The Integration of Technology in the International Baccalaureate Diploma Programme

Final Report

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1 Executive Summary

The document reports an investigation of how digital technology is being used in IB World Schools to support teaching and learning in the Diploma Programme curriculum areas of Mathematics and Science. Findings are preceded by reviewing three dimensions of this context: IB curricular aspirations, the recent history of technology use in UK schools, and a pedagogic framework of 'learning acts'. The larger part of the report then describes outcomes from fieldwork based upon surveys, interviews, and site visits to a sample of IB World Schools.

The project investigated how new technologies were being deployed within all aspects of the relevant educational practice, both inside and outside of the traditional classroom. It considered the planning and implementation strategies that lie behind these developments and sought out the obstacles, enablers and challenges that were shaping current trajectories of use. From this, we report a largely positive attitude towards adoption of digital tools: most teachers and students expected to employ such resources into the preparation or delivery of lessons or the pursuit of homework. Strategic thinking tended to centre around the benefits of a versatile institutional virtual learning environment and the potential of students being routinely equipped with personal digital devices. The latter often provided the most striking examples of innovative practice. It was unusual to hear that progress was seriously impeded by shortages of facilities or a flawed technical infrastructure. Where there were obstacles they were more likely to be associated with shortages of teacher time and a lack of opportunities for targeted professional development. We found much good practice but rather little that could be said to be strongly innovative. Thus, the most common patterns of use centred on the management of classroom exposition and the support of student inquiry from internet sources.

The report highlights areas where more innovative development in the use of ICT might be possible: notably, collaborative learning, inquiry learning, digital construction, serious gaming and simulation. It is also stressed that the IB tradition of community building could be more fully pursued through the communication potential of new technology. The present findings suggest that IB World School staff and students would reveal a receptive attitude towards such possibilities - if they were appropriately cultivated and supported.

2 Introduction

This report presents findings and conclusions from the research project 'Integration of Technology in the International Baccalaureate Diploma Programme'. In particular, the project has focused on the Group 4 (Sciences) and Group 5 (Mathematics) components of the International Baccalaureate Diploma Programme (henceforth IB DP) curriculum. Further background information about the context, and the scope of the study, is provided in section 3 of this report. Throughout the report, the term 'integration' is taken to mean a seamless and natural use of technology, where appropriate, to aid learning; the term ICT (information and communication technology) is used interchangeably with 'technology'.

The study has three broad aims. Firstly, it aims to explore and map the context of technology integration in the IB DP sciences and mathematics courses in UK schools. Then, within that, it aims 1) to document teacher and student technology adoption, comfort, and skills and 2) to identify examples of good practice of technologies-in-context to enhance learning in DP sciences and mathematics courses, and to inform IB policy and teacher practice. Within these aims, the following five research questions are addressed:

1. How do IB DP schools plan for, and implement, the integration of technology into the science and mathematics curriculums?
2. What are DP teachers' perceptions of enablers and challenges of technology integration in DP science and mathematics courses?
3. What types of teaching and learning activities occur around and through technology in DP science and mathematics courses? Do DP students use technology for academic purposes? How do DP students communicate with their teachers and is technology a part of this?
4. What are the general patterns in the DP teacher and student use of technology in the classroom (frequency, tools/applications, preferences)?
5. How do DP teachers and students in the case study schools use technology in the classroom (activities, functions)?

The main tenet underpinning this work is that whilst the technology available for use in educational contexts is fast developing in quantity and quality, the pedagogy driving the technology must remain at the forefront of the minds of those with a stake in driving these developments, whether they be teachers, curriculum coordinators, school managers, curriculum developers, or students. Thus, throughout this study, we have sought to identify such innovative pedagogical practices integrating technology use, and although we were able to find much excellent practice, rather little of what we uncovered can be said to be truly innovative, as our informants themselves recognised. However, this must be understood in relation to both the considerable pressures under which teachers are working and the limitations of the study. IB World School teachers work under pressures of time (for training and curriculum experiment) and pressures associated with assessment regimes. Although a large sample of 154 IB World Schools were initially invited to participate in the survey, we received a 26% response rate (please note, this indicates the number of schools from which individuals responded, and not a response rate in terms of survey responses received from individual teachers and ICT professionals. For further information, see section 5.5). Whilst this figure is towards the upper range for online surveys (see, for example, Sauermann & Roach, 2013) there is no indication whether the 26% of responding schools were typical or atypical in terms of innovative practices with technology integration.

The report begins with some background information about the IB DP in the UK and an overview of the science and mathematics courses within the overall curriculum. There is then a discussion of technology in education, the affordances of new technologies and the opportunities for learning that these present within science and mathematics subjects. We also discuss the take-up of such technologies in general terms in UK schools. Finally in section 4.6, we offer a framework of eight 'learning acts' for describing technology adoption. In this framework it is the pedagogy of technology that is foregrounded, rather than the technologies themselves. Thus, where possible we combine both pedagogy and technology in our analysis. In the next sections we present the research aims and the design and methods used, the findings of the study are explored, addressing each research question in turn. In the final section we identify a number of overarching themes that have emerged from the data, and make some recommendations for how the International Baccalaureate Organisation may continue its work to further integrate technology in science and maths in the DP in the UK.

We have strived in this project to develop a robust research method: one that would usefully capture how digital tools are being deployed in the IB science and mathematics curriculum. This method needs not just to summarise current provision, it should highlight the opportunities, barriers and challenges associated with this technology for education. Accordingly, we have adopted an exploratory mixed methods approach. Questionnaires were given to large numbers of participants to "scan across" to find what is representative and typical, and then interviews and case studies were used to "drill down" in specific cases to identify what forms of practice and resource are possible to realise, what ambitions are active in the system and what constraints are felt by teachers to operate against them.

Two specifically designed questionnaires were provided to practitioners in all UK IB DP schools resulting in quantitative and graphical summaries of their responses to these fixed item questions. Such items permitted labelling and counting of opportunity, barriers and challenges, but did not fully convey the manner in which those forces are experienced in context. Policy and practice has a texture that requires more probing methods. We therefore additionally used our survey returns to identify and recruit schools and individuals who expressed confidence and enthusiasm for innovation in this area. We then gathered documentary material relevant to those sites and arranged a variety of encounters with these informants, including 'grounded interviews' (where the conversation was grounded in shared reference to visible practice) and site visits where ongoing practice was observed and interpreted.

Interpreting the records of such engagements is always problematic. Research with a more qualitative flavour demands that strong checks are put in place against any misplaced prejudices of researchers. In our case, we believed that recruiting three experienced observers with relevant but varying backgrounds in the field meant that a critical dynamic of interpretation could be established. Thus, we could frame our various judgements not just on our recorded observations but also on our long experience with the literature in this area. On reflection, by combining these approaches in this way we have strong confidence in the conclusions we have reached and the map we have attempted to draw.

3 Background to the Study

The focus of this research is the International Baccalaureate (IB) curriculum in the United Kingdom and the integration of information and communication technology (ICT) in the science and mathematics classes of the Diploma Programme (DP).

According to the International Baccalaureate Organization (IBO), in November 2014 the total number of IB World Schools in the United Kingdom offering one or more of the three IB programmes was 155[1], with the majority of these (147) offering the DP. Out of these Diploma Programme schools, 56 were state schools and 78 were private schools. These figures indicate a significant change in IB DP provision in the UK in recent years, because unpredictability in government funding has led to a decrease in the number of state schools offering the DP (down from 86 in 2013). In contrast, the number of private schools offering the programme has remained stable[2]. Evidence of this funding unpredictability and consequent programme closures was made apparent to the research team during this project. The numbers of IB World Schools and those offering the DP given above are fewer than at the time the fieldwork for this project started, only a number of months earlier. As we started to contact schools inviting them to participate in the study, several schools informed us that they were no longer offering the IB DP, and one of our case study state schools reported that they will be ceasing IB provision next year due to government funding cuts. Such funding issues are relevant to this study, as good ICT provision - requiring expensive infrastructure, hardware, and software - is dependent upon a healthy funding climate. In fact, funding concerns and budgets were raised frequently by research participants during the fieldwork undertaken for this study.

This research reflects work undertaken in 40 different schools, both private and state-funded. Participants from all 40 schools engaged in one of two online surveys, and 7 out of the 40 were subsequently used as case studies. Further information about the schools is provided in the methodology section.

The English and Welsh school system is divided into a system of 'Key Stages' which map onto school years, and hence ages. In Scotland, ages correspond to Year Groups. The two systems in the respective regions of the United Kingdom are shown in Table 1. The Key Stages/School Years (England and Wales) and Year Groups (Scotland) pertinent to this study are highlighted.

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[1] http://www.ibo.org/country/GB/

[2] https://www.tes.co.uk/article.aspx?storycode=6343247

Table 1. Key stages and Year groups in schools in England, Wales and Scotland (those relating to the IB DP are highlighted)

England and Wales				Scotland	
Age	Key stage	School Years	Schooling	Age	Year Groups
3-4	Key stage 0	Nursery/Reception	Nursery/Infant	3-4	Nursery
4-5	Key stage 0	Nursery/Reception	Nursery/Infant	4-5	Primary 1
5-6	Key stage 1	1	Primary	5-6	Primary 2
6-7	Key stage 1	2	Primary	6-7	Primary 3
7-8	Key stage 1/2	3	Primary	7-8	Primary 4
8-9	Key stage 2	4	Primary	8-9	Primary 5
9-10	Key stage 2	5	Primary	9-10	Primary 6
10-11	Key stage 2	6	Primary	10-11	Primary 7
11-12	Key stage 3	7	Secondary	11-12	S1
12-13	Key stage 3	8	Secondary	12-13	S2
13-14	Key stage 3	9	Secondary	13-14	S3
14-15	Key stage 3/4	10	Secondary	14-15	S4
15-16	Key stage 4	11	Secondary	15-16	S5
16-17	Key stage 5	12	Sixth form/FE College	16-17	S6
17-18	Key stage 5	13	Sixth form/FE College		

The Diploma Programme is a pre-university curriculum for 16-19 year olds, which offers a holistic educational experience with the overall aim of developing international mindedness (IBO, 2009; see Figure 1). The core of the DP comprises the three aspects of: the Extended Essay, the Theory of Knowledge, and Creativity, Action and Service. Together these are centred around the IB Learner Profile of ten learner attributes, which are integral to all the IB programmes. In addition to this core, DP students follow a curriculum made up from six different subject areas: Sciences, The Arts, Mathematics, Individuals and Societies, Studies in Language and Literature, and Language Acquisition. The focus of this research is on two areas. First, those subjects in the 'Experimental Sciences' subject area (Group 4): namely, Biology, Chemistry, Computer Science, Design Technology, Environmental Systems and Societies, Physics and Sports Exercise and Health Science. IB DP students must choose at least one and up to two Experimental Sciences as part of their DP studies. The second focus of this research is those subjects in the Mathematics subject area (Group 5): namely, Mathematics Standard Level (SL), Mathematics Higher Level (HL), Mathematical Studies, and Further Mathematics. IB DP students must choose at least one and up to two Mathematics subjects as part of their DP studies.

Figure 1. The IB Diploma Programme

The IB DP Group 4 curriculum is based on an approach that reflects how science is done in the real world. Science in the DP is data driven. Students are expected to carry out observations and experiments and use the resulting data to demonstrate their understanding of scientific concepts, whilst also retaining 'open-mindedness' around the limitations of that data and human knowledge (IBO, 2011). There is also an expectation that students will bring an international outlook to scientific study, characterised by one which 'transcends politics, religion and nationality' (IBO, 2011, p. 17).

The real-world, global approach to the study of science is encapsulated in the Group 4 project, which forms part of the assessment for all science students. The Group 4 project is an opportunity for students to work together to design an experiment or observation, collect and analyse data, draw conclusions from the data and then to present these with an evaluation of the process. In terms of assessment, the emphasis is on the process of completing the project rather than the final product.

The IB DP Group 5 curriculum emphasises mathematics as an interdisciplinary subject important in many aspects of our lives. Mathematics is conceptualised as a way of thinking, a language, a philosophy, and an 'aesthetic experience' (IBO, 2012, p. 4). The relevance of mathematics to a wide variety of professions is underscored, and this is reflected in the four mathematics courses offered, all of which meet different students' needs, ability levels and interests. The IBO emphasises the links between Mathematics and the Theory of Knowledge curriculum component which comprises one of the three core aspects of the Diploma Programme. The 'international dimension' (IBO, 2012, p. 7) of mathematics is also emphasised, and as with the Sciences this is conceptualised as 'transcend[ing] politics, religion and nationality' (IBO, 2012, p. 7).

Within the IB DP holistic curriculum there is the expectation that ICT will play a significant role. Specifically, within the Group 4 and Group 5 subjects, the use of technology is explicitly referred to in the curriculum documentation which can be viewed in Appendices 1 and 2. The following is taken from an IBO publication outlining the Philosophy and Principles of the Diploma Programme (IBO, 2009, p. 13):

> *Information literacy, in the broadest sense, is a competence that students need to develop as part of learning how to learn.*
>
> *ICT provides a rich environment for learning beyond the classroom. Therefore, the development of virtual learning environments should be encouraged as a means to enhance access to course materials and to extend collaborative learning.*
>
> *ICT provides unique opportunities for creative learning through student collaboration and the use of digital media products.*
>
> *ICT can be effectively used in supporting the school's assessment policy, particularly in formative and peer-evaluation activities.*
>
> *ICT plays a critical role in accessing IB networks and communities of practice. Increasing access will support programme implementation, creative teacher professionalism and student learning.*

Despite this expectation, little published work has been carried out to date, investigating how ICT plays a significant role in the IB DP. The present study aims to fill this gap. Certainly, outside of the IB curriculum, the integration of technology into teaching and learning is by no means a given, and research has indicated that progressive practices are surprisingly less entrenched than may be expected, especially in developed countries where a lack of resources is rarely the main issue (Howley, Wood, & Hough, 2011). In the next section we shall review this situation in greater detail.

Put simply, we suggest the problem with technology integration for teaching and learning in schools is that there can be too much focus on technology use, and not enough focus on the pedagogies that will enable technology-mediated practice to be successful. In section 4.6 of this report, we show how we aim to redress this imbalance by using a framework for analysis centred on pedagogies, allowing us to understand learning with technology by distinguishing amongst different forms of learning. Prior to that, we review the state of technology in education and some of the technologies driving teaching and learning, and discuss the implications of these for science and mathematics curriculums.

4 Technology in Education

In this section we will review relevant research (both in the published works and beyond to the emerging "grey" literature) to set the context for findings of our studies. To do, it is useful to consider what technologies are currently expected to impact on education (section 4.1) as well as consider specific examples from science and mathematics (section 4.2). Having done so, we then review evidence for the benefits of these technologies and argue that simple answers are unlikely to be found given the complexities involved in ICT in education, not least that simply that of opportunity of use (see section 4.4). We conclude this background section by examining how digital technology could in principle transform education by considering whether and how it transforms the wider world outside school (section 4.5) before arguing that to understand its transformative potential in education we must consider how learning takes place. Thus, we offer a framework for learning (section 4.6) which introduces eight forms of learning act that can be transformed by technology.

4.1 Digital opportunities: The promise of new technologies

There is a long history of expectation associated with applying new technology to educational practice. This sense of promise has been well documented, for example by Cuban (1986). But, what Cuban recorded was a long narrative of relative disappointment. Nevertheless, against this background, technologies emerging in the past 10 years are encouraging a quite new level of anticipation and optimism in relation to educational potential (Beetham and Sharpe, 2013; Collins and Halverson, 2010; Moe and Chubb, 2009). To be sure, some commentators have expressed concerns about the ease with which transformative effects might be achieved in practice (e.g., Buckingham, 2013; Selwyn, 2010), but even they still acknowledge great opportunities and a real imperative to confront them.

In the present section we review some of those technologies that are now driving innovation in learning and teaching. Many of them are already apparent in the practices of some teachers, and we predict that they will become increasingly adopted in the near future. In identifying these promising technologies we have considered a number of published horizon-scanning ventures. In particular we have drawn on the New Media Consortium (NMC)[3], which has been conducting an extensive exercise of this kind for more than a decade. The NMC has generated various reports discussing the potential impact of different technologies and providing a predicted timescale for the realisation of this potential (Johnson, Adams and Cummins, 2012a, 2012b; Johnson, Adams and Haywood, 2011). We have focused on their reports from the last two years as well as noted topics discussed by the NMC's Horizon project contributors on their wiki[4].

We have also drawn from the Open University's annual 'Innovation Reports' (e.g., Sharples, McAndrew, Weller et al., 2013) and from the conclusions of a recent large scale UK research programme on technology-enhanced learning (Noss, Cox, Laurillard et al., 2012). In this way, 11 areas of technology innovation are identified below as having strong promise for education. These are: Social media, mobile devices, tablet computing, gaming, augmented reality, hybrid learning resources, cloud computing services, geo-learning devices, maker tools, virtual or

[3] http://www.nmc.org/horizon-project
[4] http://k12.wiki.nmc.org/

remote laboratories, and visualisation tools. The significance of each is sketched in the following paragraphs.

4.1.1 Social networks

It is no longer credible to identify social media as “novel” technology. Yet the ubiquitous social network deserves to be in this list of emerging innovations because, in the context of classrooms, it does remain a novelty. Indeed, it is simply because social networks are so widespread as recreational resources for young people that they are perceived as difficult-to-manage and distracting in the classroom. However, there is clearly an opportunity here: namely to recruit into formal learning those modes of self-organising exploration that are typical of playful participation in social networks[5],[6]. Some schools have endeavoured to reproduce these engaging structures within the ‘walled garden’ of their own virtual learning environment. Others report success by staying ‘in the wild’: for instance, success in encouraging students to harness both the expressive and research potential of blogging spaces such as Twitter. This might occur inside the classroom (Stephansen and Couldry, 2014) or outside - as a resource for use during fieldwork or other out-of-classroom activities (Charitonos, 2011).

4.1.2 Mobile devices

For many years, horizon reports have identified mobile devices as a means of enabling new forms of learning. The fact that they are continually touted as a driver of innovation should not be taken to mean that they have repeatedly failed to fulfil some fixed prediction of promise. Instead, the unprecedented pace of change in these technologies – the arrival of smartphones, better data network connections, more enjoyable web browsing, the rise of apps in many and varied guises – and the fact that mobile devices are increasingly ubiquitous, means that their significance is still continually being stressed. This is a versatile technology. For instance, mobile devices can deliver software for routine drills and practice, but they can also play an important part in supporting the challenge of collecting and managing data during fieldwork. Or they can serve as portable guides and annotation devices during visits to exhibitions. A recent development of considerable relevance to these functions concerns input and feedback. Entering data into mobile devices, which are necessarily small, has long been seen as a limitation to their use. However, users are increasingly able to input data in ways that circumvent such constraints – for example, using voice input, embedded cameras or, in a particularly innovative case, by appropriating the human body as an input surface.

4.1.3 Tablet computing

Tablet computers are a form of small touch screen device, epitomised by Apple’s iPad but increasingly now in competition with other devices, such as the Samsung Galaxy or the Google Nexus or Microsoft’s Surface. The range and cost economy of tablet software applications (‘apps’) has generated much excitement in the practitioner literature. Indeed, evaluating and filtering these applications presents a significant challenge for practitioners. One difficulty is that these apps are often described without discussion of how they were integrated into practice. Yet tablets are not useful merely to support app-based learning in classrooms. Despite the fact that they are larger than mobile phones, they are still portable and are generally regarded as personal devices by the learners using them and so can also play a useful role in out-of-class learning and inquiry.

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[5] http://steve-wheeler.blogspot.co.uk/2009/01/teaching-with-Twitter.html
[6] http://www.huffingtonpost.co.uk/katie-alice/social-media-and-teaching_b_4121742.html

4.1.4 Gaming

The term 'gamification' has become a fashionable way to describe how educational activities can be given the appealing qualities typically associated with games. 'Game-based learning' describes two types of scenario where digital games have been adopted to support teaching and learning, in either informal or formal settings. The first involves specific "educational games" that have been developed expressly to support particular learning objectives. When evaluating such games it is important to consider if and how the motivating game dynamics are integrated into the learning activity – rather than the game being merely a reward from some embedded and routine practice activity which is common but far less effective (Habgood and Ainsworth, 2011). The second scenario involves the use of more 'off-the-shelf' games which were not developed with educational aims in mind, but can be utilised by learners and teachers in ways that support learning. Thus the playing of some games may create data that can be made the basis of problem solving exercises.

4.1.5 Augmented reality

Augmented Reality (AR) describes activities in which a layer of information is placed over 3D space[7]. Examples of AR include: using projectors in a museum to display information about an artefact; using display technologies such that the large walls of rooms are perceived as an active source of information; and adding electronic tags to physical devices so that users' mobile phones can display information about them. Johnson, Adams and Cummins (2012a) suggest that good examples of AR are characterised by their ability both to display place-based information and to respond to user input. In these ways, particular instances of AR can become "compellingly intuitive" (p. 5). Outside of education, examples of AR are now becoming so familiar that they are often not noticed.

