching often requires digital resources. Managing student access to such resources, as well as teacher access to such resources, is an interesting problem. It would be naive to consider “simply connecting to the internet” as a complete solution to this complex issue.

Often an internet connection is not available, or not consistently at least. Where the Internet is available, it is prohibitively expensive, and often VSAT or 3G are the only options, and there is no educational pricing. This is combined with the fact that there is a strong demand for data: As part of the iSchool trials, schools have been provided with commercial connections, which often see use of several hundred MB per school day. In general, direct connection to the internet like this is not sustainable or practical. The teachers strongly advocate having access to the internet in the schools so they can, for example, “do more research on topics before teaching” (Abel).

One of our schools (Chalimbana) was not connected to the internet, while the other one (Chimwemwe) does have connectivity. We discuss both scenarios in turn.

At Chalimbana, teachers are able to download resources at the nearby teacher education college. Otherwise teachers may be able to use an internet cafe, or infrequent visits to a nearby town. At a classroom level we have already explored the use of local networking by running a local web server, using XAMPP combined with a compact ASUS wireless access point to enable a web server to serve files to client machines. This method allows resources to be made available easily, with the added subtlety of being about the serve only those files relevant to any salient point within a lesson thereby allowing further structure to that lesson.[8]

Expanding this paradigm would see wireless networking enabled at the school level. A far greater number of resources could be made available to the school as a whole, allowing consistency of teaching resources across classes.

Naively, one would think that such local provision would be made redundant by an internet connection (which brings us to the scenario at Chimwemwe). However, even there, local servers are being introduced to meet the requirements of serving e-learning materials, including graphics and video files. One suitable solution for this is the use of low power servers, such as the Soekris net5501. These extremely low powered devices enable significant amounts of data to be stored and served at a fast local level. If further combined with Internet access, then resources and further data can be downloaded and cached during off-peak hours, and allow a continuity of service during the school day.

4.1.5 Operating systems

Operating systems available off the shelf are primarily aimed at a single, reasonably computer literate user, who is able to carry out small-scale updates and installations as and when he or she needs it. When devices configured in this way are deployed in institutions (such as schools), management becomes unwieldy very quickly.

The ability to customise equipment in bulk is an important element in institutional deployments. An institution would want to take a basic product, such as a Windows or Linux-powered netbook, and customize it to their individual needs. However, that customisation takes time, skill, and resources outside of the initial purchase cost of the ICT. For school use, it is imperative that such management of equipment can be done effectively and in bulk.

There is a trade-off here between Open Source operating systems (e.g. Ubuntu) and commercial operating systems (such as Windows). While staff are often more familiar with commercial options, Open Source operating systems do allow programatic replication without needing to worry about licensing.

[8] Given that those resources are served from the teacher laptop, it has the additional advantage of having power from battery, similar to the student laptops.

Among established operating systems, such as Ubuntu or Windows XP, there is generally no significant difference in use as far as applications are concerned: Once an application is loaded, the students are generally unaware of what operating system is used. However, there are differences in usability of the operating system itself. On Ubuntu, it was reported that application are often "missing", or even that "all applications are missing", when in fact the Ubuntu applications menu just has a slightly deeper structure.

Our work shows that there are two components that help students find applications:

- applications appearing as symbolic links on the Desktop, and
- frequently used applications appearing on the top level of the applications menu.

Many Windows-based applications are accessible in this way, which is a benefit, while under Ubuntu applications are generally not available like this. This is easily customisable, and we recommend that this is done.

Both Windows and Ubuntu operating systems have significant flexibility in terms of menu customisation, which (in student accounts) needs to be locked down in order to maintain a homogeneous working environment for ease of management.

Given the similarity in terms of use for students, other more operational considerations thus play the determining factor. As mentioned above, due to its non-proprietary nature, Ubuntu environments are easily "clone-able" across devices, making it easier to set up full class sets. Windows 7 on the other hand is tied by its license to the machine it is installed upon. Ubuntu almost never suffers from viruses or other malware. On the other hand, there are numerous instances of computers running Windows and Internet Explorer across Africa which are riddled with unwelcome software, making computers and networks insecure or unusable. On the flip side, Linux-based systems such as Ubuntu are often slower to catch up with the latest hardware releases, largely due to hardware manufacturers not seeing an economic incentive to cater to the smaller Linux-based market. This factor was noticeable in Stage 2 of the project, when the Lenovo S10-3t machines proved to have erratic trackpad usage under Ubuntu.

As a new operating system, we also evaluated Android 2.2. Android is a lightweight open source operating system, initially developed for mobiles phones, but increasingly used on tablets. Given "root access" to a device, an Android installation is simple to replicate. For instance, re-installation of a modified distribution took less than 10 minutes per tablet, and can be fully automated. As an open-source operating system, there are no licensing constraints.

At present there are a number of disadvantages to the use of Android, including the lack of a wide range of educational applications. There are a number of games that can be used effectively, but other applications, such as office-type applications, or Geogebra and Scratch are either at an early stage of development or not available at present. In Android 2.2 there are a number of features that are currently not ideal for tablet use, but this is expected to improve with Android 3.0.