4.1.6 Resources for hybrid learning

Learning in an online environment has become an increasingly common experience, particularly as traditional distance learning practices have come to take advantage of digital networking for its ease of delivery and interactive potential. The recent emergence of MOOCs (massive open online courses) has heightened the awareness of public and practitioners for the potential of well-designed online learning. However, learning that is pursued in an exclusively online fashion remains a relative novelty in the school sector (Searson, Monty Jones, & Wold, 2011). On the other hand, in some European countries there are signs of more hybrid (or "blended") learning emerging in schools. In these cases, online and face-to-face experiences are strategically integrated[8]. In some schools a 'bring your own device' (henceforth BYOD) policy is now allowing approaches of this kind to be inclusive of all pupils. That in turn has encouraged the idea of radically 'flipping' the classroom such that expository work (e.g., from texts and videos) is done independently out of class, while class time is given over to discursive and practical exploration of that study. There are now reports of this practice emerging in UK and European schools[9].

4.1.7 Cloud computing

This technology represents a shift towards using expandable and on-demand storage facilities that are located in remote data centres. Their advantage is that they reduce the need for local (in particular, school-based) processing or storage

[7] http://www.watershed.co.uk/pmstudio/project/mscapes
[8] http://files.eric.ed.gov/fulltext/ED537334.pdf
[9] http://creative.eun.org/resources/-/blogs/8-videos-about-the-flipped-classroom

resources. This technology is not to be compared with more traditional digital tools that take the form of discrete educational applications: rather, cloud computing is a whole way of working, an economical and versatile infrastructure that may extend what a school can achieve – particularly in relation to the integration of activity across a large community. These services may even reduce the extent to which school need to rely on specialised IT staffing. Yet their use is not without controversy: the borderless nature of the cloud means that expectations for privacy and security may not be adequately met. Nevertheless, when compensating for the functional limitations of small (if economical) BYOD developments, these services are proving very powerful - and so very attractive - to schools[10]. For example, one UK school (a non-IB school) has adapted the affordances of cloud services to create a distinctive "self-organised learning environment"[11].

4.1.8 Geo-learning devices

Pervasive networking coupled with easy access to portable devices has encouraged the creation of services that exploit the intelligent reading of spatial location. This has given rise to the notion of a "blended space" of learner inquiry (Benyon, Mival and Ayan, 2012) in which learning is orchestrated across traditional resources (such as museum exhibits) and place-sensitive information sources (such as from a networked museum guide). A learner exploring such a blended space may not only have place-sensitive support for their exploration but its route may be captured and made available for reviewing and sharing later. Alternatively QR (Quick Read) codes offer a simpler and more accessible way for educators to tag a location with 'touch point' codes that link to a related website[12].

4.1.9 Maker tools

The idea that education should involve some element of learner 'production' is a long one (Dewey, 1933/1998). In relation to digital tools, this is an idea that was championed by Papert (1993) in the programming language LOGO and thereafter theorised through the principles of 'constructionism' (Papert and Harel, 1991). This idea has gained new strength recently through enthusiasm for stimulating 'maker cultures': contexts that encourage socially-organised construction mediated by digital technologies[13],[14]. Inevitably the making that is supported by digital tools is often based upon principles of programming but increasingly it recruits other digital production devices, such as 3D printing. Evidently, this form of construction offers rich possibilities for experimentation and collaborative thinking (Kuznetsov and Paulos, 2010).

4.1.10 Virtual and remote laboratories

One promise of new technology involves the extension of opportunities to have hands-on experience in research environments that it would not be practical to provide in a school setting. This might be because of the expense, or because issues of health and safety might make such provision an unwelcome risk. Virtual laboratories allow the simulation of experimental spaces in the safety of a web browser. European projects are starting to focus on disseminating provision of this kind[15]. These initiatives also promote the possibility of 'remote' laboratory experience whereby, often in collaboration with universities, students are given

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[10] http://www.ponemon.org/news-2/50
[11] http://blog.ted.com/2013/12/16/the-first-school-in-the-cloud-opens/
[12] http://www.themobilists.com/2011/08/30/qr-codes-in-museums
[13] http://makezine.com/
[14] http://www.economist.com/node/21540392
[15] http://unischoolabs.eun.org/

access to the equipment of distant laboratories whose activities they can (remotely) control. Evidently, facilities of this kind offer an authentic and compelling experience for student.

4.1.11 Visualisation tools

This refers to a range of digital resources and tools whereby users can view, explore, manipulate, analyse and ultimately communicate complex information - such as historical, spatial, and statistical data. It is now widely recognised that many complex systems and processes are more readily explained and explored if visualisation techniques can be mobilised. Consequently a variety of technologies has emerged that allows both teacher and learner to explore this possibility. They range from services that allow the construction of infographics[16] to more versatile project devices such as visualisers[17] to surfaces that allow the active manipulation of visual representations, such as interactive whiteboards[18].

4.2 What opportunities for learning in science and mathematics?

In the previous section we outlined an assortment of technologies that recent 'horizon scans' have identified as being central to educational innovation. These are technologies that are believed to offer a promise for transformations across the curriculum. However, in the present report we have had a special interest in the transformation of science and mathematics education. Therefore, in the paragraphs below we refer to ongoing projects and empirical reports that illustrate the particular ways in which some of these technologies might be implicated in teaching and learning around science and mathematics courses in IB World Schools.

4.2.1 Social networks

There is an appetite in science and mathematics areas for contact with disciplinary experts[19][20]. Simply following Twitter hashtags or known experts in a science field can be a useful strategy for researching a science topic. Social network structures offer a platform for more active communication – at least when experts can be recruited into project conversations. Donnelly, Linn and Ludvigsen (2014) have reviewed a range of science inquiry projects that have incorporated this possibility. Moreover, these networks can define a space in which any non-professional volunteer (including a student) can make data contributions to scientific research in the manner of what has become known as "citizen science" (Gura, 2013). This has made it possible for students to enjoy a legitimate participation in science investigation – as illustrated by ventures such as the 'Living Schoolbook' (Wexler, 2014), in which collaborative work is developed and disseminated. Of course, external expertise is not a necessary condition for a successful collaboration mediated by an informal social network of students: the Nquire project represents an ongoing science project based on such a self-organising network of interested young people[21].

4.2.2 Mobile devices

A common understanding of the how small, personal digital devices support learners is through their empowering of out-of-school learning: allowing study at otherwise unoccupied times. A common image for this is 'learning on the school

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[16] http://www.edudemic.com/educational-infographics/
[17] http://www.mirandanet.ac.uk/vl_blog/?page_id=274
[18] http://www.iboard.co.uk/
[19] http://www.bettshow.com/seminar/Connected-Learners-Creating-a-global-Classroom
[20] http://www.globe.org.uk/
[21] http://www.nquire-it.org/#/home

bus'. However, it can be argued that such arrangements are equally possible with that most mobile of learning devices – the traditional textbook. So perhaps more interesting examples come from portability in the context of an outdoor science investigation: this allows the student to react to field observations by consulting networked databases of relevant information (van 't Hooft, 2013). For example, this arrangement might support the identification and investigation of flora during botanical field trips (cf. Huang, Lin & Chen, 2010). However, the most innovative aspect of mobile digital devices is their role in *capturing* information – as well as delivering it. This makes them particularly useful for scientific fieldwork carried out in the inquiry learning tradition (Anastopoulou, Sharples, Ainsworth, Crook, O'Malley & Wright, 2012).

4.2.3 Tablet computing

The opportunities afforded by tablets overlap with those identified above for mobile devices more generally. However, tablets may be distinguished from smartphones (the prominent alternative mobile technology for schools) by virtue of their more usable size and the ease with which their recreational uses can be contained in school. Moreover, there are a great many apps relevant to science and mathematics subjects that depend upon more generous screen real estate – and such software is appealingly inexpensive for schools (or students) to acquire. However, a significant feature of the technology that is easily overlooked is its pen-based graphical interface. This physicality of graphic expression is particularly attractive to teachers of mathematics where some of the affordances of the chalkboard and some of the demands of algebraic and geometrical expression can be recovered (Maclaren, 2014).

4.2.4 Gaming

Science topics in particular seem to gain from allowing learners opportunity to actively experiment and manipulate raw ingredients. Gamification can allow such explorations to have an engagingly playful quality. Thus Corredor, Gaydos and Squire (2014) illustrate this principle by embedding the opportunity to control a virus and interact with cell structures in a video-based game. Their results show an advantage of this mode of encounter over traditional texts and diagrams. In such examples, the processes of some scientific or mathematical phenomenon can be embedded in the design scenario for a game and the student can be given agency in controlling (and inferring) its properties. Such experiences can be deepened by creating environments in which the 'player' is able to live out scientific investigation or decision making by participating in more scenario-based worlds of the relevant disciplinary practice. These so-called 'epistemic games' give the learner a more vivid encounter with scientific persona and reasoning (Barab, Thomas and Dodge, 2005).

4.2.5 Augmented reality

The interleaving of digital information with encounters in real world places has been most commonly applied to ventures of science learning, where fieldwork locations might be more effectively articulated for students. For instance, Kamarainen, Metcalf, & Grotzer (2014) describe their EcoMOBILE project in which an AR app[22] was used to create hotspots or triggers on the map of a fieldwork setting. These then become active in the real world locations and present multimedia information on that geographical point to the student. Such resources can enrich students' experience of scientific reasoning and argumentation. In mathematics, AR has been applied to the enrichment of what are known as "manipulatives" – namely, forms of real or virtual objects that through contact

[22] http://www.playfreshair.com/

allow richer forms of mathematical reasoning by learners. AR designs can allow creative blends of real and virtual representations in the interest of deeper reasoning (Bujak, Radu, Catrambone, MacIntyre, Zheng & Golubski, 2013).

4.2.6 Cloud computing

This form of service design is typically associated with economies of storage and processing. However, "economy" is a term that can also refer to the costs of technical support around installing and maintaining complex packages of software. Such demands are particularly acute in science and mathematics areas. Thus, Stein, Ware, Laboy and Schaffer (2013) describe a project in which a group of US schools are supported in this manner to engage with complex mathematics software.

4.2.7 Geo-learning devices

The enrichment of fieldwork experience has been highlighted in several of the technologies discussed in this section. Devices that extend exploration in sites of research by integrating information with calculated place are particularly valuable for science fieldwork supported by mobile devices. An example of this design is provided by Price, Davies, Farr, Jewitt,, Roussos and Sin (2014) who describe a GPS app that allowed students to do valuable project work in botany at the Royal Botanical Gardens at Kew.

4.2.8 Maker tools

Digital tools for "making culture" are prominent as part of the workshop environments that some schools are designing as specialised spaces to support science and mathematics curriculum innovation[23]. In those spaces one could expect to find computer-controlled fabrication devices, sensors and interfaces that can be involved in wearable devices, and computational tools that allow accessible modes of programming such as raspberry pi[24].

4.2.9 Virtual and remote laboratories

Simulation has always been a promise of digital devices, whereby experiences of manipulating the materials of science can be offered with minimal expense and minimal risk. These have been particularly effective in general science[25],[26] but also more specialised subjects such as earth science[27]. Similarly, there are an increasing number of opportunities for students to contribute data to remote laboratories or to collaborate via shared access to these services[28]. In the case of mathematics, these opportunities might include shared access to remote quantitative databases such as the national census[29]

4.2.10 Visualisation tools

Networked digital media make the use of video very easy and there has emerged some rich libraries of easily accessible materials relating to science and mathematics[30][31]. However, the spread of interactive whiteboards and visualisers

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[23] http://smithsystem.com/creating-stem-environment/
[24] http://www.raspberrypi.org/
[25] http://www.explorelearning.com/
[26] http://onlinelabs.in/
[27] http://www.learner.org/interactives/dynamicearth/index.html
[28] http://www.schoolsobservatory.org.uk/
[29] http://www.ons.gov.uk/ons/index.html
[30] https://www.khanacademy.org/
[31] http://www.science.tv/

has invited teachers to develop well-established interests in maths and science visualisations into areas where the direct *manipulation* of the visual can also be considered. Moreover, effective visualisations can be the grounding for students to work together on science and mathematics reasoning problems. For example, Furberg, Kluge, & Ludvigsen (2013) demonstrate how visual representations in science can underpin and ease communication among students studying collaboratively.

4.3 Evaluating the impact of digital technologies

In the sections above we have listed examples of opportunities apparent with the new generation of digital technologies. However, this promise needs to be set against a literature suggesting that, up until the present time, the impact of educational technology has been relatively modest.

Enthusiasm remains mixed in relation to the expected transformative effects of ICT upon teaching and learning. Studies that have compared learning outcomes for students who have used ICT versus those that have not typically reveal small or moderate effects. Kulik's work (2003) is much cited and reveals small effect sizes of around .25 to .36. Similar results are reported elsewhere. For example, Liao's (2007) analysis considers studies where classes using "computer-assisted instruction" were compared with "traditional instruction", while Sitzmann, Kraiger, Stewart and Wisher (2006) consider studies where "web-based instruction" was compared with "classroom instruction".

These conclusions are drawn from meta-analyses of published studies: that is, analyses in which a strategically selected set of controlled studies are evaluated as a group and statistics are derived that describe the scale of reported impacts. There have been a number of such analyses and, inevitably, there are now meta-analyses of the meta-analyses. For instance Tamim, Bernard, Borokhovski, Abrami and Schmid (2011) conducted such a study on 25 reported meta-analyses. They find "a significant positive small to moderate effect size favouring the utilisation of technology in the experimental condition over more traditional instruction (i.e. technology free) in the control group" (p.13).

It is difficult to generalise too boldly from findings such as these. Although well-designed technologies can make a positive difference, the scale of that difference strongly depends on a number of factors. Notably: 1) teachers may or may not receive adequate training in pedagogical practices that are relevant to technology, rather than simply training in technology operation (Kalota & Hung, 2013), and 2) the ways in which technology is integrated into those practices can vary greatly across individuals and institutions (Kim, Kim, Lee, Spector and DeMeester, 2013). Useful impacts of digital technologies may often be clouded or attenuated by contextual factors that are poorly documented. As a digital design moves from evaluation under the management of researchers and developers towards active use in classrooms, so the range of contextual circumstances in those classrooms contribute more and more variance to the impact of an intervention. Therefore the situation need not be as disappointing as these meta-analyses might imply at first sight – at least if careful attention is paid to the shaping of pedagogic practice around a technology. As Tamim et al. (2011) comment, "we feel that we are at a place where a shift from technology versus no technology studies to more nuanced studies comparing different conditions, both involving CBI [computer-based instruction] treatments, would help the field progress" (p. 13).

We have reviewed the range of technologies that are ripe for productively influencing the experiences of teaching and learning. While we have also noted that the impact of technology in the recent past has been only modest, the variability around this conclusion indicates that much depends on the manner in which technology is put to use. We will return to considering a framework for acknowledging this reality before moving to the results of our own project. However, first it is useful to acknowledge a degree of caution in the simple take-up of technology – and its opportunities.

4.4 The take-up of digital technologies in UK schools

The relationship between UK education and digital technology has always been a rather uneasy one. With the coming of tools such as the BBC Micro in the 1980s, education embraced technology with an air of optimism. There was a widespread expectation that technological developments would transform teaching and learning (Wellington 2005). Over three decades later this era is often recalled with a certain sense of nostalgia – for it is widely observed that the promised transformation has been slow to happen.

This should not imply a sluggish interest or imagination on the part of designers. Digital innovation has been a lively area of educational research and the market place is not short of developers and publishers – from large corporations to enthusiastic cottage industries. Yet, wherever the adopted fruits of such development have been evaluated, the impacts on learning - while often real - have remained modest in scale.

Observations such as these describe a pattern that is not simply disappointing, it is also corrosive. If there is a widespread perception that, historically, digital innovation has failed to transform teaching and learning, such an understanding may discourage practitioners from engaging more fully with the technology now. However, our own view is that the pattern of disappointment described above deserves closer and critical scrutiny. Doing so will suggest rather more cautious generalisations and, perhaps, a rather more optimistic perspective on the future. Clarifying just what can be expected of digital innovation suggests how a sector of practice such as science and mathematics education is best observed and described – it has framed for us in the present project both the questions to ask and the sources from whom it is best to seek answers.

In the next sections we aim to make sense of a contrast between how digital tools have been embraced in the worlds of work and leisure versus how they have been perceived within the narrower world of teaching and learning. Putting this background into place is a necessary foundation for the present research findings on ICT uptake for science and mathematics subject delivery in IB World Schools.

4.5 The wider digital world

One reason we have high expectations for how education might be changed by technology is our feeling that it is having a transformative impact on the rest of our world. It is worth reflecting on the nature of that impact, because it may differentiate and highlight the particular features of this technology that suggest its promise for teaching and learning. We can then turn directly to the narrower domain of education and consider how these features are being implemented and adopted there, and how they are experienced.

It is quite clear that in recent years a powerful and pervasive digital infrastructure has emerged in the most developed economies: largely through accessible networking and the mobility of engagement afforded by small, inexpensive, personal devices. There is no simple causal trajectory that can explain how the present digital fabric of society came about. The evolution of technology's influence has had an organic character: technical progress interacts and interweaves with cultural trends and preferences in ways that were never easy to predict, nor easy to explain. While understanding the trajectory can be difficult, we can still define the landscape of the present: we can identify those themes of everyday cultural practice that seem to have become prominently associated with digital mediation. Striking among them would be interpersonal communication, personal inquiry, and trade or exchange.

This is a simple but important observation. The most compelling impacts of digital technology have been on cultural practices that are familiar and already central to our lives: in particular, conversation, curiosity, and shopping. It is an important observation here because it is one that needs to be elaborated when discussing the relative inertia of adoption claimed to characterise education. In that sector the digital infrastructure has also evolved (sometimes more by prescription than choice) but it has not so vigorously fuelled ICT adoption and invention towards the goals of the sector. These parallels will be picked up in the next section.

Meanwhile, in relation to the everyday world, it is tempting to say that technology is "merely" elaborating existing and well-worn cultural practices. But it is important to look closer. Technology is not just 'amplifying' or easing those practices: it is re-configuring a pattern or 'balance' among the various activities that constitute them. For instance, social networking sites have brought 'identity management' to greater prominence within interpersonal communication. The participatory affordances of Web 2.0 have made bystander perspectives a more significant resource for personal inquiry about current affairs. And Big Data techniques have made review and recommendation a more central force within the pursuits of shopping. Yet identity, witness, and review have *always* been aspects of those core cultural practices. Technology has not fashioned them – but it has shifted the status of each within the expression of their 'parent' cultural practice.

In sum, what we learn from noticing digital influences in the everyday world is that while the influences of technology have reinforced core cultural practices, the nature of that influence has often involved a significant re-structuring of their constituent activities. On reflection, while old practices are being re-structured rather than new practices being invented, this re-structuring may sometimes be sufficiently radical as to justify the description "transformational". Are such observations echoed in the world of education?

4.6 A framework for describing technology adoption

Cuban (2001) has documented how each new technology of the twentieth century was greeted with the expectation that it would revolutionise teaching and learning. Yet each promise seemed destined to disappoint. In a paper provocatively entitled "Media will never influence learning", Richard Clark (1994) attempted to make some sense of this. Briefly, his argument was that learning was only determined by the various practices of educational interaction that students took part in: not the particular attributes of any media implicated in those practices. So media are simply like "vehicles" that deliver the learning goods – namely, the interactions learners take part in. It does not matter to outcomes whether we select one vehicle over another to deliver, say, an experience of collaborative learning, or expository instruction, or formative assessment.

Clark did acknowledge an important qualification that softened any implication of 'media irrelevance'. Namely, that there are clear arguments of economy and convenience that will often determine in practice whether one medium of delivery is preferable to another. And so certainly, in that sense, attending to media choices is important. But there is at least one other softening qualification that seems necessary. Clark stresses that a new technology may create a new means for enacting a practice where the goal of that practice is already in place - the novelty is simply the means of realising that goal. Nevertheless something else important may have been triggered by the adoption of the new technology. Sometimes the economy and convenience that is offered may be *strikingly* above that of other alternative or traditional means for achieving the same educational goal. In which case, the effect not only makes that technology the new preferred means to deliver that practice, it may also make the practice itself rise in appeal or importance over others within the wider cultural context. This is an observation that echoes for education the point developed above regarding the influence of technologies on various core practices within everyday life.

An example from education may therefore help make this somewhat abstract point clearer. Some enthusiasm for digital tools arises from the ease with which they allow collaborative learning among students. So, for instance, being able to communicate asynchronously on a shared digital network may well make collaborative projects less demanding to organise, more easily pursued. The technology has not made it *possible* to learn by collaboration, it has made it relatively '*economic'* to do so. The labour involved in sustaining a learning exchange of this kind (collaborating) is lessened. This does not simply make *computer*-mediated collaboration a preferred means of stimulating group work, it may also make group work a more preferred choice of instructional practice.

What this example illustrates is the idea that educational practice is constituted through a set of 'learning acts' – which may be delivered through a variety of means, including ICT. In the above example, collaboration was one such act of learning – exposition or inquiry might be others. Technology may be effective in an educational setting because it is an 'economic' or 'comfortable' means for pursuing some particular learning act, such as collaboration. But technology may also have an impact by shifting the balance within some implicit portfolio of learning acts: a portfolio of choices for learning that a teacher can make choices within.

Consequently, we offer a framework for analysing the pedagogies of technology use that is expressed in terms of these acts of learning. This will allow us to understand learning with technology by distinguishing amongst different forms of learning that it supports. That, in turn, will provide a useful vocabulary for describing the uptake of different technologies by our project schools into their science and mathematics curriculums. This framework draws on our earlier work for the UK innovation charity 'Nesta' (Luckin, Blight, Manches, Ainsworth, Noss & Crook, 2012). The Nesta project trialled a conceptual framework for understanding learning with technology by distinguishing amongst different forms of learning. We developed this framework through a modified systematic review procedure across many hundreds of published and unpublished research reports and then refined with interviews with practitioners. This resulted in the following categories:

- Learning through inquiry
- Learning from experts
- Learning with others
- Learning through making
- Learning through exploring
- Learning through practising
- Learning from assessment
- Learning in and across settings

In each case we may consider the different ways that technology is used to gain a richer understanding of the activities and practices that mediate effective teaching and learning. For example, a technology such as the smartphone is no longer considered a single unit of analysis but now we see it described in service of learning through assessment, learning through inquiry and learning in and across settings, To make this clearer, in this report we explain these distinctions: outlining the forms of activity that are encompassed by each of these learning practices and how we are looking for its manifestations through ICT in the IB Diploma Programme curriculum. For illustration, we sketch the manner in which technology might be involved in mediating the activities expressed in each of these learning practices. In the following sections we go on to explore how this is shaping the way we collect data and how it will inform the analysis we perform.

4.6.1 Learning through inquiry

Inquiry, together with reflection and action, is at the heart of the IB curriculum (IBO, 2013), and inquiry learning with ICT is more than browsing, far more than 'mere' exploration. It defines a particular approach to understanding the world in an active manner. It involves asking questions, forming hypotheses, testing them, re-forming questions, and ultimately systematising the fruits of inquiry for sharing and critique. Technology can play an important formative role in stimulating and sustaining this cycle. In IB World Schools we are looking for ways in which technology is recruited into such a structured mode of knowledge building at DP level.

4.6.2 Learning from experts

Much educational experience is centred on what is sometimes termed "the more knowledgeable other". Two forms of relationship with the learner are typically distinguished: the instructional conversation and the expository monologue. These extremes are well marked and recognised, notably as the tutorial and the lecture (or text), although it is possible to see a continuum between them. In relation to ICT, in the IB World Schools we are looking for tools and practices that equip the learner to study text (the rise of e-books is an example) or tools that facilitate student-teacher dialogue (from the synchronous Skype to the asynchronous discussion board). ICT may also function as an "intelligent tutor" for example by setting individualised problems for students and offering adaptive help to tutor them to succeed and although these are rare, they are also being sought.

4.6.3 Learning with others

ICT offers particularly rich opportunities in this area. "Collaborative learning" refers to situations where one or more peers work together to construct shared understanding. This approach has been seen as an imperative in educational theorising but now is seen in popular understanding of what working in the modern, globalised economy requires. The classic collaborative situation involved working together with one or more other students at a shared computer. However, the opportunities that development in technologies have wrought means that there are now a variety of ways to learn with others through more distributed or "networked" learning to create an experience of participation – as well as joint or collaborative problem solving. Given the strong collaborative ethos of IB World Schools and the (international) network they have access to through initiatives such as Global Engage, we are being particularly attentive to the support of these modes of learning.

4.6.4 Learning though making

A potent way to learn is through making things, for example, when learners create animations or program a simple robot. In so doing, learners actively construct knowledge in the process of constructing these material or symbolic artefacts. There is also a performative dimension to such construction, the outcomes can be shared and displayed, thus giving the learner a rewarding sense of audience for their efforts. In IB World Schools we are seeking examples of how ICT can empower learners to be 'makers'. This might exist through the opportunities for programming that the technology allows or we may find ICT as a part of the wider and more general activity of design engineering.

4.6.5 Learning though exploring

'Simply' browsing is a longstanding part of the students and teachers' experiences. The internet offers a rich space of activity for such explorations. On the other hand, navigating and systematising such a complex and disordered space calls upon distinctive skills and confidence. So while technology provides the opening for imaginative browsing, it will be important for teachers to furnish guidance on how such search can be intelligently executed. In IB World Schools we are asking how easily the internet is available for exploration by teachers and students, but also what strategies for supporting this are in place.

4.6.6 Learning through practising

That which has been learned may be consolidated or elaborated by processes of practice. Traditionally this form of learner activity has been marginalised as less glamorous and less creative. Yet research is clear in showing the importance of practice as a component to be included in effective educational practice (e.g. Ericsson, Krampe, & Tesch-Römer, 1993). Technology offers approaches to such practice that can be creative and, perhaps even glamorous. For instance, this may be achieved through the effective use of multi-modal representations and the design of more adaptive or 'smart' forms of interaction perhaps in the form of well designed educational games. In IB World Schools we are looking for recognition that practice needs support and that technology offers a convivial means of doing so.

4.6.7 Learning through assessment

Much teaching circles around the challenge of feeding back to learners useful messages about their progress and useful messages about how it may be developed or re-mediated. This feedback is folded into methods of assessment yet assessing is not always welcomed – either by teachers who may find it oppressive, or by learners who may fear intimidation and failure. Yet technology can now provide engaging and versatile means of assessment-for-learning, although, of course, all too frequently it does not. In IB World Schools we are considering how far technology has been recognised as a creative resource of this kind.

4.6.8 Learning in and across settings

It is widely acknowledged that learning has a 'situated' dimension (Brown, Collins, & Duguid, 1989): so one risk is that what is learnt can become locked into the narrow range of contexts where it was encountered. Extending the routines of learning outside of classrooms is important. Moreover, this involves going beyond merely reproducing the same experience somewhere else, an idea which is embedded in the IB DP curriculum through the emphasis on CAS. Technology allows that experience to be re-cast as it is encountered across different locations representations and activity structures. Ubiquitous and mobile technologies are clear examples of how ICT can assist in extending learning outside of the classroom. School virtual learning environments may also be a form of support for learning in and across settings. We are looking in IB World Schools at how far these opportunities are being resourced and developed in the science and mathematics curriculum.

5 Research Aims, Design and Methods

5.1 Research aims and questions

The research design has been framed around three over-arching aims and five research questions nested within these aims as shown in Table 2. (It should be noted that in the original proposal seven research questions were identified. However, in this report, two questions - d. and e. below - have been amended to refer to teachers *and* students, as indicated by the use of bold typeface. In the proposal, these comprised two questions referring to students only, with two further identical questions referring to teachers only. Thus, the same issues are covered but presented in a more condensed way.)

Table 2. Research aims with corresponding research questions

Research aims 1	Research aims 2	Research questions
1. To explore and map the context of technology integration in the DP sciences and mathematics courses in UK schools	2.1 To document teacher and student technology adoption, comfort, and skills	a. How do IB DP schools plan for, and implement, the integration of technology into the science and mathematics curriculums?
		b. What are DP teachers' perceptions of enablers and challenges of technology integration in DP science and mathematics courses?
		c. What types of teaching and learning activities occur around and through technology in DP science and mathematics courses? Do DP students use technology for academic purposes? How do DP students communicate with their teachers and is technology a part of this?
	2.2 To identify examples of good practice of technologies-in-context to enhance learning in DP sciences and mathematics courses, and to inform IB policy and teacher practice.	d. What are the general patterns in the DP teacher **and student** use of technology in the classroom (frequency, tools/applications, preferences)?
		e. How do DP teachers **and students** in the case study schools use technology in the classroom (activities, functions)?

5.2 Research design

Our fieldwork strategy aimed to document both the extent and the character of ICT use around science and mathematics subjects. To achieve this we drew upon self-report measures (survey and interview) that involved both classroom teachers and those staff who are responsible for the oversight of ICT implementation and innovation. Given the known problems of low return rates from surveys and the difficulties of generating rich data from such an approach discussed in section 2, we also drew upon direct observation of ICT-based practice in a number of case study schools and gathering institutional documentation that illustrated patterns of use.

Consequently, our research design enabled us to start with some wide-lens insights into patterns of ICT use, drawing on 146 individual responses to the surveys (more information about the survey method is given in section 5.5 below). These were supplemented by more detailed understandings from a limited number of schools (14), allowing us to draw upon the varied and often highly individualised perspectives of the informants in each school.

We are not, therefore, claiming to portray a tightly representative view of the use of ICT in IB World Schools. For sure, our findings may still suggest how to characterise what is more or less commonplace – both in terms of resource and experience. But that may not be our most useful contribution. Our aim has been more to combine the broad-brush data from the survey with the individualised thumbprints taken from qualitative approaches. With this synthesis we can address our research questions in ways which we hope are insightful and helpful to an organisation keen to understand how ICT integration is both successful and problematic, how the successes can be harvested elsewhere, and what can be done at curricular level to address some of the challenges.

5.3 Participant schools

154 schools were initially contacted by the research team, of which 58% were private and the remainder state schools. The research reported in this section reflects work undertaken with schools who responded to our requests. In total, 40 different schools,16 state and 24 private, from across Scotland, England and Wales responded (at the time of this research study, no schools in Northern Ireland were offering the IB Diploma Programme). All schools offered the Diploma Programme either to all students aged 16-18 attending the school, or to some of the students of that age. Where the DP formed only part of the curriculum offering in the school, pre-university level alternatives available to students were A-levels or BTEC qualifications in England and Wales, and the examinations offered by the Scottish Qualifications Authority in Scotland.

Participants from 40 schools engaged in one of two online surveys, and 14 out of the 40 schools engaged in follow-up activities designed to generate qualitative data – either telephone interviews or as sites for case study observations.

5.4 Ethical considerations

The research design was approved by the University of Nottingham School of Education Ethics Committee. The University of Nottingham Code of Research Conduct and Research Ethics, the British Educational Research Association's Ethical Guidelines for Educational Research (BERA, 2011) and the Economic and Social Research Council (ESRC) Framework for Research Ethics inform this decision. Particular consideration was given to the non-identification of schools and respondents within those schools. The ethical approval procedures have been revisited at several stages throughout the research process to ensure compliance. See Appendix 3 for full ethical documentation.

In this report schools and individual participants have been labelled so as to preserve their anonymity. Schools which participated in telephone interviews or case studies are referred to by a letter (e.g. School A, School B); schools which participated in one of the two surveys are indicated simply as either 'UK state school' or 'UK private school'. Individuals are labelled using their role (e.g. Biology teacher; ICT professional, Director of Sixth Form). Where use of a role description may increase chances of identification of that individual, then a more generic term has been used. For example, many different and sometimes unusual labels for the person in the school most familiar with ICT provision, such as 'Technology Integrationist', have been subsumed under the more general term 'ICT professional'.

5.5 The survey

The survey stage took the form of two online questionnaires developed by the research team. Existing survey instruments were considered at length but rejected as they did not fit the needs of the research, as they were either a) focussed solely on frequency of use of technology not on how the technology was used for teaching and learning and/or b) focussed solely on routine implementation of technologies rather than considering both more common technologies (internet, whiteboard) and more innovative ones (e.g., 3D printing, augmented reality). The surveys were designed using Bristol Online Surveys, because University of Nottingham ethical guidelines prevent the use of all online survey tools with servers in the United States of America.

The first survey (*Technology in science and maths*) was addressed to classroom teachers of those curriculum subjects. The majority of the questions were compiled following the conceptual framework for understanding learning with technology outlined in section 4.6. Consequently, the questions focused on prominent activities for learning and teaching with technologies in the school, but also addressed resourcing, perceptions of *pros* and *cons* of working with ICT, staff support and professional development. The questioning was based on reporting frequency of engagements with technologies in the science and mathematics curriculums over the duration of the academic year to that point, supplemented by open text questions for clarification (see the full survey in Appendix 4). Questions were designed without a "forced choice" as they all contained an odd number of items.

The second survey (*ICT provision in your school*) was addressed to the person(s) in the school most familiar with ICT provision (henceforth referred to as 'the ICT professional'). The questions probed issues surrounding ICT infrastructure and resourcing and focused almost exclusively on provision of ICT facilities (see the full survey in Appendix 5).

In order to check for clarity of wording and layout as well as consider the scales chosen for frequency of engagement, we piloted the survey on an existing population known to us. The pilot questionnaires were distributed to University of Nottingham Postgraduate Certificate of Education (International) students, who were also teachers, working in mainly international contexts. Participants were asked to fill in the survey as if they were teaching in this area but in addition we added free text boxes to each page to allow them to comment upon the questionnaire. A total of 29 responses were received, and substantive content and layout/formatting changes were made to the questionnaire as a result of the responses and the direct feedback from respondents. One consequence of this process was that responses from the pilot questionnaire expressed concern about the dangers of eliciting demographic data from respondents, even though the survey could be completed anonymously. As schools are identified, respondents were discouraged by the inclusion of questions pertaining to subjects taught, length of time teaching, and, for example, whether the respondent was a Pamoja Online coordinator for the school. They felt this would allow an individual to be identified without their informed consent. Therefore reluctantly the decision was made to remove this information from the questionnaire so as to maximise the likely number of respondents who would complete the survey.

Once the two surveys were finalised, IB Coordinators from UK IB World Schools were contacted and asked to pass on the survey URL links to relevant staff members. From the list of 162 schools provided, messages were received from eight schools indicating that they were no longer offering the DP and thus the initial sample size was taken as 154. Overall response rates where possible and the breakdown of responses for each survey are in Tables 3, 4 and 5 shown below

Table 3. Survey response rates

Surveys responded to	Number of schools
Both surveys	23 (15%)
ICT provision in your school only	3 (2%)
Technology in science and maths only	14 (9%)

Table 4. Responses for Technology in science and maths survey

Number of respondent schools	37 (24%)
Mean number of responses per school	3.16
Individual teacher respondents*	120
Maximum number of teacher respondents from one school	10
One response per school	14

* It is not possible to determine the response rate for individual teachers as we do not have access to information about the number of staff teaching on the relevant IB DP programmes in each school nor whether they received the survey from the IB Coordinators.

Table 5. Responses for ICT provision in your school survey (one response per school requested)

Number of respondent schools	26 (17%)

5.6 Photos

In our original proposal we described an ambition to gather photographs that would be narrated with practitioner or student voices ("sound photos"). This would represent an innovative method to express the participants' experiences and perceptions. The method would involve deriving themes from transcriptions of our fieldwork conversations and aligning those themes with a relevant image (usually a photograph). The theme would be retrieved for the benefit of the participant/informant who would then make a spoken reflection on it, mediated by the image. We did perform relevant image gathering but the demands of making the voice recordings were considerable. Time was one obstacle, as the initiative forced another layer of interaction onto what were always tight and busy schedules. But we were also aware of an unease associated with accountability through voice. Such unease for informants may relate to how the format has a potency for listeners: hearing ideas spoken by their owners seems to impart a strong force to those ideas. At this point we are awaiting some sound photos that are promised from one case study site but they have not been delivered in time for this report. However, some of the photography collected has been used here and thus has contributed to our representation of central themes.

5.7 Telephone interviews

As discussed in section 5.5, the survey could be completed anonymously but respondents who self-identified as 'doing interesting things with ICT in the classroom' were given the opportunity to leave an email address by which they could be contacted to participate further in the project. Consequently, any respondent to either survey who provided their contact e-mail details was sent an invitation to participate in follow-up telephone interviews. The total number of invitations sent was 30.

A total of 12 respondents agreed to engage in the telephone interviews. An overview of the respondents is given in Table 6. A method of semi-structured interview was applied to allow the interviewee and the respondent to explore those areas of ICT integration which were interesting and potentially unique, whilst also ensuring consistency of questioning. The interview was structured into seven parts and the semi-structured interview schedule can be seen in Appendix 6. The interview focused on the issues raised in the surveys but went deeper to allow respondents to describe the specific ways they and their schools use ICT for teaching and learning in IB science and mathematics disciplines. In particular, participants were encouraged to talk freely about their practice. The aim of the research team was to identify a) good practice and b) schools which could become candidates for case study observations.

Table 6. Telephone interview participants

School identifier	Role	Type of school	Location
A	Science teacher/ IB Coordinator	Private	England
B	Deputy Head	Private	England
C	Biology teacher	State	England
D	Chemistry teacher	State	England
E	Physics teacher / IB Coordinator	Private	England
F	Physics teacher	State	Wales
G	ICT professional	State	England
H	IB Coordinator	Private	England
I	IB Middle Years Coordinator	Private	England
J	Maths teacher	Private	Scotland
K	Science teacher	Private	England
L	Physics teacher	State	England

5.8 Case study observations

Based on the survey and telephone interview results, nine schools were selected where ICT appeared to have been successfully integrated into the curriculum and/or where technologically innovative practices were evident, and these schools were invited to become case study schools. No response was received from two schools, one further school had had a change of staff and therefore was no longer able to participate, and another school sent documentation used to support ICT integration in lessons but was unable to host a visit. Two further schools, who had responded to the original survey but who had been unable to participate in a telephone interview were contacted and were willing to host a visit, resulting in seven case study schools in total, from both the state and private sectors, covering England, Scotland and Wales. The seven case study schools are shown in Table 7.

Table 7. Case study schools

School identifier	Type of school	Location
C	State	England
D	State	England
F	State	Wales
I	Private	England
J	Private	Scotland
M	State	England
N	State	England

Our aim was to map the use of technologies-in-context on a small scale, and to document whether and how the demands of the IB DP science and mathematics curriculums were met by various forms of innovation. We used documentary analysis, sound photos and grounded interviews during the case study observations. However, as discussed in section 5.6, as the case study observations progressed, we became aware that due to demands on time and teachers' commitments elsewhere, we needed to be flexible in terms of research methods. Consequently, photos and audio recordings were often used instead of sound photos, and grounded interviews were used alongside more conventional interviewing techniques in cases where participants did not have the means of sharing digital practices or products at the time of the interview. In some cases, schools had arranged in advance for the research team to be able to carry out class observations, and ethical approval was granted for this. Although not included in the original proposal, the opportunity for class observations was welcomed as a means of enriching the data and offering a further means of triangulation and generating robust and reliable research findings.

6 Research Findings

Findings from the study are presented below, addressing each research question in turn. The Tables in Appendix 7 demonstrate how data from the three phases of the study were used to address each question, mapping the method and the specific details for that method, on to the analysis rationale for each question. We present our findings in this section consistent to the methods used to generate them. Thus, analysis of questionnaire data is descriptive, (i.e. this study was not designed to test hypotheses using inferential statistics). Tables present the percentage of respondents for each response allowing detailed inspection of each item. However, this granularity of presentation can make patterns difficult to identify and so graphs of central tendency are a useful complement. As these data are based on rank and, moreover, as there are not equal distances between items, the most appropriate measure of central tendency is median (the central value in ranked data) rather than the more familiar mean (the average of the ranked values). Consequently, graphs of medians are also presented throughout. In terms of interviews and case studies visits we present summaries of our observations combined with quotes from participants (anonymised) and photographs to illustrate the phenomena under discussion. We note the research questions refer to concepts such as 'IB DP schools', 'DP teachers' and 'DP students'. At the outset, we wish to exercise caution around the use of these terms in case they indicate homogenous categories. Our preference, borne out by the data, is to see schools, teachers, and students as diverse entities.

6.1 How do IB DP schools plan for, and implement, the integration of technology into the science and mathematics curriculums?

Data generated through the surveys, the telephone interviews and the case study observations indicated that planning for effective technology integration was a key priority and a recurring challenge. This challenge can be characterised as having four components: (1) A hardware infrastructure that defined the backbone of information transmission within a site and thus comprised central servers and supporting clients through hardwired connections and a WiFi service. (2) A software infrastructure that would manage administrative data and site-wide management of key resources relevant to teaching and learning. This would typically include some form of virtual learning environment (VLE), course management software (CMS), or learning management system (LMS). (3) An access infrastructure for managing how users engaged with these resources. This would be centered on consideration of the range and character of end-devices that would be encouraged for student use. (4) An implementation infrastructure that managed pedagogic practice around these structures. Schools needed to establish a variety of means whereby knowledge and experience was grown and disseminated within the teaching community.

Whilst technology planning and the resulting infrastructure systems were consistently good, the practices within the infrastructure systems were highly variable and thus integration occurred along a continuum ranging from what could be categorised as 'high confidence' – in other words a seamless use of technology to enhance students' learning in appropriate and creative ways, often specific to science and mathematics curriculums, to 'lower confidence', where technology was used more for the transmission of information and involved more generic tools.

Here, we present the research findings related to the planning and implementation of technology with regard to five distinct areas:

i. Hardware infrastructure: Network provision

ii. Software infrastructure: Learning platforms
iii. Access infrastructure: BYOD
iv. Implementation: Whole-school strategy
v. Implementation: Knowledge-sharing

6.1.1 Hardware infrastructure: Network provision

Internet access and WiFi provision were readily available in almost all sites but the extent to which this provision was strategically planned varied from school to school. The extent to which the internet was made easily accessible also varied: from those schools where a 'bring your own device' policy and high bandwidth ensured easy access (School D) to schools where there was up-to-date hardware but poor bandwidth, to schools where the hardware was reported as being more of a hindrance to accessibility than the bandwidth itself:

> *It's .. it's .. the big challenge is actually just getting enough computers that are working and it is particularly bad at the moment I wouldn't .. I would say that in this class I would actually have hoped that we have to get seven working so they can do stuff individually and that we couldn't do that today as I say is probably the lowest point that this has ever reached … so it can't really get any worse! (Biology Teacher, School C)*

A number of questions on the survey for IT professionals directly addressed this question of network and WiFi provision. Firstly we asked about wireless access, "Who has access to WiFi in your school?", as reliable WiFi access is an important enabler for other technologies to be successfully integrated in the learning and teaching and facilitates other aspects of good practice such as BYOD approaches. The data in Figure 2 indicate access to WiFi provision shown by percentage of schools responding.