There were also issues around the software keyboard, which is tricky for interaction with flash. Keyboard-based data entry in Flash applications and games can be difficult because the software keyboards "slides" onto the screen, altering the layout of the page and flash object. At times, it was not actually possible to enter text into Flash applications, or only to do so when an external USB keyboard was present.

However, devices running Android 3.0 should be reconsidered, as it may bring improvements. Items to be investigated would be a suitable suitable onscreen keyboard (with special characters easily accessible for maths typing) as well as external keyboards and docking stations. If the devices can use a standard USB keyboard, then it may be possible to produce simple docking stations in country, essentially consisting of a standard USB keyboard and a holder for the tablet.

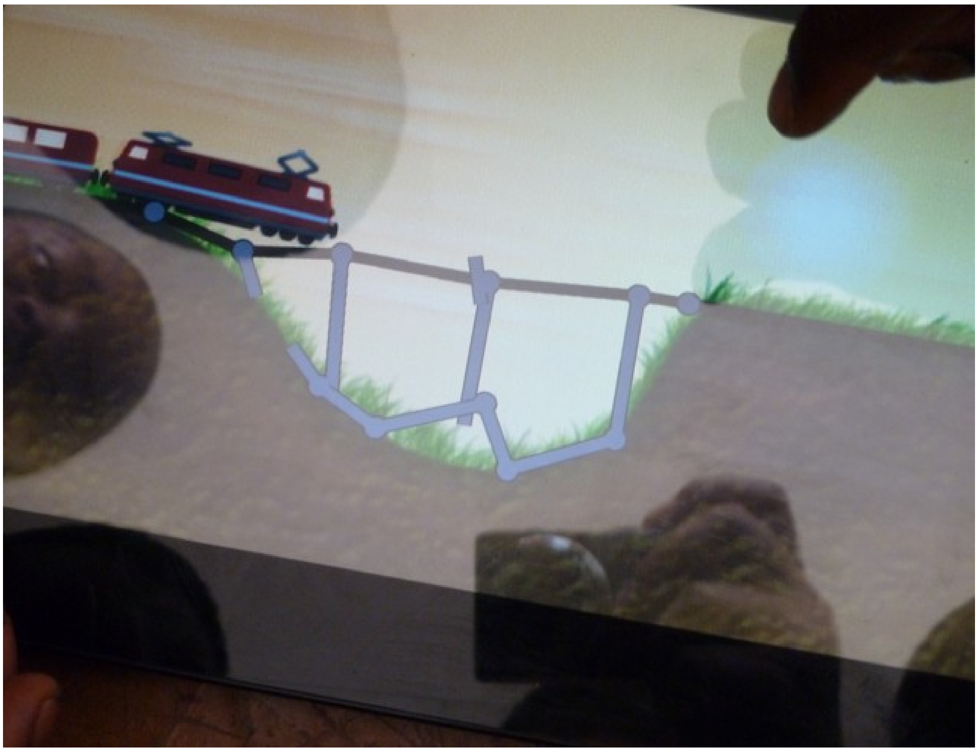
4.2 Supporting interactive classroom teaching

4.2.1 Overview

We placed particular emphasis on using the computing equipment to support interactive teaching and learning. Our fieldwork therefore investigated which devices could successfully support interactive teaching and create an environment conducive to learning. The intervention was too short to actually measure learning although we have some observations and teacher reports of students making progress during a lesson. As the teachers were getting to grips with brand-new technologies, novel teaching and learning resources, and were still in the process of developing an interactive teaching style, we inevitably had to provide a lot of support. This included suggestions for resources to use with the devices, ways of using them, questions to ask the students, etc. in addition to technical support. (Teachers themselves devised the activities where these were not predetermined by the resource and they formulated the student groupings.) Our conclusion was that under these conditions engaging and pedagogically interactive lessons can take place although it is of course not guaranteed. Some teachers continued to use a lot of closed questioning for example; further professional development in the area of interactive teaching is required and is planned for the parallel OER4Schools project.

To encourage open-ended activities, we drew on simple games and applications used in primary and secondary education in the UK and US (in particular Scratch and Geogebra). All of these were open source and usable at low bandwidth and selected to evaluate the (technically and pedagogically) interactive potential of the devices. Below we draw on the lesson observations to describe three of the (four) most interactive lessons of the seven we observed in Stage 2 in order to illustrate some potential uses and values of the chosen devices. Other games used but not featured in the highlighted lessons included:

X construct. (http://twitter.com/crossconstruct, https://market.android.com/details?id=de.hms.xconstruction). The objective is to build a railway bridge across a crevice, using a number of bars. Once the bridge is built, the user runs a train across the bridge to test for the stability of the construction. Level by level, the crevice gets wider (and more bars are available to cross it). This activity proved engaging but it was used only by a few pupils who had finished their work, thus we do not describe it in detail here.



Students let train run in X Construct

Fractions pairs game (http://www.bbc.co.uk/skillswise/numbers/fractiondecimalpercentage/comparing/comparingall3/flash0.shtml). Brian found this online pair matching resource himself; it requires the user to match a fraction with the corresponding decimal or percentage and gives feedback about correctness.