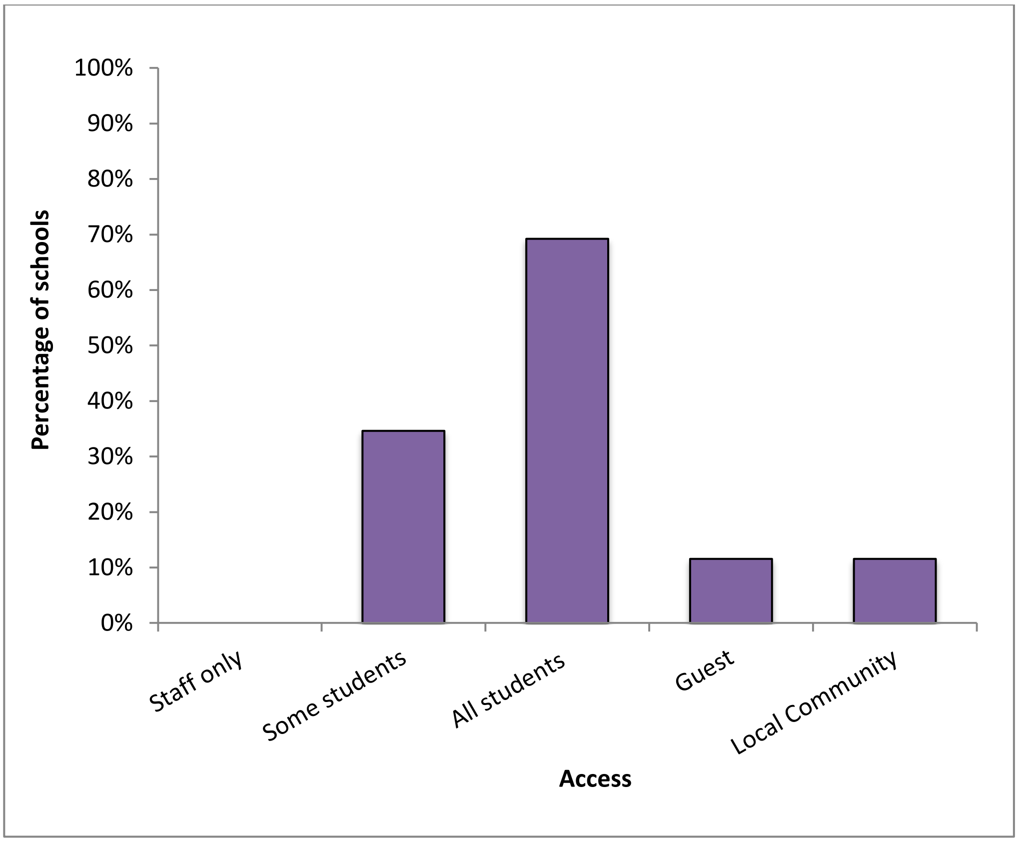

Figure 2. People that are given access to WiFi ICT survey (ICT Survey n = 26) NB totals can sum to more than 100% as multiple responses possible

These data reveal that in the majority of responding schools, students and their teachers can access a wireless network. Moreover no school that provided a wireless network reserved its use exclusively for teachers (although, as other data make clear, schools may operate different networks for staff and students). However, these facilities are typically dedicated for the school community with only a small number of schools allowing access to non-members.

6.1.2 Software infrastructure: learning platforms

The ICT survey results showed that over 80% of responding schools used a VLE, CMS or LMS (Figure 3).

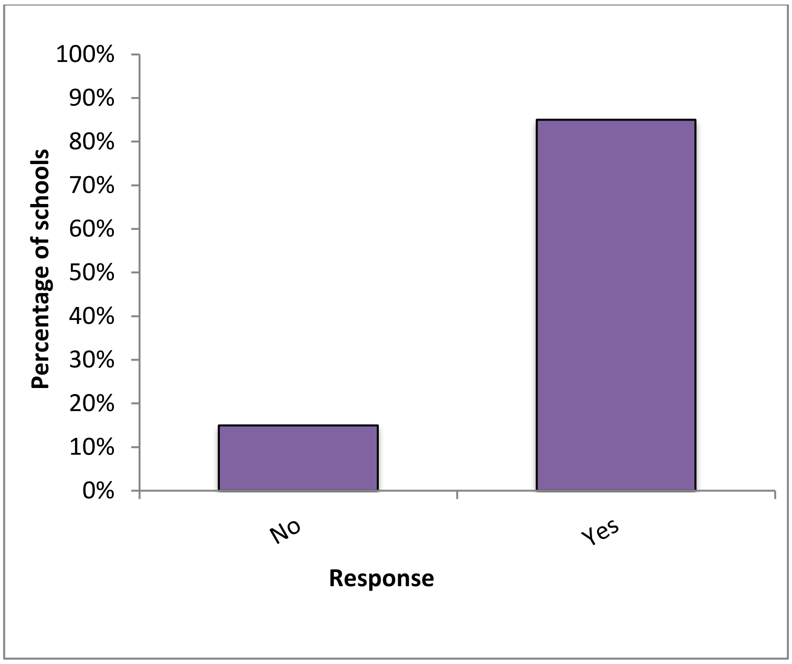

Figure 3. Percentage of schools using a virtual learning environment (VLE), course management software (CMS), or a learning management system (LMS) (ICT Survey n = 26)

When asked to specify which system was in use, 12 different systems were mentioned. In two cases the IB-specific software ManageBac was named. Out of other systems mentioned, some were specifically designed for education (e.g., Moodle) whilst others (e.g., Sharepoint) were designed for business/commercial environments and adopted for educational purposes. Table 8 shows the full range of answers provided by survey respondents (not all those who claimed to use a VLE/CMS/LMS provided the name when prompted by the survey).

Table 8. VLE/CMS/LMS named by respondents

VLE/CMS/LMS	Number of respondents
Moodle	4
Sharepoint	4
Managebac	2
Firefly	2
Google Drive	2
Blackboard/Edmodo/Google Apps for Education/Fronter/My Big Campus/Saber/Studywise/Finalsite	1 each

Out of the case study schools, not all used a virtual learning environment but all schools used some form of digitally based course management system. Reflecting the survey results, the majority of the case study schools used Moodle. One school used Moodle in conjunction with ManageBac, and one used ManageBac exclusively.

In one case study school, there was a vision whereby the functions of a VLE system would be rolled into a configuration that would extend the work of the school further into the domestic environment:

> *I want to involve parents and guardians more into the assessment and live tracking of the students. So I want to be able to get teachers to be able to communicate the progress of their students with parents as soon as it happens. I would like parents to be able to log on somewhere and be able to track how their students are developing. [based in pilot].. obstacle is finding something logistically that will do it and then training the teachers to do it. (Physics teacher, School I)*

and another school in which such a radical form of platform-enabled integration was already in existence:

> *… their parents can see for example if they children are missing a class.. the parents can log on and we do the attendance and it appears in real time and they can access that. (Science teacher, School K)*

This use of VLE/CMS/LMS for monitoring purposes is not one which has been widely discussed in the literature. Whilst using technology for such purposes may hold a certain attraction for parents and teachers, a discussion of the merits and demerits of such a system are not within the scope of this report, focusing on teaching, learning and curriculum matters.

6.1.3 Access infrastructure: Bring Your Own Device

Our observations indicated that the BYOD policy in schools was one of the main indicators of a successful ICT planning and integration strategy. Responses to the 'ICT provision in your school' survey, sent to the ICT professional, indicated that almost all schools have some form of BYOD provision (Figure 4), although many schools had restriction policies concerning the use of students' own devices.

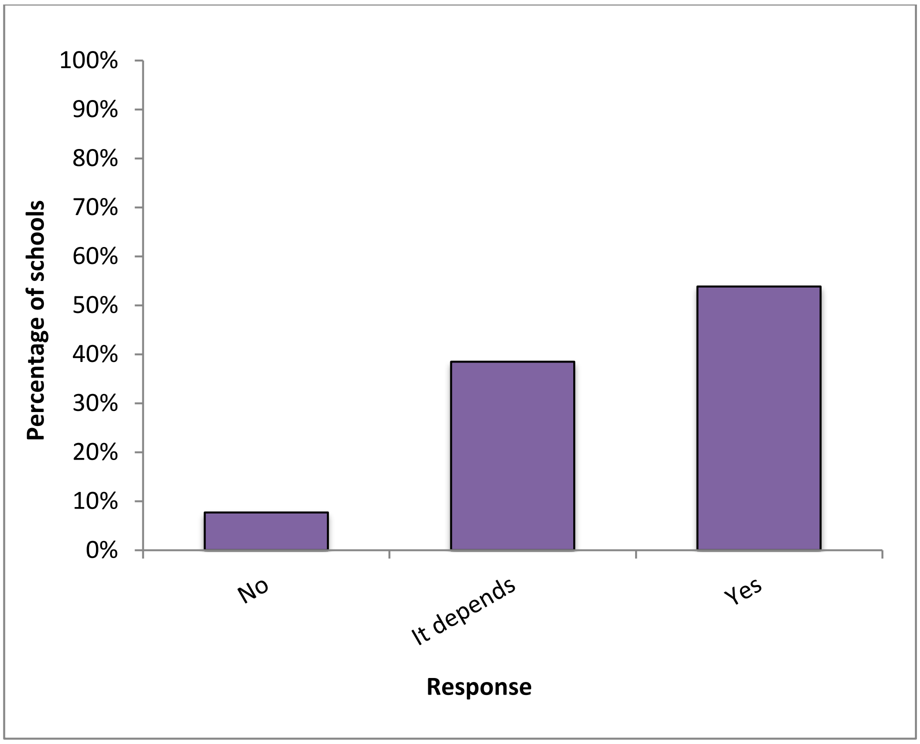

Figure 4: Percentage of schools giving permission for students to bring in their own (ICT Survey n = 26)

Commonly it is permitted for Diploma Programme students (and others their age in mixed curriculum schools) to use their own devices, but younger students are often forbidden from doing so:

> *KS (Keystage) 5 able to BYOD. KS3 and 4 are not (ICT professional, UK state school)*

> *Yes - used with permission only in 11-16 school (no IB students) Actively encouraged in Sixth Form. (Director of Sixth Form, UK state school)*

Other schools set constraints around how they are used, with again older students given greater autonomy:

> *All students are entitled to bring their own devices. 6th Form students are encouraged to use their own devices in lessons and personal study. Lower school students are not allowed to use personal devices during lesson times. (ICT professional, UK private school).*

One school mentioned that students who required technologies as "assistive" devices would be permitted to use them whilst the majority would not. Finally a couple of responses suggested that these policies are in flux with the school intending to implement BYOD in the following academic session.

In many schools there was a growing commitment to tablets. A variety of reasons were mentioned. The most obvious are those to do with economy, ownership and mobility. But there are other practical advantages compared to laptops that are also relevant. One of these is the quick response of tablets.

> *… it takes so long to get on [the network] with the laptop that people really don't use them in IT very much so the iPads don't use the … they use a different network. … we use them with Socrative [a voting system] and things like that and you can just use them for two minutes on an iPad and whereas for the laptop you would have to wait for it to start up and then to connect the network and then they would have to log in (IB Coordinator, School M)*

Overall the increasingly global availability of mobile hardware devices such as phones and tablet computers alongside generally effective WiFi provision suggests that there is now scope to maximise the potential of these devices for collaborative learning, learning outside the classroom, and learning through inquiry and exploration. These issues will be touch on further in sections to come.

6.1.4 Implementation: Whole-school strategy

In the survey and interviews with the ICT professionals, a factor which emerged as key to successful technology integration was the importance of a whole-school strategy.

In three cases, schools had developed highly distinctive ICT strategies. At School F and School J the strategy could be described as one of 'open-mindedness' with efforts being made to provide staff and students with the digital tools which will enable them to become successful teachers and learners irrespective of constraints which may previously have been an impediment, such as being restricted to an Apple or Windows operating system or restricting access to social networking sites. The IT professional at School J described the two-year reform of the system which is still in progress, and explained how in that time their goal has been to change the question from 'What kind of Apple would you like' to 'What tools do you need to do your job effectively':

> *Last year we have put in 22 Windows desktop PCs in our Technology and Design department and that has completely changed and transformed the way that they can teach because they can now run CAD software that was not available in Apple format (IT professional, School J)*

This 'platform agnosticism', in other words not having an allegiance to one particular operating system, was discussed by the same participant as having significance in how the school was planning to implement its BYOD policy. For this school, the flexibility of being able to bring any device to school, knowing that full internet access can be available and that there would be support for that device, was the ultimate goal:

> *It's not really BYO device if we say 'BYOD as long as it is an iPad'. It doesn't really encapsulate the true spirit of the BYOD. We want you to BYOD and if it is Galaxy Note or if it is an Apple iPad Air or if it is a Tesco Huddle or a Microsoft Surface – great! All faiths are welcome and that is the right way to do it. (IT professional, School J)*

The ICT professional at School F explained how filters are used to monitor bandwidth use and internet traffic providing the school with data that 90% of BYOD traffic is currently used for social networking but how, in a sense, making this available to students is part of a wider strategy:

> *I have my reservations about BYOD, but we are going to implement it because even though it is used I would say over 90% for the*

social side that will start to turn .. they then start to use it especially right at the beginning of an academic year and then coming in to October .. students are feeling their way by the time we hit February and March they are going to be thinking .. I need to get something out of this academic year … they are going to start to do their assignments and they are going to start to do everything that the need to achieve this year and they are going to be familiar with using technology .. so it is not going to be a leap and then somehow they panic and turn around and say .. I don't know how to connect my device to this network .. they know how to connect that already because they have been using it for social purposes. (IT professional, School F)

A further important aspect of whole-school strategy concerns procurement policy. In a fast-changing domain such as ICT, arguably there needs to be flexibility of response. This was not widely acknowledged but was evident in at least one reflection on managing a resource budget:

Staff know that if they need something they must always justify it in educational terms it but once it's justified we run a pilot and then we would roll it out. That's what we did with bring your own device…. Every year I have to ask the bursar for some amount of money and he says 'what do you want it for' and I say 'just in case someone asks.' But they don't want that; they want you to say it's for this number of computers or whatever. But I have been strong in saying no we put the money in and as the staff are developing the capability and as they are having meetings… we are obliged to give them the money and I think many schools don't provide a 'just in case' money. They tend to dedicate to a project…. Technology moves so fast you want to be able to respond quickly…that's what we have done very well and we have been very brave and sometimes taken risks. (Deputy Head, School B)

6.1.5 Implementation: Knowledge sharing

In one discussion of the will to innovate through technology, a teacher despairingly commented "I am sure there are lots of things I simply don't know about". A major challenge of implementation is filling the knowledge gap – and then motivating the uptake of that knowledge in practice.

A common theme in our conversations was various means of drawing on the knowledge of other professionals and modes of pursuing such sharing. This was not always seen as easy to achieve as it was necessary that any knowledge-sharer had a suitably deep familiarity with the science and mathematics curriculums:

We don't have the expertise… a lot of its about 'finding'… What we need is advice from someone who knows about curriculum content… You need someone who really was curriculum focussed. ..anything that's too general is not so useful….finding new things is what you might be limited in finding time to do. (Biology teacher, School C)

Most schools took continuous professional development (CPD) seriously as there are requirements to provide it. However, there was great variation in the strength of any imperative to attend or the frequency with which the opportunity was taken up by staff. One organiser of these events commented: "Just getting the staff to use [technology] at all at the moment is where we are." A commonly-declared reason for neglecting CPD was felt pressure of time:

> *I think (CPD) is ok. Professional development is never a waste of time but it's not so much that we need big training courses it's about having time to share ideas and share best practice and … 'come and see how it works in my lesson'… yes professional development, but not only like a course that you can go on … sharing here and between institutions would be really good (Biology teacher, School C)*

This is one area where it would seem that the technology itself could be supportive. And some informants did identify online tools as a useful source of knowledge sharing. Thus, the IB's Online Curriculum Centre was identified by a small number of informants:

> *I suppose I find the OCC useful. There is a bit on it which is the sharing community and there is someone who had done ICT and physics, like a website .. I find that very useful because you can go on that and see what other people are doing and so you can share the worksheets that they have used. I find that very useful. (Physics teacher/IB Coordinator, School E)*

However, invoking the OCC was relatively rare, despite these obvious opportunities. Promoting sharing through the OCC might be encouraged more vigorously by the IBO. Other teachers had found subject-related bulletin boards useful, notably the Royal Society of Chemistry (where a teacher had membership). While one school had put in place its own library of online professional development resources that could be taken up at times that suited:

> *So there is a huge online staff use … Some of the courses are compulsory so the staff, even before they start, have to complete various courses… safe guarding things etc .. for example: "New Staff Welcome Event" .. and then the staff sessions will be in there [reading from screen] .. "Staff Development Programme" information and "Teaching and Learning Assessment" (IB Coordinator, School N)*

A much looser solution to knowledge sharing was reported in one school that was encouraging the use of social media to access expertise from elsewhere – particularly through following others on Twitter:

> *All the people who are in the department are on the same Twitter account and we just retweet things that we think are relevant to the course and tag them with a hashtag relevant for the course… It feels like it works .. and you get the Twitter feedback and it shows how many people have used them .. and some of the links you get 2,000 people look at them! (IB Coordinator, School M)*

With oppressive demands on staff time, it will be important for school management to cultivate more informal and just-in-time methods of knowledge sharing. Online resources and confidence with participation in micro-blogging environments may be solutions that need to be more widely adopted.

6.2 What are DP teachers' perceptions of enablers and challenges of technology integration in DP science and mathematics courses?

The teachers who participated in this study were very forthcoming about enablers and challenges of technology integration in DP science and mathematics courses. The factors they cited as enablers and challenges were both general and subject specific.

In this section, we look firstly at the survey item which directly queried DP teachers views on the barriers to using technology in their classrooms, as shown in Table 9 and then discuss enablers and challenges to integration of technology in the IB DP science and mathematics curriculums in more depth drawing on the views of participants in the case study observations.

Table 9. Barriers to ICT use in teaching and learning (Teacher Survey n = 120)

Barrier to ICT use	Not at all	A little	Partially	Yes	Yes, a lot	Missing
Appropriate content/material does not exist	28%	36%	24%	11%	2%	0%
Inadequate internet bandwidth or speed	39%	28%	19%	6%	8%	0%
Insufficient technical support	29%	38%	12%	13%	8%	0%
Lack of funds to purchase content/material	32%	23%	18%	15%	13%	0%
No, or unclear, benefit in using ICT for teaching	48%	16%	24%	10%	2%	0%
Not enough computers	32%	20%	16%	16%	17%	0%
Pressure to prepare students for exams	14%	18%	19%	32%	18%	0%
School space organisation	29%	16%	31%	15%	9%	0%
School time organisation	28%	17%	24%	18%	13%	0%
Unsatisfactory pedagogical support	47%	27%	17%	8%	2%	0%

These data were recoded to the following ranks as 1 = not at all, 2 = a little, 3 = partially, 4 = yes, 5 = Yes a lot to enable calculation of median responses for each of the barriers listed in the table. These median scores are depicted in Figure 5 please note longer items are slightly paraphrased in Figures for clarity).