4.2.2 Abel's Grade 7 Scratch lesson

Resource. Scratch (http://scratch.mit.edu/) is a Logo-like programming environment that makes it easy to create your own interactive stories, animations, games, music and art. In creating a Scratch project there are important mathematical and computational concepts to learn, whilst it also offers a framework in which to think creatively, reason systematically, and work collaboratively. A simple, but powerful, application of Scratch in this lesson (the second of two related lessons) was using it to explore the numberline, manipulating a dog sprite to perform the actions.

Technology. 9 Lenovo S10-3t tablet-laptops used in laptop mode, 3 X61 laptops and 3 Edge laptops, plus the teacher's own laptop linked to a projector and used by both teacher and students for demonstration to the whole class. Students worked in groups of 2-4 to a machine.

Lesson objective. To learn about the number line, and correspondence between "real world actions" (walking backwards and forwards) and addition / subtraction using the numberline. To learn how instructions in Scratch correspond to mathematical operations (such as: “Repeated moving forward is like addition. In future lesson: “Looping moving forward is like multiplication”).

Research aims. To explore use of touch screens. To explore the practicalities of project work extending between lessons and using a local wifi access point and web server technologies (XAMPP) to distribute prepared resources.

Abel displaying 2+2 on a whiteboard

Lesson overview. This lesson started late after a visit to the head teacher’s office; when the researcher and teacher returned to the class, they were astonished to find that the students had autonomously helped themselves to the computers, distributed them equally around the room (two per table), started them up and found their way back into Scratch which they had used for the first time in the previous lesson. (Note that Scratch was only introduced to Abel on the previous day too.) Half of them had used the desktop icon, and half used the top level Start menu to access the resource. The students were engrossed in their activities and resisted the teacher’s attempts to distribute more machines and to break up the groups spontaneously created.

Students were asked what they had learned during the previous lesson, and they demonstrated this in turn (how to move the cat sprite forwards and backwards, make it “cry”, etc. Abel then demonstrated addition using the dog sprite to move along the numberline. The students’ task was to do the sum (10 - 20 + 50) and to represent it graphically. Students worked in groups on this and most were successful. At the end the class packed away the laptops but some groups did not stop!

The students were highly engaged and the lesson exposed the open nature of the Scratch resource, allowing interactivity in teaching style.

The lesson shows that project work could usefully extend across a number of lessons, and that students remained engaged. Distributing resources via a wifi access point was an efficient way of getting resources to student laptops. Once teachers and students get used to this, it is likely to work very smoothly indeed.

4.2.3 Sydney's Grade 9 GeoGebra lesson

Resource. GeoGebra (http://www.geogebra.org) is a very powerful multi-platform dynamic mathematics software for all levels of education that joins geometry, algebra, tables, graphing, statistics and calculus in one easy-to-use package. It now offers dynamically linked multiple representations for mathematical objects through its graphical, algebraic, and spreadsheet views. It is available in 45 languages and has received several educational software awards in Europe and the USA. GeoGebra has hundreds of thousands of users worldwide, and they have shared thousands of free applets and worksheets via the GeoGebraWiki (http://www.geogebra.org/wiki) website.

Technology. 9 Lenovo S10-3t tablet-laptops used mainly in laptop mode, 3 X61 laptops and 3 Edge laptops. Students worked in groups of 4 to a machine.

Lesson Objective. To learn about coordinates in the plane A=(5,3), x=5 and y=3, i.e. the relation between points and their (x,y) coordinates. To learn that the point (a,b) is the intersection of x=a and y=b.

Research aims. To investigate the use of a complex and open-ended mathematics environment (Geogebra).

Lesson overview.
Students were initially asked to show the coordinates of a point on the mini whiteboards. Only about half got it right. They then spent quite a bit of time on an exercise in GeoGebra. There were no particular GeoGebra file loads; students just placed points and lines in the XY plane, trying to relate numerical coordinates to location of points. We noted that the students had been given the Lenovo & X61 computers with the screens folded down (tablet mode), but some turned the screens upright (netbook mode).

Girl uses little finger to draw line through 2 points in Geogebra

Students were asked to answer the question "What is the relation between the point A on the plan, and the numbers 5 and 3?" [Answer: (5,3) are the x-y-coordinates of the point A.] Some diagrams and answers began to emerge as they explored the software. One group of students had the answer written on their mini whiteboard, but they had not drawn any points. Another group's tablet showed lots of points; for another group questioning revealed that they had figured out that the point in relation to the numbers 5,3 was something to do with lines (i.e. x=5, y=3), but they could not quite work out which line, and kept drawing lines from the origin to point A. Finally a reasonable proportion of students managed to draw the right lines and to explain their answer. One student, Richard, seem to have understood this best, and he and another student were was asked to circulate to help peers. Other groups later managed to find additional points on the line.

The majority of students appeared to improve their understanding and some were ultimately able to articulate to their peers what coordinates were, as illustrated in the lesson video [see it in collection at http://sms.cam.ac.uk/collection/1087359]. Although students had been exposed to (x,y) coordinates the previous year, Sydney was very surprised that the students managed to answer the question correctly. Despite teacher expectations, then, the students managed to use the software successfully, and the lesson content fitted well into the curriculum. This lesson also demonstrated how group work promoted use of local language.