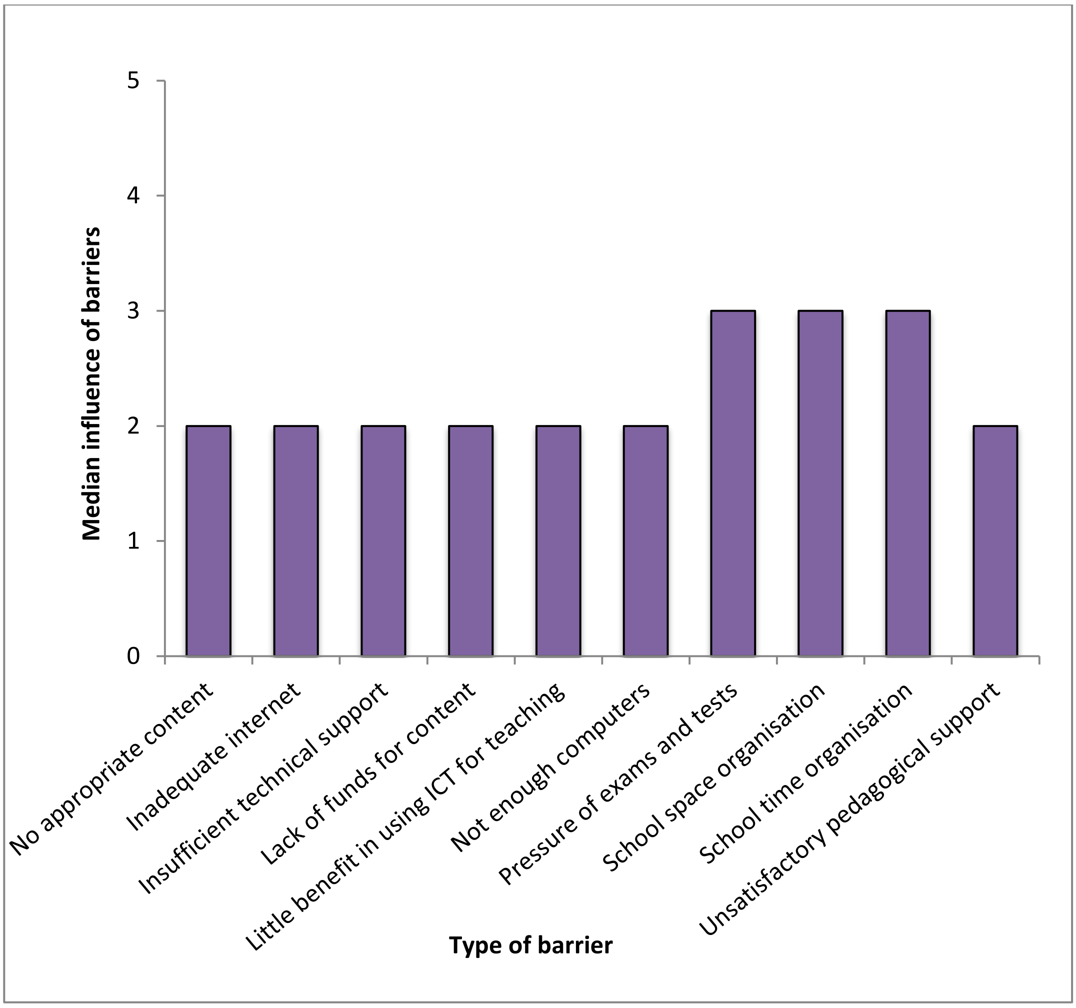

Figure 5. Barriers to the use of ICT in teaching and learning (Teacher Survey n = 120)

Although no single issue is seen as producing an insurmountable barrier to the ICT in teaching and learning, three issues are raised as causing more problems than others – school space organisation, school time organisation and the pressure to prepare students for tests and exams.

Teachers did not feel that there is little benefit of using ICT (48% responded this was not a problem at all and only 2% felt it was) nor is pedagogical support a concern (47% indicated that this is not a problem with only 2% seeing ii as a significant concern). In terms of basic infrastructural issues – access to the internet was not a significant problem (68% reported internet bandwidth as either not a problem or only a slight issue) although more teachers reported a concern around insufficient numbers of computers.

We also asked teachers "Are there other ways that your use of ICT is adversely affected?" and around 20% of respondents took the opportunity to respond. Typical responses, as in the other free text boxes, clarified their answer around issues that were raised in the closed questioning (e.g. "poor quality laptops") however there are occasional responses which addressed other issues with one teacher reporting parent hostility as an issue, one different levels of access by staff and students and three mentioned problems caused by software updating or compatibility issues (e.g. flash not working on IPADS or operating system upgrades causing other software to fail).

These issues were elaborated upon in more depth in the case study observations, and further detail is provided below, categorised under the following seven headings:

i. Enhancing student understanding
ii. Time
iii. Money
iv. Continuing professional development (CPD) and training
v. Differentiation and inclusion
vi. The syllabus
vii. Employability

6.2.1 Enhancing student understanding

For IB science and mathematics teachers, one of the clear benefits in bringing technology in to the classroom is the positive effect on student understanding in terms of learning through inquiry:

> *I mean in making measurements it is a bit easier for students just because … like if you are measuring temperature with a thermometer and you have to look at where is the line going up to .. but if I am using a probe then that gives me an actual number so .. it is much more accurate and precise so .. I think it's a bit easier for the students to use once you get past the kind of technical issues. (Science teacher, School I)*

and learning through exploring:

> *The organic chemistry where we were modelling reactions, the benefit is: it's not static, if you draw it on paper, it's difficult for a lot of students to envisage the movements of electrons, they find it very tricky. With this activity, they can have a model and they can move it and they can film that movement, they can see it happening. For a lot of them conceptually that is much easier to grasp. (Chemistry teacher, School D)*

It is encouraging that these teachers can see beyond technology for technology's sake, and have a strong sense of the pedagogical advantages of integrating these technologies (data probes in the first instance, and iPads for stop motion animation in the second) into the learning opportunities for students.

6.2.2 Time

When asked explicitly about challenges to the integration of technology in science and mathematics, many teachers said that time was the main obstacle. Sometimes this was expressed in terms of hours, and sometimes in terms of more general workload considerations:

> *More pressing is time. It is about the change, you know how you teach the lesson, but it is about the risk; so you take the risk, but if it does not work, then you need to re-teach. But it's time. (Physics Teacher, School E)*

> *It doesn't save workload as developing good resources whether electronic or paper takes time and effort and it's the thinking that takes time. (Biology teacher, School C)*

> *It is basically that there is so many resources that need to be created in order to go for the flipped lesson you need to know that you either need to find or create all of those lessons and also I think I guess we always have to remember that there is still going to be the same number of hours in the day (Maths teacher, School J)*

> *It's a question of time… for instance apps… there are some that are good but it can be a bit hit or miss so there is a nice physics simulation that I downloaded and there is a nice vector game but it's a question of finding it or hearing of it and then I have to find time making sure I am confident using it and then decide whether I can just give it to the girls and then decide whether I have to make a worksheet or task to structure it for use.. that whole process can take an hour that doesn't sound like a lot but when it's not essential it will go to the bottom of my list all the time. (Physics teacher/IB Coordinator, School E).*

Whilst time is a notoriously precious resource, finding ways of supporting teachers to ensure that an initial outlay of time becomes a sound investment could be considered by the IBO and by individual IB World Schools. For example, effective CPD and training may have such an effect. Further discussion of this point is made in section 6.2.4.

6.2.3 Money

Money was not a frequently cited challenge to technology integration, but one IB Coordinator from a state-funded school made the following point about financial constraints and the resulting impact on lower income schools:

> *I love IBIS and I think that there is a lot of technical support of technology out there but it costs a lot of money .. anything that is associated with the IB .. it is a bit like a wedding .. you know .. as soon as a provider knows it is for a wedding .. they sort of triple the price .. and it is a bit like that with the IB and I think that because we are state funded we struggle to use some of the things that some of the independent schools use, because of the cost. (IB Coordinator, School F)*

This participant went on to discuss the Lanterna Online resources, and the prohibitively high cost per-student of the school providing those, meaning costs would have to be passed on to parents, when, in the participant's words, "it is already quite an expensive course to have a child go through".

As discussed in section 3, government cuts have impacted upon state-funded IB schools, and the costs of integrating handheld graphic calculators, systems such as IBIS and Managebac, and e-resources for learning may continue to be a significant challenge to schools offering the DP in the UK.

6.2.4 Continuing professional development (CPD) and training

CPD and training were regarded by participants as both enablers and challenges to technology integration. The survey asked respondents about professional development concerning technology-based learning as prior research indicates this can be an area of significant concern (Kopcha, 2012). We queried two areas through the survey instrument: 1) the amount of CPD time on ICT issues and also whether teachers valued ICT as a way to engage with professional development.

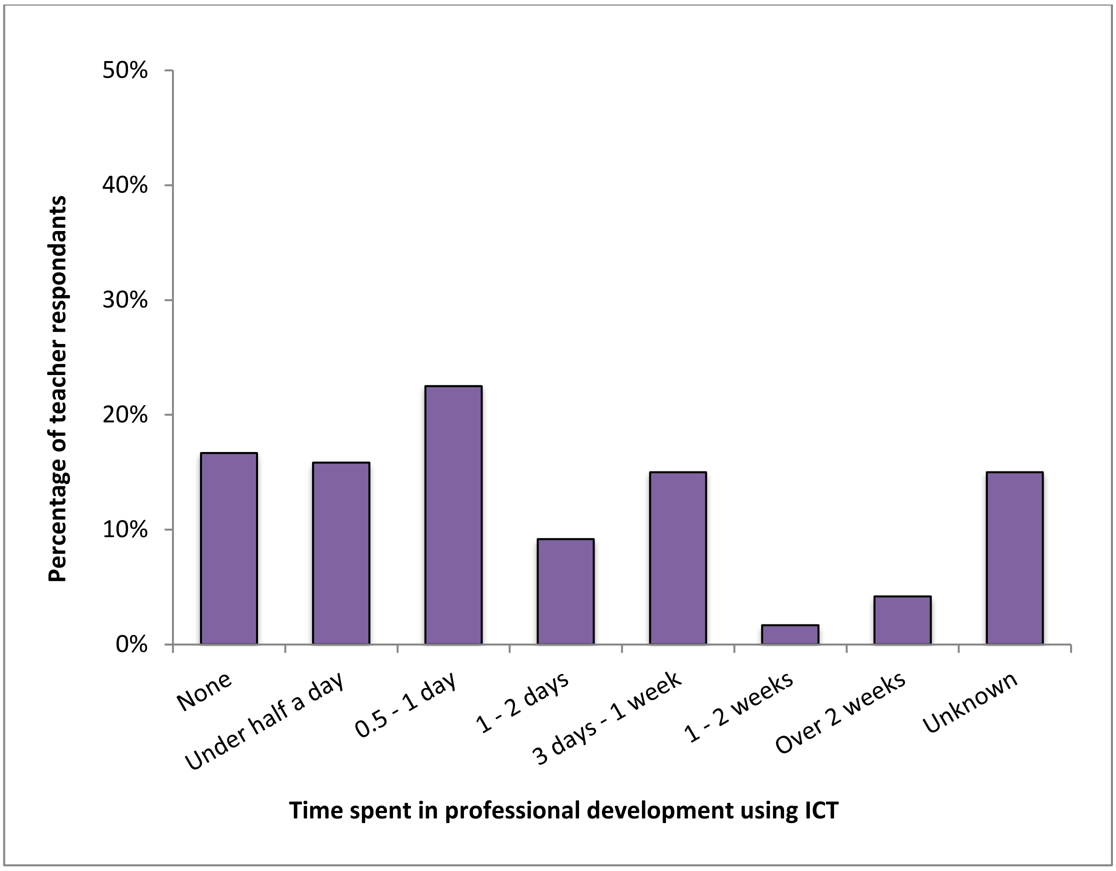

Figure 6: Amount of time teachers spent on ICT related professional development over the last two years (Teacher Survey n = 120)

Over half the teachers who responded to the survey had less than one day's worth of CPD concerning ICT in the last two years, whereas only 6% spent over one week in CPD (

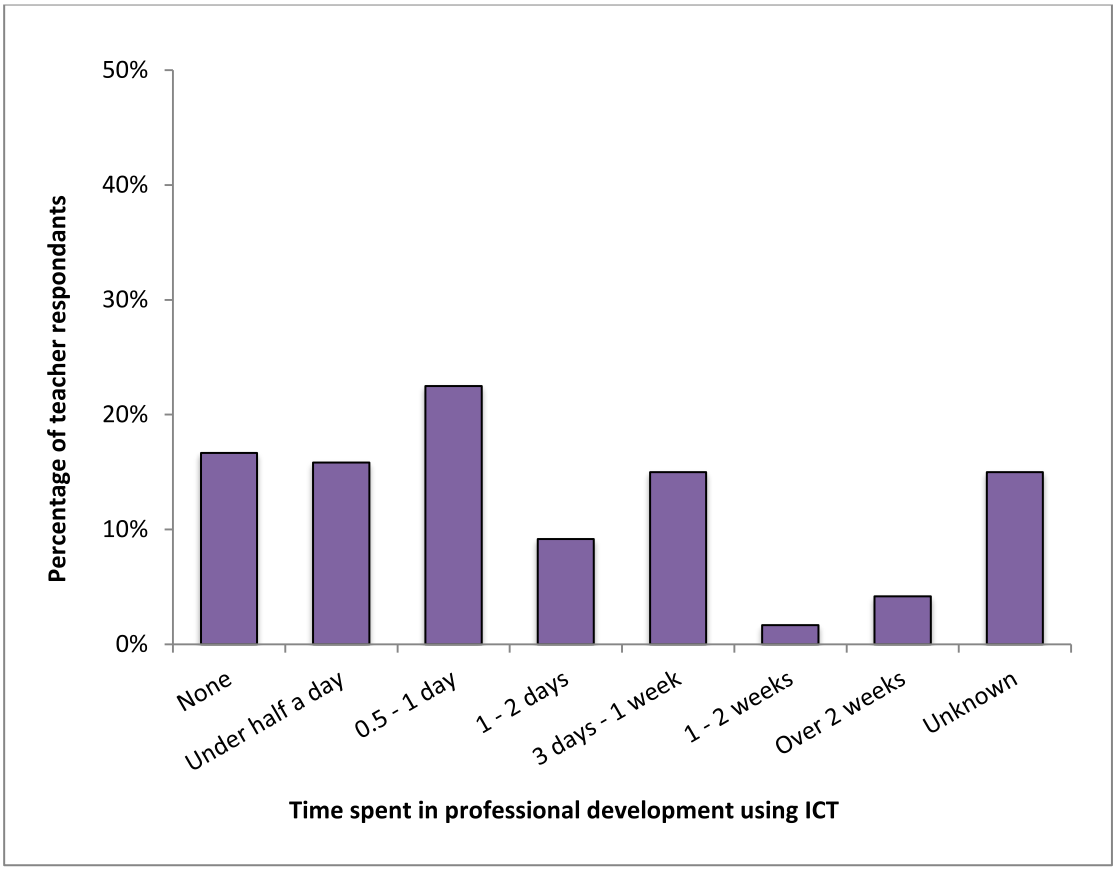

Figure 6). In terms of valuing ICT as a means of engaging in CPD, 40% of teachers also reported that they used some form of ICT (e.g. Twitter, online community fora) for CPD activities.

In the interviews, teachers discussed the importance of CPD for technology use in more depth. Knowledge development and knowledge transfer emerged as key challenges and enablers for effective technology use and means of gaining knowledge were described as coming from formal and informal sources:

> *the exchange of learning materials which have been generated as part of the IB's training programme .. last year this time I was ready to go down to Wellington college for my IB training and it was worth it as much as anything else as the list of resources which can be used to promote teaching (IB Coordinator, School J)*

> *I could bob across the corridor and say "[colleague's name] my white board is not working!" and he will then sort it out or if I can't get the data logger to work or I have forgotten how to do it since the last year then he will take the time to show me how to do it. (Biology teacher, School C)*

> *(pause) I think it's OK. Professional development is never a waste of time. So I would not turn it down. But it's not so much that we need to go for a training course it is about having time to share ideas and people to share best practices "oh, I've found this new thing that works", do you want to try it out, come and see how it works in my lesson … yes, professional development but not as the course you would go on, but sharing practice within the institution and among institutions. (Biology teacher, School C)*

but it became clear that depending on the level of comfort with ICT use, CPD is more important for some teachers in some contexts than for others:

> *… there is new software every year - and some people are more comfortable with that then others. And sometimes people struggle if there isn't support for doing new things. But then other people are very comfortable with technology and happy just to get on and play with things. (Biology teacher, School C)*

and this may be especially marked in schools where colleagues have the skills and capability to support their peers:

> *the support we get is from [colleague's name] and from each other of .. "How would you do this?" .. "How have you taught this?" (Maths teacher, School J)*
>
> *.. how do you support each other with technology use?*
>
> *Teacher group interview (First maths teacher, School J): I come in every morning and ask [Megan]. "How do I do this?"*
>
> *Teacher group interview (Second maths teacher, School J): It's very much on an adhoc ..*
>
> *Teacher group interview (Third maths teacher, School J): You kind of .. certainly in the school quite a few years before I kind of got involved in them and it more .. once you have the need you have to and therefore you suddenly realise actually what they can do and how powerful they are .. but it is quite a time consuming kind of task to get up to speed and it is only really when you hit a topic that you have got to teach and you think that there must be a way of doing that on the Nspire .. so you just ask around and somebody has probably discovered it and they pass it on .. but it is a kind of a .. it is all kind of done .. you learn by a necessity rather than sort of sitting down and let's just experiment .. it is .. I need to be able to do this ..*

In summary, CPD was regarded by participants as both an enabler and a challenge to technology integration. Formal CPD opportunities were rare, and this is an area for consideration and potential development by the IBO and by individual IB World Schools. Informal CPD opportunities and knowledge sharing occasions were crucial for teachers to feel competent users of technologies which they felt the need to use, either explicitly or implicitly.

6.2.5 Differentiation and inclusion

One distinctive pedagogic perspective on technology arose sufficiently often in our conversations to be worth highlighting here. That is the challenge of student differentiation: or responding to individual learning needs. Here is an example based on the challenge of keeping up with the pace of exposition in a classroom lesson:

> *One of the things we do that we find very useful is to use them [iPads] to take pictures that record learning that's going on. So we have a number of students who find it very difficult to take in information and write it from the board at the same time. So they*

will take pictures of what's going on the board and in that way their learning is improved. … we have just been doing organic chemistry: things like the oxidation of alcohol … For transition metals, they have to know the colour changes. So using the iPads to take pictures of those experiments that they are doing, and then writing notes, is a much more powerful way. (Chemistry teacher, School D)

And in the following comment, we see an example of an appeal to the variety of learning styles that can be encountered in a single classroom.

People learn in different ways. Some are hands-on, some are auditory - like to listen - some people like to see things. I am a visual learner for example. But if you use a big variety of techniques through technology, students can latch on to one. You have to match the learning styles of students, they don't all learn in the same way. …they are 21st century kids, they don't want to be taught in a 20th century way. (Science teacher, School K)

The concept of 'learning style' has come in for criticism lately (e.g. Coffield, Moseley, Hall, & Ecclestone, 2004) with this criticism is focused on the implied immutability of 'style'. A more positive perspective on this concept is to acknowledge that there are distinct learning 'preferences' among students and then to see teachers' responsibilities less in terms of narrowly accommodating to each instance. Instead the responsibility would be to cultivate those areas where preferences are less active and thereby create a diversity of learning styles for the individual.

Whilst responding to individual learning needs is considered good pedagogic practice, so is inclusivity. In this context, inclusivity can be defined as ensuring that all students, regardless of need, feel comfortable in their learning environment and are enabled to have an effective learning experience. This notion of inclusivity and the potential for technology to jeopardise it was remarked upon by one of our student participants:

But some apps only support some forms of smart phone .. so .. and the trouble is that if you are saying .. alright .. if you put importance on very high tech apps then people will be left out of that .. if they don't have a particular type of smart phones that supports that app .. so you can't make it key to the lesson otherwise some people won't be able to follow along with the lesson .. but it is just a good supplement to the lesson (Student, School N)

However, a different view was put forth by the ICT professional in another school talking about tablet computers and advocating a fully open and 'anything goes' approach to BYOD:

…there is a view among the teaching staff that revolves around social equity and tablet envy .. and all that sort of stuff so .. you know .. they're not .. some of them are not comfortable with the idea that I might bring in the latest iPad Air because my Dad is rich .. and you might have that crappy little Tesco Huddle .. which will do exactly the same job but it is a £100 device versus to £500 or £600 kind of device .. and that will .. illuminate the difference in our social standing .. now we don't apply that thinking to sports shoes or school bags or any of those other things that kids have ..

phones .. that the kids carry around with them so I am not sure why we are applying it in that context. (ICT professional, School J)

In conclusion, inclusivity factors may be perceived by some as a challenge for successful BYOD implementation. However, as the Chemistry teacher in the first quote in this section noted, for students who have special educational needs, having recourse to the use of technological support can result in improved learning. Our own expertise in this regard would lead us to see differentiation and inclusivity not as challenges but as enablers for technology integration.

6.2.6 The syllabus

The particular requirements of the IB DP science and mathematics syllabuses presented both enablers and challenges to teachers and students.

In some contexts, the IB DP was considered the driver for technology integration throughout a whole school or department. This quote is from a teacher in a school where there was a second curriculum offering alongside the IB DP:

> *… for IB .. you have to know how to use the handheld calculator and the calculated papers depend upon it .. so with our introduction of covering IB here now for four or so years ago .. it was the vehicle for bringing technology into maths classrooms (Maths teacher, School J)*

A chemistry teacher from the same school invoked the importance of the ‘clear message’ inherent in the curriculum which resulted in the widespread use of technology in that department:

> *In the curriculum as it is written there is a clear message that in science subjects like chemistry that students should be able to using data and automatically doing data collection and we have sort of included that .. (Chemistry teacher, School J)*

These comments emphasise how, by explicitly requiring technology use, the curriculum has the power to change not only how IB students’ learn, but how wider school communities adapt and change their pedagogical practices.

However, three IB Coordinators from different schools suggested that not enough technology use is required by the IB, this time not in terms of the learning activity but the learning process:

> *If I was looking for something it would be for the IB syllabus to change because teachers will do what the syllabus tells them and what the examiners want at the end of it so if the syllabus changed to include more technology…then we would change to adapt to it but while it’s still all examined on pen and paper that’s the way we will go on teaching. (IB Coordinator, School H)*

> *You also have to be careful because the IB and A-Levels are quite .. let’s be quite honest .. they are very traditional way of examining student’s knowledge .. and it’s mainly .. you learn this and we will examine how much you can .. in the cases of Sciences and Maths that does apply and there is a lot of application rather than just rote learning so that is good .. but it is still paper and pen .. in a*

room for a long period of time for two or three hours' work or whatever .. so .. we have to be a little bit careful. (IB Coordinator, School N)

I would almost say that it is a strange combination because the IB tends to be much more forward thinking and progressive in their curriculum compared to some of the things that are covered in the A-Level and they tend to be much more .. there is a contemporary feel to the kinds of things that the students have to cover .. but that isn't born out in the kind of methods that they are expected to go through .. in order to acquire the information and engage in discovery learning .. so .. it's a bit of a mismatch I think really and there is almost that kind of traditional values that are instilled in IB students that .. you know .. the idea that reading a book is .. is you know .. it is that kind of classic student behaviour. (IB Coordinator, School F)

One challenge of the IB DP which we were told about repeatedly during our fieldwork was the intense and heavy workload involved for students to be successful on the programme. This quotation is representative of many other similar views:

with the DP it's .. I find that it is a bit .. that it can be a bit more challenging to implement technology just because you are dealing with .. it is just such a heavy course load and I think that if there was less content in a lot of the courses that you would have kind of have more room to give it and be a bit more innovative and use more technology (Science teacher, School I)

We return to the issue of the heavy demands on teachers and students in the DP in section 7.2 below.

6.2.7 Employability

One enabler of technology integration which we thought we would encounter in our discussions, and were surprised not to do so with any marked frequency, was the issue of employability and the need for students to engage with technology in their future workplaces. Two (rare) examples illustrate how a career/workplace perspective might be invoked in relation to technology:

The pupils would come out to a lesson and check their phones for an email from their tutor or whatever and they would pop it back into the bags before they went to break. …and it was very much like a business environment (Deputy Head, School B)

I think in terms of careers, I think that is where it goes and we get students who have left who have come back and they have worked for Sainsbury's in property and stuff like that .. and that is what they do all day is that they take pictures of sites and then they locate them and say what will be there. (IB Coordinator, School M)

In the first case the informant is generalising the structure of digital communication in school (email) to the wider world of future workplace communication. In the second, the informant is noting how a technology (tablet photography) recruited into a classroom project would link to technologies commonly used in high street employment contexts.

6.3 What types of teaching and learning activities occur around and through technology in DP science and mathematics courses? Do DP students use technology for academic purposes? How do DP students communicate with their teachers and is technology a part of this?

As discussed in section 4.6, the main conceptual framework used for the data analysis in this report was the framework of eight learning acts. The data presented in this section show that learning through exploring and learning through inquiry are the most prominent learning acts for IB World School teachers and students. What was clearly apparent, however, through the data analysis, was that despite the affordances of ICT within the IB DP curriculum, it is still used frequently for traditional transmission modes of teaching/learning (predominantly expository learning acts). Nevertheless, in all schools, technology was used for academic purposes, and in all schools electronic means of communication were used between teachers and students and, to a lesser extent, between teachers and parents.

Two parallel questions in the teachers' survey addressed the question of what types of teaching and learning activities occur around and through technology, the first focused on the teachers' activities and the second question asked about student activities. The questions have some common items (e.g. both teachers and students browse the internet to find information) however most reference the distinctly different functions that technologies serve for these groups (e.g. teachers post homework, students perform virtual experiments). However, both sets of questions were informed by the learning acts framework and both also consider communication explicitly.

Table 10 Frequency of teachers' usage of ICT activities in preparing or teaching (Teacher Survey n = 120)

Activity	Never	Occasionally	Monthly	Weekly	Daily	Missing
Browsing the internet to find learning resources for students	3%	8%	16%	39%	35%	0%
Browsing the internet to find information yourself	1%	8%	10%	32%	49%	0%
Digital communication with a wider community of teachers	14%	33%	15%	20%	18%	1%
Digital communication with parents	16%	36%	26%	18%	5%	0%
Digital communication with students	4%	22%	18%	38%	19%	0%
Posting homework for students	25%	26%	11%	26%	12%	1%
Using ICT for feedback and /or assess students' learning	32%	38%	12%	15%	3%	0%

These data were recoded to the following ranks as 1 = never, 2 = occasionally, 3 = monthly, 4 = weekly, 5 = daily. This coding enabled the calculation of median responses for each of the activities listed in the table. These median scores are depicted in Figure 7 (please note activities are slightly paraphrased for clarity).

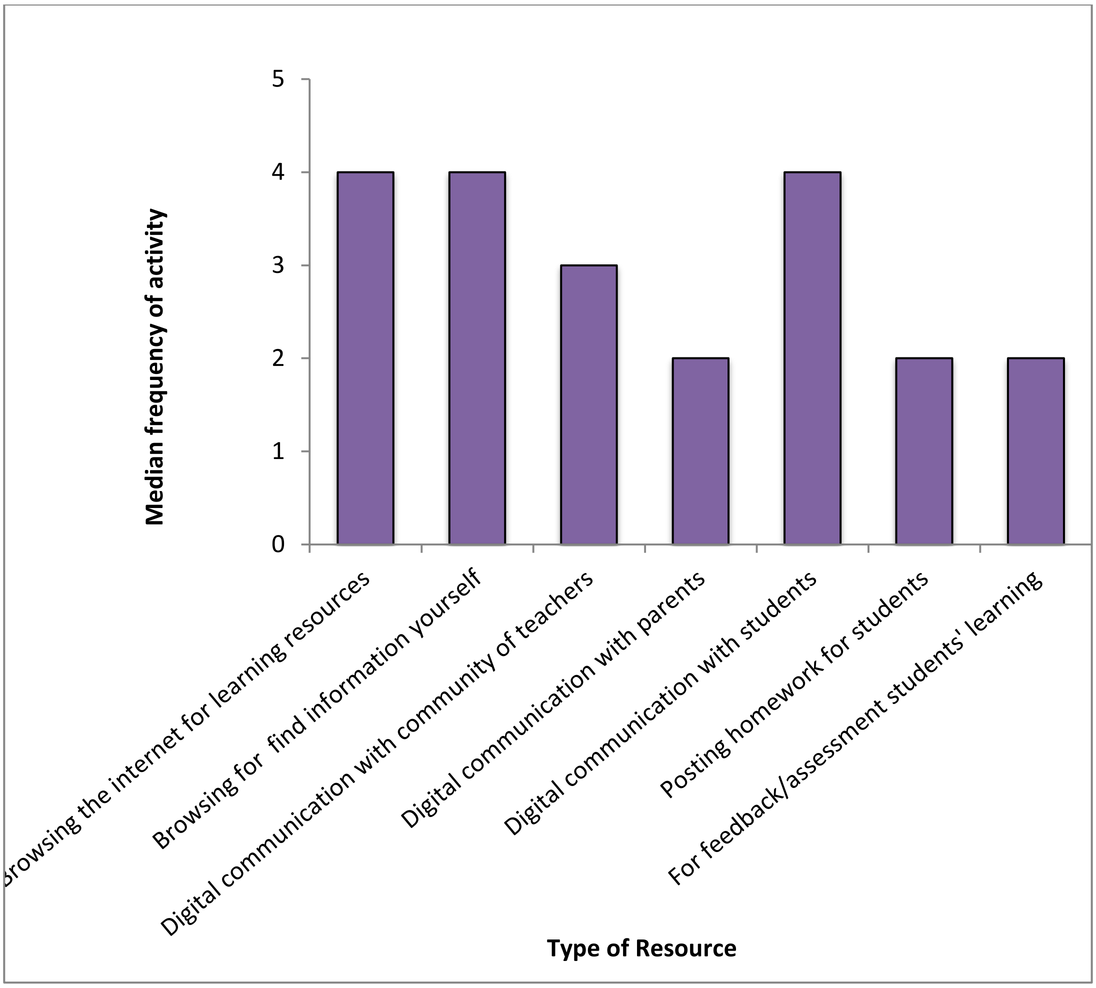

Figure 7: Median frequency of ICT related activities in teachers' preparation or teaching (Teacher Survey n = 120)

These data show that for most of the respondents, technology frequently supports their teaching activities. Echoing the use of technology outside the classroom, it is unsurprising that browsing for information/resources on the internet is very common, with most teachers reporting doing this either daily or weekly.

The other activity that technology is reported most frequently supporting is permitting teachers to communicate directly with their students with again the majority of teachers reporting this is done daily or weekly. These findings were enriched by the case study observations in which teachers discussed in more depth the communication they participated in with students:

> *They have email. All our students have a Gmail and that is the main way of communicating with them. (Maths teacher, School J)*

> *the latest stuff to be added is of course Google Hangouts … the students are using it effectively and we know that the staff are using it effectively and the students are as well .. because the staff come back and tell us in the rooms actually collaboration was happening and not just because it was dictated or .. or prescribed it .. collaboration was actually happening because the student wanted*

it to happen as well .. which is excellent. (ICT professional, School F)

In terms of communication with others involved in education (parents, their wider professional communities) technology was still used but less frequently – we can assume that this is because the activities themselves are performed less frequently rather than because alternative non-technological means are employed and this was also suggested by the interview data, although less technologically advanced forms of communication - parents' evenings and telephone contact - were still given as an important means of communicating with parents:

> *for all our students we have ManageBac which is everything get put on there … the reporting … the attendances… and also the homework gets set on there, and the parents will all have access to it … and they can also access and they can see … they don't have to ask the students now or the child … 'do you have homework?' … So everyone is well connected in terms of ManageBac kind of thing (Biology teacher, School I)*

> *the amount of paperwork that goes home is virtually nil now .. and we do need an email address for every single parent so they can communicate with them and they can communicate with us and the web portal where parents perhaps want to contact the school they fill in a contact form so it is seemingly exclusively digital short of parents evenings (Maths teacher, School J)*

Finally, it is clear that the use of technology for assessment or posting homework is not a commonplace activity (with the majority of teachers reporting doing so either occasionally or not at all). However, even here there is large variation with 12% teachers reporting posting homework daily for example whilst 25% never did so at all.

We also asked teachers in an open format if there are other teaching activities they used technology to support. 25% of respondents reported activities in response to this prompt however many of the responses reported technology supported learning activities engaged in by their students which is the subject of a subsequent question and so we analysed in reference to that question. But for those teachers who did make reference to teaching activities some of them took the opportunity to expand on their answer to the frequency data for example by pointing the types of resources they searched for on the internet (e.g. videos, Prezi [32]and PowerPoint) or the specific technologies they used to create quizzes (e.g. Qwizdom[33]) or hardware used to present resources (e.g. projectors) or used by students (graphical calculators). The only activity that occurred with some degree of frequency not included in the closed questions was teachers reporting on using technology to present specific resources for students (3D animations, videos) with the occasional response indicating they had created these resources themselves rather them finding them on the internet. Further analyses regarding teachers making resources are presented in section 6.5.1.3.

The second aspect of the question interrogated teachers about the frequency of learning activities supported by technology in which their students engaged. Teachers were asked to rate the frequency with which specific ICT related

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[32] http://prezi.com/

[33] http://qwizdom.com/

activities occurred in their classes on a scale ranging from “never” to “daily”. Their responses are presented in Table 11 below and the medians in Figure 8.

Table 11. Frequency of learning activities supported with technology (Teacher Survey n = 120)

Learning activity	Never	Occasionally	Monthly	Weekly	Daily	Missing
Browsing the internet to find information	11%	36%	24%	20%	8%	1%
Capturing or measuring data in class using ICT	26%	48%	16%	9%	2%	0%
Capturing or measuring data outside class using ICT	56%	37%	4%	2%	2%	0%
Communicating with experts	73%	26%	0%	0%	2%	0%
Contributing to blogging or discussion forums	81%	15%	2%	2%	0%	0%
Contributing to collaborative projects using ICT	62%	29%	4%	3%	1%	0%
Developing and presenting multimedia	30%	46%	15%	8%	1%	0%
Developing electronic portfolios of personal work	53%	27%	11%	5%	4%	0%
Engaging with dynamic maths visualisations	51%	32%	8%	6%	3%	0%
Engaging with simulations using ICT	24%	34%	24%	14%	3%	0%
Experimenting in virtual or remote laboratories	63%	24%	8%	3%	2%	0%
Participating in peer to peer exchanges using ICT	73%	18%	2%	3%	3%	0%
Playing educational games	27%	54%	14%	2%	1%	0%
Programming objects such as robots or vehicles	97%	1%	1%	1%	0%	0%
Representing data visually(charts/graphs) using ICT	6%	25%	42%	20%	5%	0%
Using geo-learning or augmented reality (AR)	92%	4%	2%	0%	0%	0%
Using immersive virtual worlds	97%	1%	0%	1%	0%	0%
Watching digital video	13%	40%	22%	21%	3%	0%

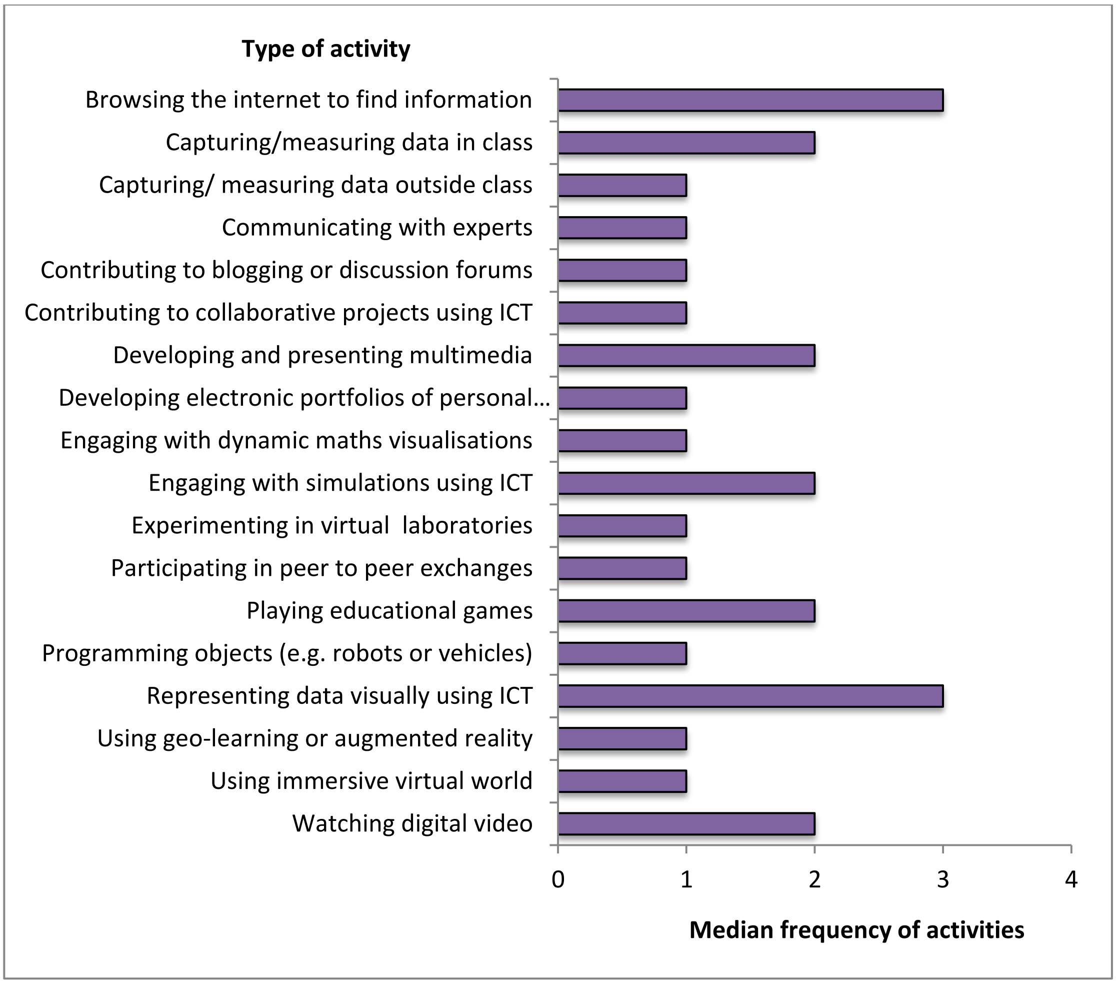

Figure 8. Median frequency of ICT related activities in students' learning activities (Teacher Survey n = 120)

The items chosen for this question had deliberately referenced technologies that we suspected may not be in routine use in classrooms (in line with the ambition to identify innovation and best practice) as well as the commonplace technologies that surveys such as those commissioned by the European Union (e.g. Wastiau, Blamire, Kearney, Quittre, Van de Gaer & Monseur, 2013) have explored. Consequently it is unsurprising that for many of the activities referenced the majority of teachers reported their students used them infrequently or even never (e.g. use of immersive virtual words or augmented reality and programming robots). Perhaps more surprisingly, there is little reported technology supporting communication, with no activity in this area occurring any more frequently than "occasionally". Those activities that are engaged in most frequently are *browsing for information on the internet* and *representing data visually* however even these only occurred for most classes on a monthly basis. Finally, classroom based data handling, developing presentations, watching videos, experimenting with simulations and playing games all occurred at least occasionally for most respondents.

As before, teachers were asked to report on other activities that may have been omitted from the list. Only a few teachers responded to this prompt and those that did either described an activity in more detail (e.g. explaining it is Excel they used to represent data) or they tended to emphasise the use of graphic calculators as a way to handle data and solve problems (this had also frequently been referenced in respect to the teachers activity question). There are no examples provided of unexpectedly innovative activities with other responses pointing out that students take notes or write assignments using word processors or reading digital books.

The pattern that emerges when one considers these two items in combination is that teaching activities are routinely supported by technology but learners' activities far less frequently. Furthermore, in both cases teachers rarely reported on innovative uses of technology, with browsing for information the most common activity for teachers and students. Consequently, other aspects of the survey were designed to establish why that might be the case. One possibility is that teachers do not consider technology to be a valuable way to support the learning activities of their students. This issue was probed directly in the survey when we asked teachers to reflect upon the eight different forms of learning their students could engage in and consider the extent to which technology may be useful.

Table 12: Teachers' perceived importance of technology for specific learning activities (Teacher survey N = 120)

	Not Imp.	Somewhat Imp.	Imp.	Very Imp.	Crucial	Missing
Browsing or exploring in an open ended way	3%	21%	29%	30%	17%	0%
Collaborating with others	5%	32%	30%	26%	8%	0%
Coordinating learning in-class/out-of-class)	4%	33%	30%	22%	12%	0%
Creating or making things	19%	28%	33%	14%	4%	1%
Making discoveries/solving problem through inquiry	2%	24%	32%	31%	11%	1%
Practising some skill or rehearsing existing knowledge	5%	36%	29%	23%	7%	1%
Receiving assessment and its feedback	17%	39%	22%	15%	7%	1%
Watching demonstrations or listening to experts	5%	28%	36%	21%	11%	0%

These data were recoded (1 = not important, 2 = somewhat important, 3 = important, 4 = very important, 5 = crucial) and the median shown in Figure 9.

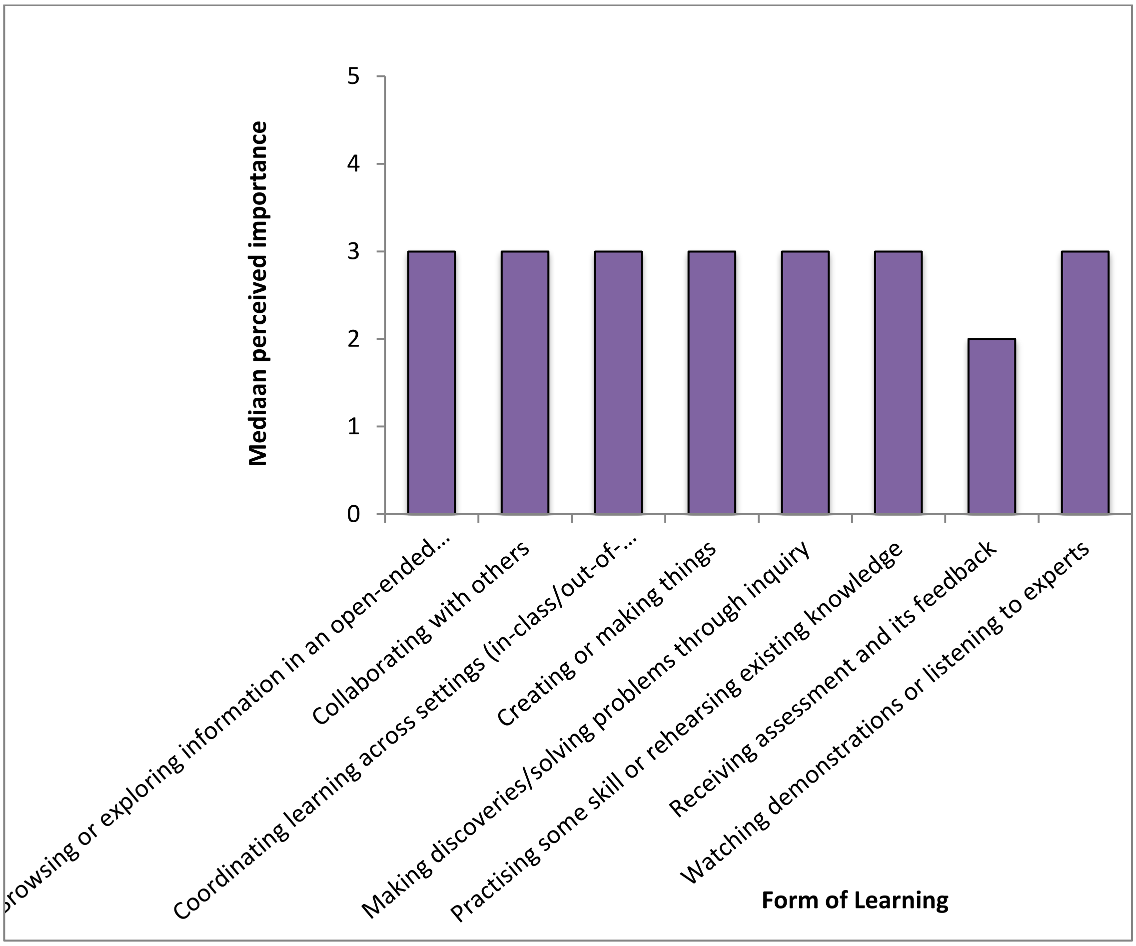

Figure 9: Median perceived importance of technology for specific forms of students' learning (Teacher Survey n = 120)

These data suggest that overall teachers view technology as important for their students' learning and in the case study observations it became evident that some teachers appreciated the benefits of ICT to help their students access complex ideas through a familiar and engaging medium:

> *You have a classroom environment which is in their world so when they are actually learning perhaps hypothetical or obtuse concepts we are able to put things in a concept that is in the world and they are comfortable with that… (Deputy Head, School B)*

Moreover, the survey data indicated that all forms of learning activity were seen as similarly supported by technology with the single exception of feedback and assessment where technology is not considered to play an important role. However, technology for browsing for information was most likely to be seen as crucial whereas technology to create things was most likely to be seen as not important (Table 12). Moreover, the overall similarity across the median perceived importance hides variation in individual teachers' perceptions of importance of technology for supporting learning activities – in every form of learning some teachers saw technology as crucial and some as completely unimportant. In general what these data suggest is that the relatively low reported use of technology by students in DP classrooms is not due to teachers' perceptions that it is unimportant.