4.2.4 Brian's Grade 7 Un-Block Me lesson

Resource. The objective of Un-Block Me (http://www.quickflashgames.com/games/unblock/) is to move a red brick out of a rectangular space by moving other bricks out of the way (some can move horizontally, some move vertically). It requires players to develop strategies for moving bricks in turn so that sufficient space is created for the red brick to be moved, arguably developing spatial awareness. This resource was actually selected at the last minute because no electricity or internet were available to support use of the online iSchool resource that had been planned, and the resource had been loaded onto the tablets in advance.

Technology. Advent Vega multi-touch tablets; 3 out of the 8 had unresponsive screens, so only five were used. Students worked in mixed ability groups of 4-5 to a machine; the teacher had planned – and preferred – to use two netbooks per group of four.

Lesson Objectives. To become familiar with tablets; to collaboratively formulate strategies to solve 2D puzzles.

Research aims. To assess importance of tablet form factor in supporting collaboration.

Brian's classroom; children awaiting instructions for Un-Block Me.

Group playing Un-Block Me.

Lesson overview.

The students found the activity highly engaging and played the game solidly for 1.5 hours, going well over the expected lesson end time. In a subsequent interview they stated "the game makes you think fast". They were encouraged by the teacher to teach each other about computer use and he commented that one group worked quickly in this lesson because they had had much more exposure to computers. The teacher reported that some students were initially afraid to touch the screens as they were unfamiliar with a touchscreen.

The lesson video [http://sms.cam.ac.uk/media/1120700] illustrates fluid multi-user interaction and turn taking. The activity clearly encouraged teamwork although there was some evidence of working towards a common goal without discussion too.

The game can be viewed (and played) from any angle, thus students can collaborate 360 degrees around the device. We observed that the 10” surface was big enough to accommodate up to 5 and as it allows interaction on that surface, rather than on a mouse pad, control is “decentralised”. Once you have used the screen, you need to pull your hand back, to clear the view on the screen, thus after you have made a move, you need to relinquish control (or when you are “idle” you cannot have control, as you can with a mouse/trackpad/stylus). We also observed that students were at times moving blocks alternately. This would not have been possible with a single interaction device, thus a capacitative touch screen was of real benefit here (rather than just a resistive touch screen).

4.2.5 Teacher perspectives

The findings in this section and the next one derived from analysing the self-report survey and interview data. Other demands on the teachers’ time meant that responses to the surveys varied enormously in the level of detail and in how informative they were; not all sections were completed and some comments were very brief or general. In some cases text was duplicated from the previous survey.

The teacher perspectives about the degree to which uses of the mobile devices facilitated collaboration, student learning and engagement were unanimously positive. They typically reported that students were very interested in the activities, “excited to use the resources”, “everyone wanted a go on the equipment” and students were reluctant to finish the activities and hand the equipment back. The survey item asking teachers to mention a good point about the lesson led to responses such as “all was well since each understood the lessons and did the activity as expected of them” (Brian). They occasionally reported specific learning gains: “After I gave them the Wikireaders, they were able to distinguish between a bird and a mammal” (Eness).

Several teachers commented on how children had been able to work independently, which they are not normally expected to do. Except when group sizes were too large, for instance when 6 children fought over a wiki reader (!), teachers considered that the equipment very effectively encouraged collaborative work: for example, “students worked in an interactive group where all took turns to answer questions”, although some copying of answers was reported. Abel described how introducing group work reduced teacher talk, freed the teacher from the front of the room, enabled peer tutoring and provoked productive discussion (which our work for OER4Schools indicates previously would have been considered “noise” in the negative sense):

> “When students were showing each other place values this made me talk less.”
>
> “When pupils were able to plot integers on the numberline using whiteboards individually, it gave me time to go around and check their outcomes.”
>
> “When I divided them very well and chose "teachers" of each group. To this I was very happy seeing students teach others and this brought positive "noise" in class situation.

It also encouraged peers to help each other:

> “They were able to make amendments and correct one another during the time of entering their measures in the spreadsheet” (Sydney).

Occasionally teachers reported on pupils sharing and comparing their ideas or the findings they obtained from computer work, and reflecting on these. For example,

> “From the task given, pupils gave a variety of responses as to what the average was. This rose curiosity and discussion, and at the end, they reached a consensus.” (Sydney).

4.2.6 Principal perspectives

The principals were enthusiastic too, and keen to expand the project to include more teachers and more equipment. The principal at Chalimbana asserted that both teachers and children had acquired technology skills that were very important in today’s “world of computers”. She considered that “the students were learning and the aims of the school were met”, likewise parents had been very appreciative of the new opportunities for their children, who previously had no access to computers at school. She also had some concerns however:

> “The pupils weren’t conversant with the computers, so the teachers were taking a lot of time to teach one concept. Because of time, teachers were not covering all the subjects that we teach in a day. And I am sure that some pupils had a language barrier, failing to express themselves properly in English.”

The principal had been inspired to get further training for her teachers and had approached the adjacent teacher education college; she recognised the need for pedagogical as well as technical input:

> “The college is ready to educate the teachers in computers. So I talked to the college person and they sent us some forms. That’s why we really need this project. They will be computer literate quite all right, but how to use it in the classroom.”