6.4 What are the *general* patterns in the DP teacher and student use of technology in the classroom (frequency, tools/applications, preferences)?

The survey directly addressed this issue by asking teachers to rate the frequency with which they or their students used a variety of hardware or software. The items selected again followed the strategy of including everyday technologies as well as more innovative ones.

Table 13: Frequency of use of hardware and software by teachers and students (Teacher survey n = 120).

Technology use	Never	Occasionally	Monthly	Weekly	Daily	Missing
3D printers	98%	2%	0%	0%	0%	1%
Classroom voting systems	74%	23%	2%	0%	0%	2%
Digital probes/sensor	44%	36%	13%	5%	1%	1%
Interactive whiteboard	28%	13%	7%	11%	40%	3%
Laptop or desktop computer	3%	14%	12%	13%	58%	1%
Mobile device	29%	31%	5%	13%	21%	2%
Programmable objects	93%	3%	2%	0%	1%	1%
Real time communication	89%	4%	2%	2%	3%	1%
Short messaging systems	86%	7%	3%	2%	3%	1%
Social networking	81%	8%	3%	4%	4%	1%
Touch tables	98%	0%	1%	0%	0%	1%
Virtual learning environment	38%	19%	9%	23%	11%	0%
Visualiser	61%	14%	5%	7%	13%	0%

Traditional computers are by far the most frequently used technology with many teachers reporting daily use and almost no teacher not using a laptop or desktop computer in their classroom. The second most frequently used technology the interactive whiteboard was used daily by 40% of teachers but nearly 30% never used it at all. However, as can be seen in Figure 10 most technologies with any degree of regularity we asked about are not used in IB classrooms (the most frequent response being "Never") – this includes specific science and maths technologies, (e.g. sensors, programmable robots), high profile technologies such as 3D printers and touch tables. However, it also includes technologies that are now in common use outside the classroom such as social networking and Twitter.

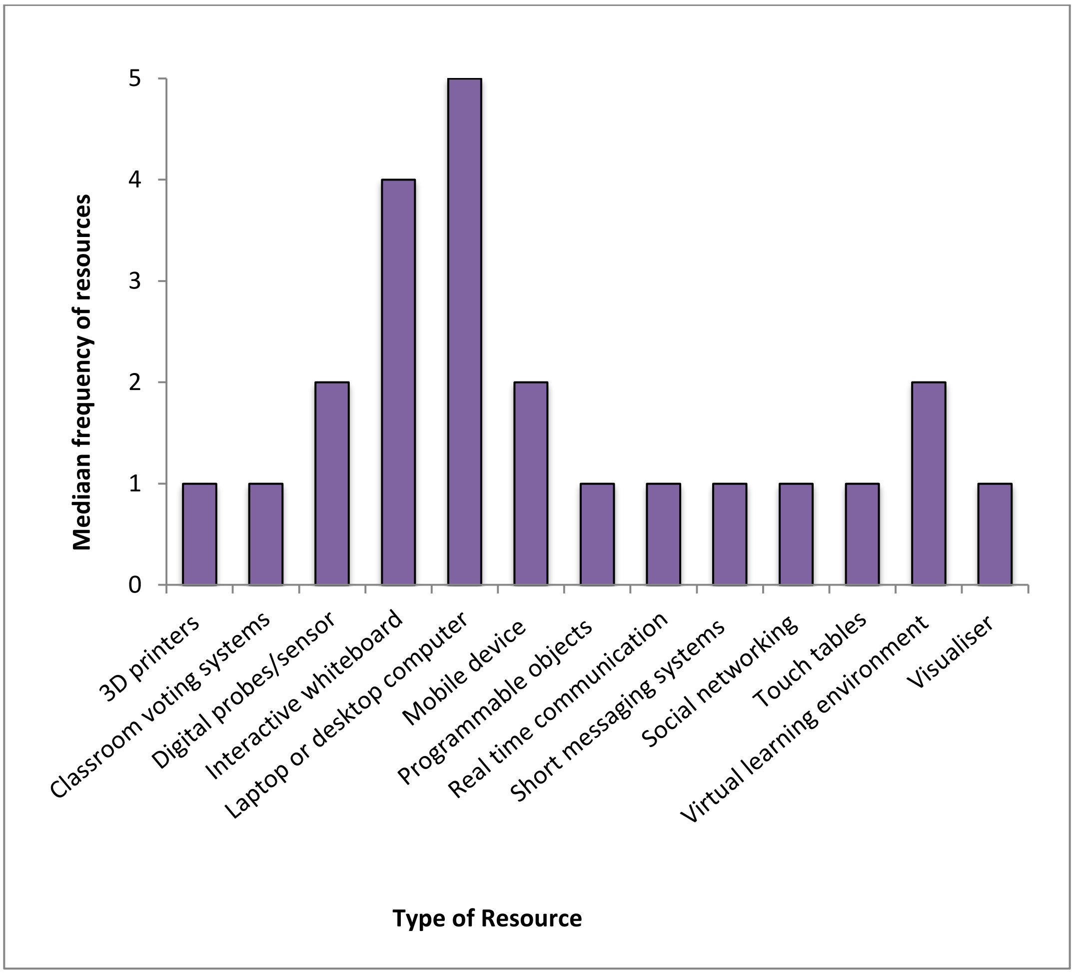

Figure 10: Median frequency of resources used in classes (Teacher Survey n = 120)

An open and compulsory question asked DP teachers "to briefly identify the ICT resources (if any) that you regard as most valuable for either teaching or learning" to probe their preferences for technology. These data were expressed in free text and were subsequently recoded and condensed by the research team (e.g. YouTube, digital videos, Khan Academy were all coded as video) and are graphed in Figure 11. Most teachers reported multiple valuable forms of ICT and the diversity of response here is striking

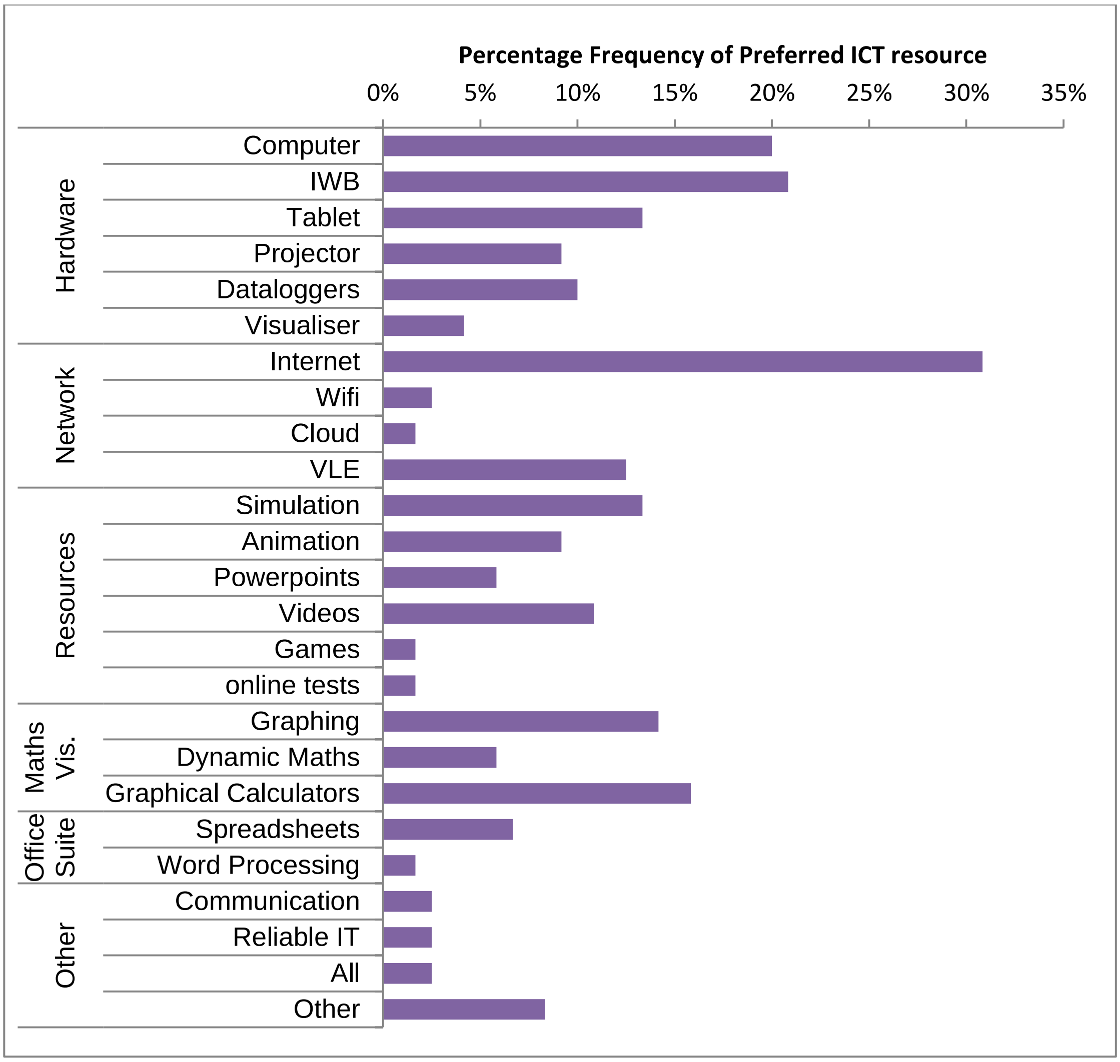

Figure 11. ICT resources most valuable for teaching and learning (Teacher Survey n = 120)

The forms of ICT considered most valuable by teachers are dominated by network resources (internet, VLEs) and hardware (computer, interactive whiteboard, graphical calculators and data loggers). However, resources such as animations and videos are also very popular as are graphing software and maths visualisation software (e.g. Geogebra). On the other hand, communication was only mentioned by a very few teachers. Items coded as other are only referenced by one or two teachers and included e-books, authoring software, lecture capture and classroom voting systems. Three teachers responded that all ICT had a role to play and is valuable in supporting learning, whereas one teacher responded that there is no ICT resource that is of value to them.

Table 14: Table showing the percentages of schools offering ICT resources to teachers only or both teachers and students (ICT survey n = 26)

	Teachers only	Teacher and students	Not available
3D printers	8%	15%	77%
Classroom voting systems	12%	27%	62%
Desktop computer	42%	46%	12%
Digital Probes/ Sensor	19%	42%	38%
Interactive Whiteboard	69%	15%	15%
Laptop computer	27%	62%	12%
Mobile device	23%	46%	31%
Programmable objects	12%	19%	69%
Real time communication	27%	27%	46%
Short messaging systems	19%	35%	46%
Social networking sites	19%	31%	50%
Touch tables	8%	4%	88%
Visualiser	42%	8%	50%

As teachers' and students' use of technology is clearly influenced not only by personal preferences and curriculum objectives but what technology is available in their local environment, we also asked the IT representative to list which of these technologies were available for staff and students. Their answers are shown in Table 14.

The most frequently unavailable technologies are 3D printers, touch tables and programmable objects confirming that teachers and students would not be in a position to regularly use such technologies even if they had desired. In contrast computers and to some extent mobile devices are frequently available to both staff and students. Interactive whiteboards are also frequently available (85% of schools reported their use) however in nearly 70% of cases they are seen as for teachers use only. Interestingly, the three communication technologies referenced (social networking, real time communication and short message systems such as Twitter) are available in half of the schools, so the low frequency of use reported by teachers cannot be explained simply by availability.

6.5 How do DP teachers and students in the case study schools use technology in the classroom (activities, functions)?

As discussed in section 6.3 and 6.4, IB DP teachers and students use technology in a multitude of ways which are both functional and activity-driven. For teachers, these uses range from the more everyday, such as projecting data onto a whiteboard, to the more technologically complex, such as recording instructional videos to support learning, to the pedagogically innovative, such as setting up simulations in class to generate inquiry-driven learning situations. Students use technology to get better access to learning materials, to generate and collect data, and to support them in inquiry-driven learning approaches.

In this section we offer an analysis of how technology is used by both teachers and students through examples drawn from the case study schools. Where applicable and relevant, we have indicated how these examples relate to the opportunities for learning through new technologies discussed in section 4.1 and 4.2, and the eight learning acts which comprise the framework for technology adoption discussed in section 4.6.

6.5.1 Teachers' uses of technology

Teachers' use of technology in classrooms can be characterised by a diverse spread of practice, which ranges from the use of technology purely for expository purposes (for example presenting learning outcomes to students on PowerPoint slides) to more intricate involvement of technology for investigative, diagnostic and organisational purposes. In this section, we present illustrative examples of technology in use in four categories:

i. Presenting information about the lesson
ii. Presenting lesson content
iii. Making lesson content
iv. Facilitating inquiry-driven learning

The examples used in this section are drawn from observed classes and from teachers' descriptions of their own practices taken from interview data.

6.5.1.1 Presenting information about the lesson

There were numerous examples of teachers using technology to present process-driven information about the lesson itself to students. For example, we observed both learning outcomes of the lesson, and the instructions students needed to follow in order to complete activities in class, projected onto a whiteboard from a data projector. Some teachers described how they used technology in this way frequently, and how it provided the means for structuring a lesson:

> *In my teaching with the DP students, I also use computers a lot for either PowerPoint slides and to structure the lesson and to get them to do activities and think about and to sort of elicit discussions (Biology teacher, School I)*

> *Interviewer: we saw that you were using Edmodo and you were putting up .. is it right to say that you were putting up documents that you had previously put on Edmodo .. initially?*

Interviewee: Yeah so they had been posted prior to the lesson and so they were so that they could be integrated but the lesson could proceed without those documents as well if necessary. So again it is an extension using the technology. (Biology teacher, School D)

An example of instructions on PowerPoint slides from a Year 12 biology lesson can be seen in Figure 12.

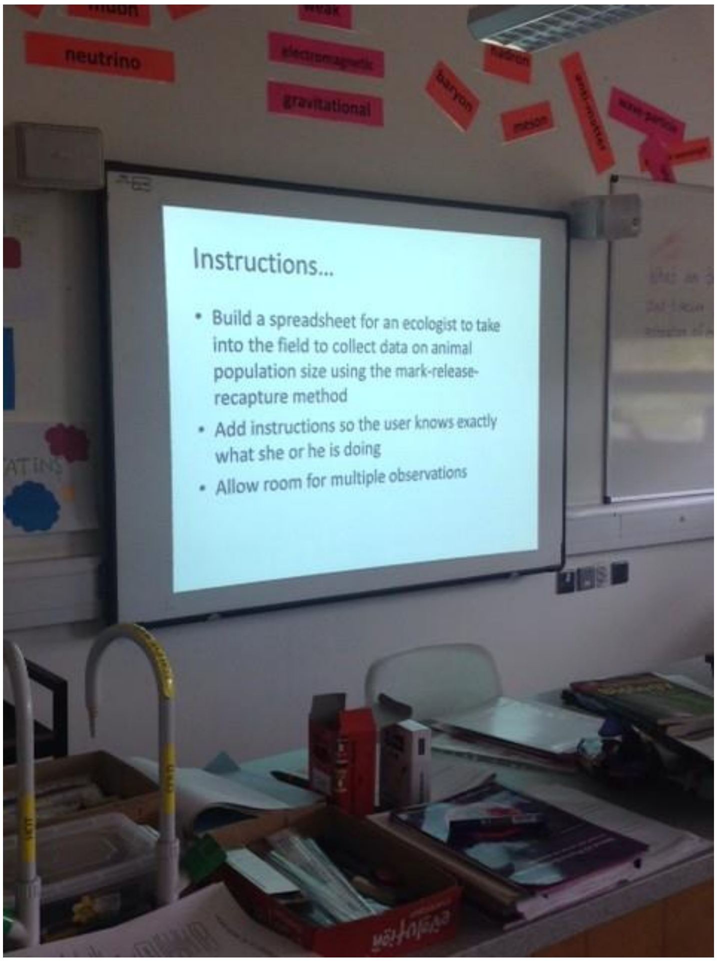

Figure 12. Instructions provided to a class on a PowerPoint slide

6.5.1.2 Presenting lesson content

As well as using technology to allow students to follow the lesson structure and format, teachers also used technology to present ready-made content-driven information:

I use PowerPoint to present the content (Chemistry teacher, School I)

In some cases, the examples given simply replaced 'old technology' such as books or blackboards with contemporary ICT such as e-books and interactive whiteboards. One teacher explained how e-books ensure that all students can access to the textbook content, even when textbooks themselves are not accessible:

e-books are great .. at the moment I don't have text books for my class .. hopefully they are coming next week .. only two months late! So I have just been having the e-book up and I have just been plugged into an iPad and put it on the screen .. and then show it like that and also having an e-book .. I press a button it gives me full work solutions. (Maths teacher, School J)

These uses of e-books are examples of how technology has been employed in IB World Schools to facilitate 'learning from experts'. In the illustration given by the Maths teacher from School J above, "the more knowledgeable other" comes in the form of a) the text itself and b) the worked examples which are easily accessible by both teacher and student. Whilst the technology does not enable these forms of learning, it does afford a more immediate and more dynamic means of presenting expert knowledge to learners.