The principal of Chimwemwe (an iSchool already equipped with some netbooks, desktop computers, and internet) described the impact upon teachers, learners and the community, from his perspective:

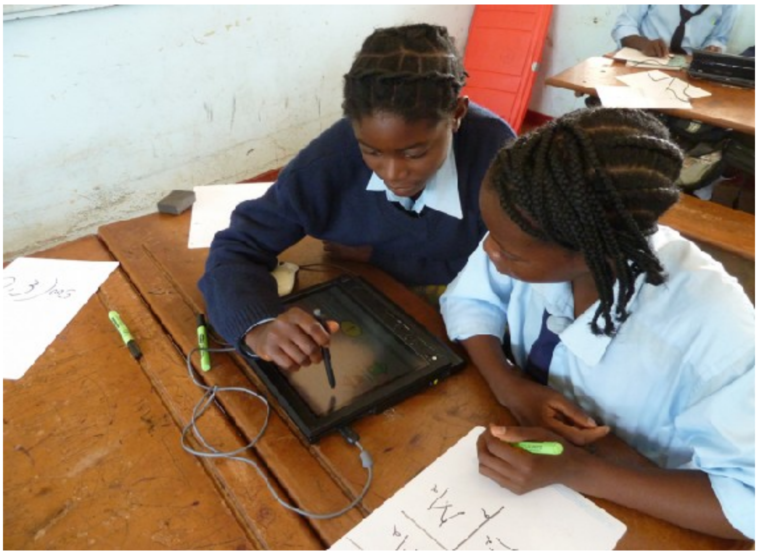
“The children see a different picture, it has helped the teacher to be alert [because] almost the whole time when the teacher is teaching, the child is able to see everything on the screen. At least the teacher and the children are moving at the same pace. Even the children are now alert, a child that just wants to hide, everybody is looking in front, even that child now will be alert. And interest again has grown.

The teachers want to give [the children] the best, it has developed their sense of self-worth, they are also able and considered to be like other people who are well to do, like other schools that are paying more, more educated with more facilities.

This school because of these gadgets, the attitude of the community has drastically changed. Now they are linking this school with better schools in Zambia. So they are bringing their children here. [Grade 1 numbers have increased this year] because the community have said “let us take our children here, they can learn better than at other schools”.

Not only the laptops, these children have been given a camera, “can you go into the compound”, people see these children in groups with the camera, ask “what is this”? Parents see that there is a projector in class. It’s not just the laptops. Whiteboards, spellings. Can you write this word in three seconds, can you all lift up who has written correctly in three seconds. All these had a part to play.”

4.3 Gender, socio-economic background



Girls working together

There are no differences specific to gender, observations, and reports from students and teachers indicate that in actual device use, there are no differences. When using a device initially, the boys are happier to just get going. This seems to be because they have some exposure to video games. One can pay a small amount of money at the market to use video games for a period of time, which is predominantly taken up by the boys. However, these differences had only a minor impact on the actual use and most teachers reported that both sexes showed interested and participated equally in the lessons and discussions using ICT. Typical comments included:

"As a teacher, I don't see any difference because I treat them as one." (Brian)

"Boys dominated the use of the computers though they all participated equally" (Sydney).

"Boys are more into video games than girls. I think boys use the equipment more than the girls. But they all want to use it, it's just that the girls don't really know how so they let the boys explore" (Abel).

"The girls think the devices are for boys. It all depends on the type of activity you give them. If it's something to do with drawing, you will find both boys and girls doing the activity. But girls are more into activities like typing, whereas boys would rather play games. Boys like things like mazes, moving from one place to another. Girls would rather tell a story, and then type it out" (Abel).

Differences in socio-economic status (SES) are there, but generally less pronounced than levels of "exposure". Taking a culturally sensitive perspective (Tillman 2006) in interpreting what the teachers told us about wider cultural influences, we now take a more nuanced approach to SES.

Exposure encompasses more factors, including how long children have been at a school using computers, access to a computer at home or in the community, and so on. The term “exposure” is used in different ways at different schools, but generally refers to whether a child has encountered a broad range of influences. At Chimwemwe, this primarily means whether the child has encountered computers before (either at Chimwemwe or at another school), but there do not seem to be large differences in economic background. However, at Chalimbana there are also economic differences that contribute to “exposure”, with some parents primarily relying on temporary labour (“piece work”), and others being employed at the nearby college. However, “exposure” can also come through non-economic factors, such as a parent working on a “white man’s farm”, with their child having some contact with the extended household, meaning that they may speak English better than other children. Overall, students who have been stimulated through a range of different environments (“exposure”) are generally likely to be better at speaking English and articulating their thoughts. This affects the degree to which they understand lessons in English, and in turn has an effect on their approach to participation in lessons and to use of computers.

When asked about what made some students more familiar with computers than others, the teachers said it had to do with their background: “Most of them come from a very poor background, where neither parent has ever touched a computer before” (Brian). This disparity complicates the integration of ICT, where some students have had exposure previously and pick up computer skills quicker while others need more exposure to catch up.

Other challenges that teachers identified from the lessons included:

- It was difficult “to encourage pupils to express themselves in English and freely” (Sydney).
- Sometimes the teachers “could not engage pupils to further discuss topics after a good introduction due to the language barrier” between English and the local languages (Abel).
- Though the equipment supported discussion in class, it did so for “only those that can speak English” because students with weaker English skills were unable or lacked the confidence to discuss with the whole class (Abel).

4.4 Conclusion

All of the six participating teachers were extremely positive about their experiences. They asserted that uses of the mobile devices facilitated collaboration, student learning, motivation and independent working. The principals described the beneficial impacts upon teachers, learners and the community. In the most interactive lessons at least, the students found the activities very engaging on the whole, although limited proficiency in English was an obstacle to participation of some. We also identified some barriers to successful classroom use:

- devices can be difficult to use
- insufficient equipment or internet access
- difficulty in finding suitable online resources
- power issues
- language/culture barriers
- time constraints

As the teachers were getting to grips with brand-new technologies, novel learning resources, and were still in the process of developing an interactive teaching style, we inevitably had to provide a lot of support. This included suggestions for resources to use with the devices, ways of using them, questions to ask the students, etc. in addition to technical support. Our conclusion was that under these conditions some engaging and pedagogically interactive lessons can take place although it is of course not guaranteed.

On the technical front, the recent advent of compact devices running Android posed an exciting opportunity to trial these in a new context. We found them a bit limited since a widely used version of this operating system (2.2) available on tablets is geared towards smaller screen sizes, and they have access to a limited range of applications. Although the multi-touch tablets are an evolving technology that brings teething problems with it, in certain ways they were pedagogically more successful than the netbooks though. Particularly where games could be viewed (and played) from any angle, students could collaborate 360 degrees around the device. We observed some fluid multi-user interaction, turn taking and teamwork, illustrating the potential value of the mobile technologies in this context, and confirming the findings of Alvarez et al.'s (2010) study with university students.

Tablets are limited for text or data input however, and suitable onscreen keyboards or docking stations need to be considered, where a keyboard is helpful. The swivel screen models we trialled combined the advantages of both modes of use but were more costly, and are thus not a viable option at present. The Advent Vegas take a USB keyboard very easily though and drawing on local craftsmanship, these could easily be turned into cheap docking stations, potentially giving the best of both worlds. Finally, distributing resources via a wifi access point proved an efficient way of getting resources to student laptops where schools had otherwise limited or no connectivity.

Dissemination. The project findings are being disseminated in the immediate future via presentation at:

- a joint Humanitarian Centre and Centre for Commonwealth Education ICT4D Mobile Learning event, Cambridge, March 2011;
- the international *Computer-Assisted Learning Conference*, Manchester, April 2011;
- e-Learning Africa conference, Dar es Salaam, May, 2011;
- UKFIET Conference, Oxford, Sept 2011.

5 Recommendations

In this section we offer some advice for teachers, school administrators, and education ministers on how to choose the best technology systems, and to support their effective and sustained use.

Teacher development opportunities are essential. When first exploring new ICTs, teachers both in the UK and in Zambia tend to use technology as a one-to-one substitution for non-ICT-based activities (such as students copying from the projector replacing copying from the blackboard), rather than to promote inquiry-based learning (such as using open-ended ICT-based activities to develop problem solving skills). In order to take advantage of the ICTs in this way, professional development opportunities need to be provided, such as school-based workshops, peer observation and discussion. Although this was not the subject of the present pilot, it is advantageous to take a whole-school approach, working across all teachers, grades, and subjects. Depending on capacity, this could be rolled out gradually. (This is the focus of our ongoing OER4schools work.)

A holistic approach to inquiry-based learning. ICTs are not, and should not considered to be, the sole resource for inquiry based learning. They do not replace non-ICT-based tools, but rather are integrated into an inquiry-based learning landscape. When using ICTs, for instance for project-based work, other resources are needed, such as measuring tapes, counters, boards for writing. In creating inquiry-based learning environments, we thus have to take a holistic approach, and create environments with a range of resources. We also need to bear in mind, that non-ICT based project work is possible, and that we can support teacher to do so with tools that are very cheap and can be ubiquitous in a school (such as mini-blackboards) for a fraction of the cost of the ICT installation. Thus it makes sense to introduce such non-digital tools (with appropriate pedagogies) alongside the introduction of ICTs. For instance, in a school with 1000 students, each student can be given access to mini-blackboards for the cost of a small number of netbooks.

To be successful ICTs need to be integrated into project based or curriculum based activities. This ideally means connecting with the “real world” in some way. Imagine a project that is graphing the growth of plants. The ICT brings a rich experience with the use of spreadsheets and graphing. But if the entire budget was spent on ICTs and none was left for cheap non-ICT resources like tape measures then the ICTs lose their interface to the real world.

Mini-blackboards are interesting in this regard. These blackboards can be used in project-based activities to provide a bridge to the ICTs. Moreover inquiry-based and collaborative learning with ICTs can be supported with these inexpensive non-ICT tools.

Enable ICT-ownership through microfinance. Generally Zambians, like most of us, are keen to have access to and own ICTs if possible. Teachers often are enrolled in higher education (for instance by distance), and being able to use ICTs as part of the studies is an additional incentive for teachers to own ICTs. Teachers in government schools also have government contracts, with (at least in principle) regular incomes, and there is a degree of disposable income. We recommend to enable ICT-ownership through a microfinance scheme, supporting teachers to upskill themselves.

Possible classroom deployment ("right now, 2011"). Based on the current pilot project (with limited scope), we make the following recommendations regarding purchase decisions. We recommend purchasing a blend of equipment, consisting of

- Mini blackboards (or mini whiteboards as appropriate, ideally school-wide, at least a class set)
- One teacher laptop with wifi hub (for small deployment)
- One projector
- Student netbooks (maximum group size 4, for instance at least 20 for a class of 80)
- Trolley for transport, storage, and charging of netbooks

The teacher laptops should be configured with an an environment that teachers are familiar with, and while Ubuntu is the preferred option from a maintenance point of view, Windows should be considered as an alternative, if the teachers can draw on an existing support network. The student netbooks should be configured with Ubuntu, to keep the environment as rubust and easy to maintain as possible. In terms of cost of student netbooks, it is possible to procure netbooks for less than $300 per unit. Netbooks with swivel screens are useful but expensive, so at present laptop form-factor is recommended.

For larger deployments, especially with internet connectivity, provisions need to be made to manage resources and bandwidth carefully.

Consistent environments for student computers. We recommend that student netbooks are set up with Ubuntu, with the following provisions:

- Student accounts need to be restored to default state on each login. (Students files should be moved to documents location, and automatically be deleted after a period of time.)
- Lock down panels, so that students cannot unlock them
- Superfluous elements (such as the calendar) should be removed, as they tend to be distracting, and get the students stuck.
- Distracting notifications (such as virus warnings, requests for updates, etc) need to be disabled in student accounts.
- Login should be password less, wifi should connect automatically, enabling the machines to just be turned on.
- The default web browser should be configured with a default address, for instance on the local network, that allows students to access their lesson materials in a single click. (If there is only a single classroom set in use, the starting page could be the resource page itself, otherwise the students should just need to click on the name of their teacher, the title of the current lesson or similar.)

Future classroom deployments ("post 2011"). Technology changes quickly, and future deployments will need to take new technological developments into account. At present, it seems that tablets running Android could be a suitable solution for student laptops. Touch displays do support interactivity and collaboration, but for accurate use (e.g. for mathematics) a stylus may still be needed.

Increased networking and collaboration. Further work towards developing a network of interested stakeholders to facilitate discussion around ICT use in primary schools in Zambia is needed. Potential stakeholders include government (such as the in-service teacher education department at the Ministry of Education), schools involved in the fieldwork, higher education institutions (such as the Institute for Distance Education and the School of Education at University of Zambia), and other initiatives and organisations (such as iSchool.zm themselves). Our plan is to continue networking meetings and to expand the number of interested parties. Our attendance at the prominent e-Learning Africa conference in Dar es Salaam in May will provide an important opportunity here.

Students investigating together

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Appendices

Appendix 1: Interview questions

Teachers

Describe experiences with each device.
- How versatile is the equipment? What are the constraints?
- What support is needed?
- What are the factors for integrating equipment smoothly? What are the obstacles?
- How easy or difficult was it to use the various kinds of equipment?
- form factor: Netbook vs. tablet ("Is it easier for groups of 3 to work with a tablet than to work with a netbook?"; Does a tablet encourage a "culture of sharing"?)

Most significant change in terms of having the equipment in their classroom? And of using the equipment in an interactive way? *(organisational, pedagogical, other? probe about whichever one isn't mentioned)*

How does using the equipment support student learning? Can you give **specific examples** of student learning?

How does it work for students to use the equipment collaboratively in pairs or groups?

Has your Headteacher offered any particular form of encouragement or support, or has your participation largely been left up to you?

How did you feel about taking part in this pilot project? *(probing for ownership issues)*
What suggestions would you make for the future? (not more equipment)

What are the most effective strategies or using limited numbers of units with large classes? (Carousel-type approaches, etc., one wiki reader per class with keeper?) ("This is all we have - how will you use it? It it useful?")

Learners

- How do you like the equipment and why? How easy or difficult was it to use the equipment?
- What does it add?
- How does it support your learning? Can you give specific examples of what you learned?
- What has been the most significant change?
- Does using the equipment in pairs or groups help you to learn better or not? Why?

- What suggestions would you make for the future?
Gender:
- (interview boys/girls separately - do you have equal opportunities to use the equipment?)
- What opportunities do computing technologies bring to your community?
Economic backgrounds?
- Do you have equal opportunities to use the equipment in class?
- What opportunities do computing technologies bring to your community?
- What are the community needs met through ICTs?

Head-teachers

- How has your experience been with the project? How did you feel about taking part?
- What's been most valuable?
- What has been challenging?
- What has been the most significant change in your school? *(organisational, pedagogical, other? probe about whichever one isn't mentioned)*
- What do you see as the factors for integrating equipment smoothly? What are the obstacles?
- Have you been encouraging or supporting your teachers to participate, or have you largely left it up to them?
- How does the project fit with your aims for the school?
- Does it serve the needs of your school community, in particular the learners'?
- What suggestions would you make for the future?
- What are the issues in taking the pilot to scale?

Appendix 2: Sample survey form

School name: XXX

Teacher name: xxx **Grade:** ….8.........

Date: DEC. 2010 Time: Lesson start: 08:20Hrs. Lesson end: 09:40Hrs.

Topic: measurement and drawinng.

ICT resources and equipment used: computers and kodak comeras.

Nondigital resources and equipment used: WHITE BOARD and TAPE MEASURE.

Mode of use of each kind of equipment (eg whole class use / pairs / groups; some students only / all students; turn taking? Etc.) GROUPS........…..................................
…..

Power:

Were there any issues with power that interrupted use of the equipment? *[X] No* *[ ] Yes*

Were the devices charged sufficiently? Did they last long enough? *[ ] No* *[X] Yes*

If there were any of those issues, or any other power issues, please describe:

N/A…...................................…........................

…...................................…...................................…..

Usability:

How easy was the equipment for you and the children to use?

[ ] very good, *[X] usable but with some issues,* *[ ] not very user-friendly,* *[ ] problematic*

Comments:

NOT COMPUTER LITRACY THOUGH THEY TRY…..................................
…...................................…...

…...................................…...................................…..

…...................................…...................................…..

How many children used each unit? Please give the number: …8.............

Were the screens visible enough? *[ ] No* *[X] Yes*

Did the students manage to use the equipment well? Were there user interface issues, either with the software or hardware? Please describe:

NO EXCEPT FOR THE COMMENT ABOVE…...................................….................................
…...

…...............................….................................…...

…...............................….................................…...

Student reactions:

Did the students stay on task?

[ ] Yes, all the time, [X] most of the time, [ ] sometimes, [ ] rarely, [ ] not at all

How did the students respond to using the new resources? Please describe:

VERY WELL DESPITE SCRAMBLING.THIS RESULTED IN THE LOW LESSON PROGRESSION ...….................................….................................…...

…...............................….................................…...

Did they participate more than / less than / same as usual?

[ ] much more, [ ] a little more, [ ] the same, [ ] less than usual, [X] much less than usual

Did use of the new equipment support discussion? Comment...

YES.THEY WERE ABLE TO MAKE AMENDMENTS AND CORRECT ONE ANOTHER DURING THE TIME OF ENTERING THEIR MEASURES ON THE SPREAD SHEET.

…...............................….................................…...

…...............................….................................…...

…...............................….................................…...

Did the students fight over the technology or was there enough to support your mode of use?

THEY FOLLOWED INSTRUCTIONS THUS IT WAS NOT EVIDENTLY NOTED .

…...............................….................................…...

…...............................….................................…...

Were boys and girls participating equally? Please comment:

YES THEY DID ....…...................................

…..

…...............................….................................…...

Please mention a good point about the lesson: .PUPILS WERE ABLE TO USE COMPUTERS UNDER GUIDANCE AND HELP,THEY MANAGED TO MEASURE LENGTHS AND ENTER THEM,THEY ALSO EXPLOITED GEOGEBRA AS ONE WAY OF DRAWING.

…...

…...............................….................................…...

Please mention a challenge about the lesson:.TO ENCOURAGE PUILS TO EXPRESS THEMSELVES IN ENGLISH AND FREELY.THUS MOST OF THE VIDEO AND SOUND RECORDINGS ARE IN LOCAL LANGUAGES... ..…..

…...................................…......................................…..

Please suggest what might be done better next time.
JUST TO ENCOURAGE THEM REMOVE THE FEAR OF THE USE OF ICT EQUIPMENTS .
…..

…...................................…......................................…..

If you have any further thoughts / suggestions, please write them down!

WE NEED MORE ICT EQUIPMENTS THAT CAN BE SHARED BETWEEN OR AMONG THREE PUPILS,WE MAY ALSO NEED OUR OWN INTERNET AND INSTEAD OF DEPENDING ON NISTCOL..…...................................…......................................…..

…...................................…......................................…..

…...................................…......................................…..

Appendix 3: Observation focus

- How is the equipment being handled?
- Group dynamic: Observe: Patterns with groups of 3-4 using one laptop. Is it always the boys? Is it always those of more advantaged economic background? Or is it even?
- TTL: Time-to-live, how long does it take to set up the class?
- Teacher time spent on technical assistance vs. actually teaching?
- Is the integration of the equipment "fluid" (e.g. wikireader always on hand) or is it "by special effort" (i.e. getting the equipment hauled in for a dedicated lesson)
- Is the use of the equipment by the students "fluid"?
- What equipment promotes "dynamic use" (i.e. children moving about) vs. equipment that makes the learning experience "static" (i.e. children staying "put"). (Needs suitable equipment as well as teacher input)
- How does using the equipment support interactive teaching and collaborative, inquiry-based learning? What are the obstacles? (Limits in terms of resources or the way it's used. Things that support/hinder inquiry.)
- What teacher strategies were more or less effective? (e.g. strategies to use piece of equipment collaboratively)