Other examples of ready-made content-driven materials discussed by teachers include web-based scientific simulations such as those produced by PhET [34] (Figure 13) or the VPLab[35] (Virtual Physical Laboratory, shown in Figure 14). From the teachers' and students' perspectives, being visually engaging these ICT-based materials have the advantage of enriching teacher-led demonstration, and thus helping students to understand more abstract principals and multi-dimensional concepts:

I teach Chemistry in the DP so because we are working on a very kind of microscopic level it is useful to use simulations and so we use a lot of .. you know .. online simulations. (Chemistry teacher, School I)

For video purposes like for me .. it is the most useful to be able to watch a video that demonstrates what you are doing .. further what you are doing like .. like a case study and video .. or a documentary (Student, School N)

It is the simulations the [PhET] through the University of Colorado and we use those mainly. So yeah .. you know .. they will have a variety of tasks kind of relating to each topic so I will usually go through and I usually modify one and then and then have the students do one and .. you know .. and just .. and I find they are really good especially for students the visual learners and .. you know .. trying to understand these very kind of abstract concepts .. you know .. it's good to have the visual. (Chemistry teacher, School I)

we use .. obviously the computers and the digital projector for animations .. and especially teaching quite abstract concepts like protein synthesis …where students can not actually see it but if it is animated they can actually sort of make connections and it becomes visual then. (Biology teacher, School I)

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[34] https://phet.colorado.edu/
[35] http://www.colpus.me.uk/vplab/

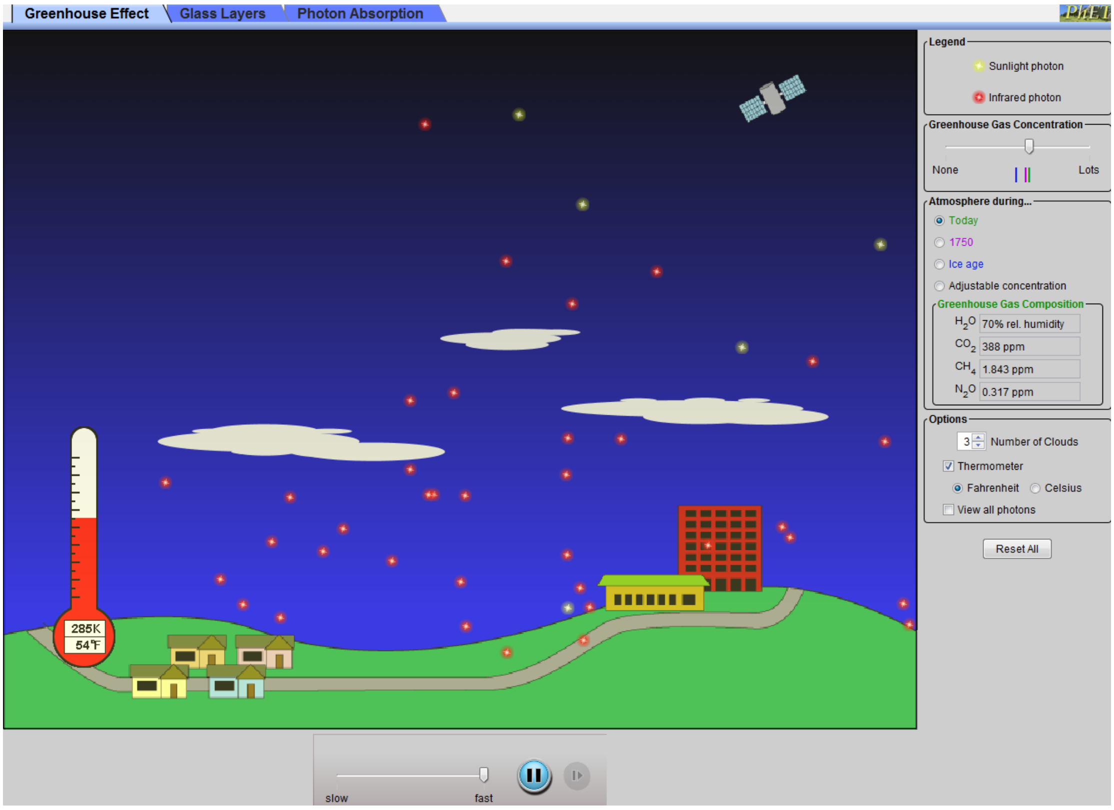


Figure 13. Example of PhET Greenhouse Effect simulation

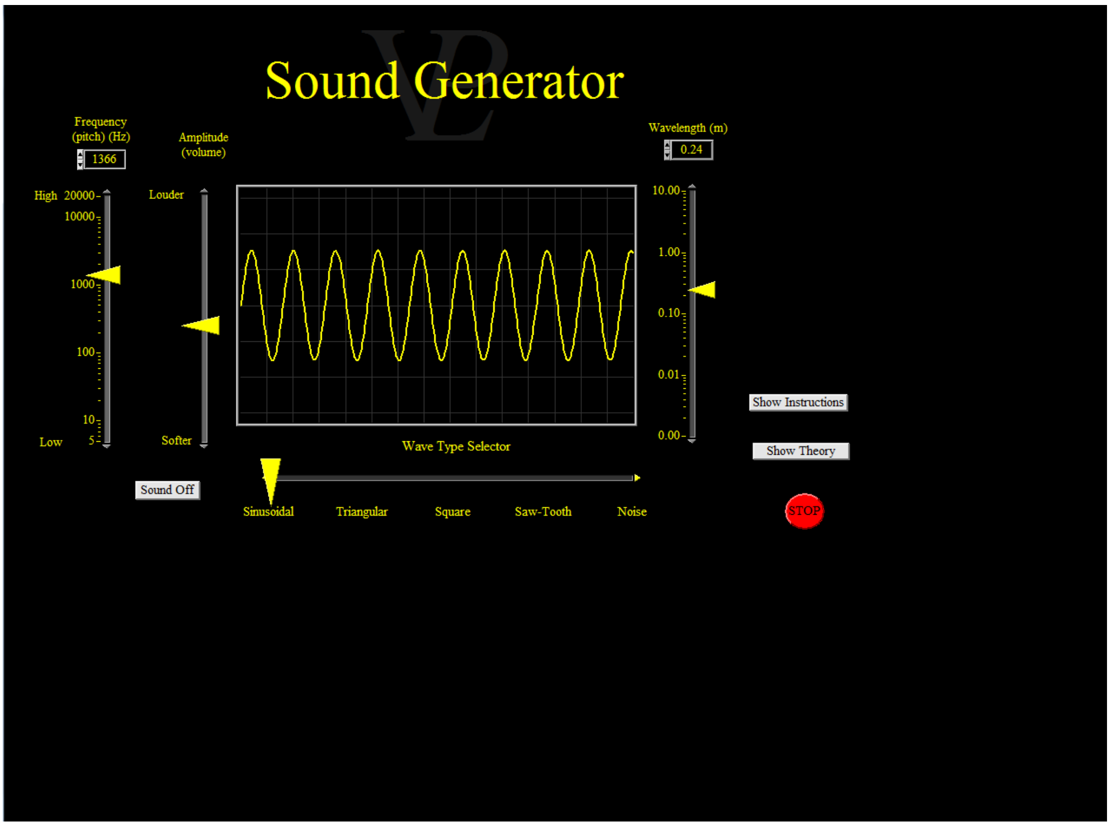


Figure 14. Example of VPLab Sound Generator simulation

The PhET, the VPLab, and other similar websites are examples of the 'virtual and remote laboratories' discussed in 4.1.10 and 4.2.9. Their use in IB World Schools allows students to engage with a wider range of experiments and observations that may otherwise be constrained by physical and budgetary factors. Nevertheless, these simulations were not always lauded by research participants, and caution was advised by one participant who felt that such simulations may not give students the basis of real-world science which is emphasised within the IB Group 4 curriculum documentation as being a feature of scientific study within the IB (e.g. IBO, 2011):

> *I think sometimes you have got to be careful because you don't want to give the students the impression that .. well .. that they can't get a proper realistic view of experimental science if they are using a computer to for example there are .. are packages where you can do virtual chemistry so you have .. you know .. a flask and you pour something in .. and chemical A and chemical B .. and that is fine and that has got its place but .. really there is no substitute in that kind of environment for doing proper experiments (Chemistry and Physics teacher, School F)*

6.5.1.3 Making lesson content

As well as using ready-made content-based materials, teachers also talked about making ICT-based materials for expository purposes. One teacher recorded all his IB mathematics lessons and made them available on the school's VLE for students who had missed lessons or for students to watch again. In other cases, teachers made screencasts or recordings using tablet computers which again were uploaded to the VLE:

> *it's students sitting in a lesson saying yes .. I understand that whatever part of Chemistry or Biology or whatever .. and then they say .. they go away and then confronted with the homework .. "Well .. I could do with hearing that lesson again." So clearly if I am just sat at home with an iPad .. I can literally just record myself teaching that .. for the want of a better phrase .. on to the VLE .. so if they want to hear .. and obviously not every lesson because some of them are quite straight forward .. but some of the more difficult and challenging topics whether it be IB year one or year two .. then they can listen in again (Science teacher, School N)*

> *the kids have got iPads and I create little video tutorials of .. a bit like a white board with verbal commentary and so I am .. I have used video tutorials with my voice over a lot. For the IB with them using Nspire handheld I have created video tutorials and if I have to do certain things on Nspire .. so I give them access to the work solutions to my questions .. I have hand-written work solutions of what you would have to write down and if you had to do this question on the calculator .. how would you do it on the calculator (Maths teacher, School J)*

Making lesson content is another example of how technology has been appropriated in some IB World Schools to enable 'learning from experts'. In section 6.5.1.2 above, on presenting lesson content, the learning from experts took the form of learning from an unknown 'more knowledgeable other' (e-book authors). In this case, the teacher takes on the role of expert themselves and thus becomes a very familiar 'more knowledgeable other' for their students. This role is increasingly seen by some teachers in this study as being lost to the teaching profession, as teaching approaches which are more learner-centered, such as collaborative learning and the use of flipped classrooms, necessitate the teacher to adopt the role of facilitator rather than the more traditional role of one who imparts knowledge.

6.5.1.4 Facilitating inquiry-driven learning

Inquiry-driven learning is the cornerstone of studying in the IB DP. The PhET, the VPLab, and other similar simulation websites discussed earlier in section 6.5.1.2 offer plentiful opportunities for engaging in inquiry-driven learning in the DP science curriculums. Through using these simulations, students can form and test hypotheses, and develop a questioning and critical approach to scientific study. As well as being visually engaging, simulations allow teachers and students to test safely (and cheaply) different solutions to scientific problems and questions.

One participant explained how the use of questioning and discussion within a group-work format can support an inquiry-driven approach using the example of a lesson based on a simulation of the generation of solar power:

> *we do this as a group activity so you can see here .. you can see the sun rising and setting .. first of all we have a discussion about whether or not .. or how will the solar output .. and so what happens is the sun rises .. and this is the energy going from a maximum and what you can do is you can do an ideal day where there is no cloud .. or a real day with cloud so .. these are the solar cells. and so they will follow the sun across the sky to get an optimum amount of energy .. yeah so now what we do .. first of all we .. we have a chat about how that varies within the day .. and that can vary and then we have a discussion about the clouds and the absence of clouds and therefore which part of the world would be best served for solar production and so forth and then this always makes them intrigued ... so what will happen now of course .. is that the output will be less and we talk about why that would be less so they can see that on the trace here and so they have to try explain why it is going to be like that .. (Chemistry and Physics teacher, School F)*

In addition to the use of virtual and remote laboratories, opportunities for inquiry-driven learning are available for IB DP students through the use of graphic display calculators (GDCs). The four IB Mathematics courses all require that students use GDCs for their coursework and during their assessments. The minimum requirements for GDCs within the Mathematics courses are available for reference in Appendix 8. In one case study school, the use of TI-Nspire handheld GDCs was integrated fully into all the mathematics classes in the school. This pattern of adoption was facilitated by one teacher who acted as the TI-Nspire champion, using GDCs in all his classes and mentoring other members of the mathematics department in how to use this particular technology:

> *we have a seven day repeating cycle .. and every day two, period eight and they can come along and talk Nspire stuff .. and a lot of the people doing IB came along to these session and just drip feeding and they said .. how do I do this I have forgotten how to do that .. have you got an activity for teaching this. and so I have supported my staff .. so over the last two or three sessions in that*

> *manner so we have got to the point where the IB teachers .. are all getting okay with the Nspire and they are all helping each other and they are no longer seeing me as the source of all the answers (Maths teacher, School J)*

The use of this GDC was valued by the teaching team in the school for the opportunities and ability it gave students to explore and experiment with different mathematical functions:

> *.. if I look at the Nspire it is about that exploration and they can access any type of function and they can look at any type of function and see how the function is changing [it] is really powerful because before previously to draw everything just took forever so it takes the boredom out of drawing it .. (Maths teacher, School J)*

> *they can now explore themselves rather than us really having to tell them .. (Maths teacher, School J)*

and one teacher made the analogy with an 'electronic playground':

> *it helps my students explore without fear and what I mean with that is .. the graphical calculator environment it is like a playground and whatever you type in the handheld will do and it will do it correctly so you can experiment and try a few things out without fear of getting it wrong and you will get answers that may surprise you and challenge your thinking but you are not going to do anything wrong … it may not be about solving equations by the traditional route but it is correct so it is that ability to have a play .. it is like an electronic playground. (Maths teacher, School J)*

Typically teachers would project the GDC display from one handheld device onto a whiteboard, and then set up mathematical problems for students to work out on their own handheld devices (or on one borrowed from the school). Teachers would then model the correct answer via the handheld device displayed on the screen. An example of this can be seen in Figure 15.

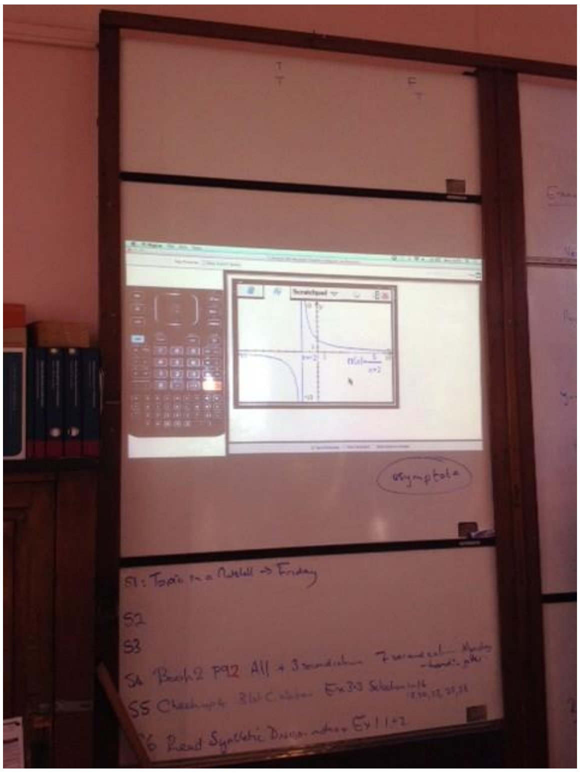


Figure 15. Example of a GDC handheld display projected on to a whiteboard for teaching purposes

One teacher described how using GDCs in this way enables a more learner-centered, inquiry-driven approach to learning:

> *"The lesson is in their [students'] hands and I think that sums up what makes a technology lesson not a traditional lesson. A traditional lesson is someone at the front doing exposition so who is driving the lesson forward. It's the teacher. They have an agenda. They have a certain amount of work they have to get through and so the pace and direction is dictated by them and the students are either on board or not. And if they are not, then they are not going to get on board again very quick. And the nature of using handheld technology is that you have given them something they can explore at their speed and their pace and they bring their ideas to you. (Maths teacher, School J)*

A creative use of technology to facilitate inquiry-driven learning was observed in a biology lesson on auxin generation in shoots. A mobile phone was used to mimic the light source needed for shoots to grow (see Figure 16). Students were given tubs of Play-Doh to hold to represent the shoots, and the light source indicted which direction they should bend in (away from the light due to the distribution of heavy auxin in the shoot). This is not only an example of 'learning through inquiry' but also of 'learning with others' as each student had a part to play in creating the simulation and in constructing a shared understanding of the generation of auxin in shoots. Whilst technology was, in some ways, peripheral to the simulation described above, in section 6.5.2.2 we explain how the use of technology by students themselves in this lesson was essential to further their understanding of the biological processes at work.

Figure 16. A creative use of mobile technology in a demonstration of auxin generation in shoots

6.5.2 Students' uses of technology

As we have shown through earlier research questions, technology provision for student use tended not to be problematic for the schools involved in this study. In many cases, BYOD policies meant that students were able to use their own technology in school, and for students attending private schools, this often meant that they had access to more up-to-date technology than if it had been provided by the school. One IT professional noted "most kids have got their own devices anyway and most of them have devices that are probably superior to what the school would offer and ask the parents to pay for .. so that's makes it fairly difficult conversation to have with the parents" (School J). In one case, a private international school, the school continued to provide laptops to students despite also introducing a BYOD policy, as this suited the wishes of diplomatic parents:

> *we wanted to scrap providing netbooks altogether but then, our diplomatic cohort, they liked to have a device on the school bill because they .. because their country obviously pays for all the schooling so that is why we still keep it included. (ICT professional, School I)*

The specialist technologies used exclusively in science and mathematics classes, such as data loggers and GDCs were, in all cases, supplied by the schools and readily available, although students usually supplied their own GDC. Laptops are used for a wide variety of purposes, but especially within science for working with spreadsheets and accessing databases. These were either brought in by students as part of BYOD, or supplied by the school on an individual basis directly to the student as in the case of the netbooks discussed by the ICT professional at School I above, or alternatively were available in the classroom on a trolley or in a cabinet for students to borrow for the duration of the lesson.

From our observations, we can assert that BYOD facilitates integration of technology for learning in progressive and creative ways, and in schools where BYOD was entrenched we captured examples of innovative practice and these are described below. However, what we would describe as true BYOD was only seen in two case study schools.

In this section we illustrate how students use technology in science and mathematics under the following headings:

Using own devices to support learning in class
Inquiry-driven learning and technology integration
Using technology in assessments

6.5.2.1 Using own devices to support learning in class

In one case study school which had a strong, fully operational BYOD policy for students in the DP, students were observed using their own devices in multiple ways to support their learning in class. These included:

i. Accessing the VLE/LMS/CMS to download resources for use in the lesson
ii. Accessing third party online resources, such as databases and quiz software
iii. Using tablet computers to take photos of whiteboard screens and books

Each of these is elaborated on briefly, below.

i. Accessing the VLE/LMS/CMS to download resources for use in the lesson

In instances where teachers had uploaded resources for the lesson into the VLE/LMS/CMS, students were observed accessing these materials on their own devices during the lesson Figure 17. This allowed them to view those resources more easily than would otherwise have been possible, and to benefit from the hyperlinks provided in the materials which took them to further resources.

Figure 18 is an extract from a paper copy of a resource which was uploaded to a VLE/CMS/LMS by a Chemistry teacher, and also shown on a whiteboard for students to read in the class. Those students accessing the document on their own device, via the VLE, would have been advantaged in easily navigating to the website indicated by the URL and encircled in red in Figure 18.

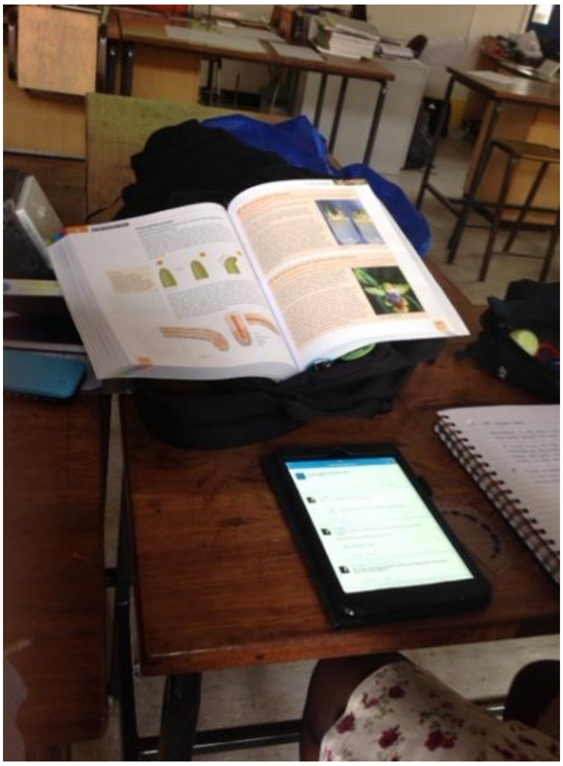
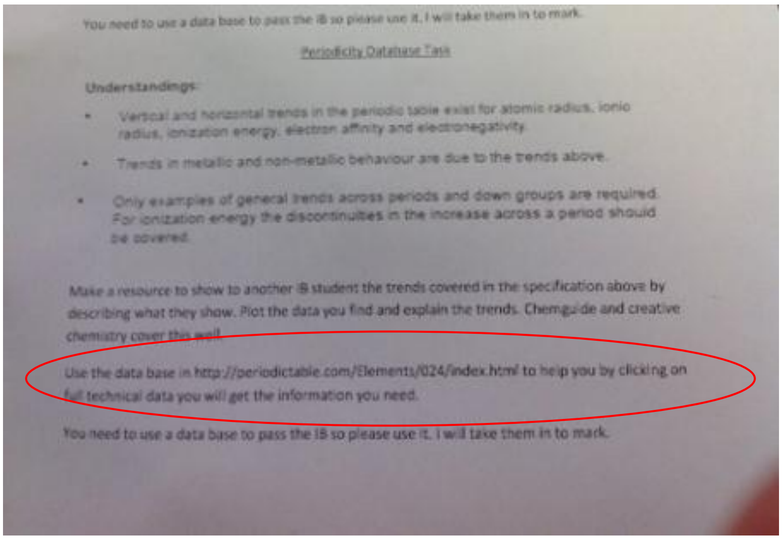


Figure 17. Accessing the VLE 'Edmodo' alongside more traditional 'technologies'



You need to use a data base to pass the IB so please use it. I will take them in to mark.

Periodicity Database Task

Understandings:

- Vertical and horizontal trends in the periodic table exist for atomic radius, ionic radius, ionization energy, electron affinity and electronegativity.
- Trends in metallic and non-metallic behaviour are due to the trends above.
- Only examples of general trends across periods and down groups are required. For ionization energy the discontinuities in the increase across a period should be covered.

Make a resource to show to another IB student the trends covered in the specification above by describing what they show. Plot the data you find and explain the trends. Chemguide and creative chemistry cover this well.

Use the data base in http://periodictable.com/Elements/024/index.html to help you by clicking on full technical data you will get the information you need.

You need to use a data base to pass the IB so please use it. I will take them in to mark.

Figure 18. An extract from a paper copy of a resource uploaded to a VLE/CMS/LMS

ii. Accessing third party online resources, such as databases and quiz software

Integrated BYOD approaches enable hassle-free access to a wealth of learning resources available online. As seen in Figure 18 above, students were frequently directed to third party, external online resources (i.e. not those uploaded by a teacher to a VLE/CMS/LMS or available via an intranet). The image in Figure 19 shows how students could access the database using their own device, and, in this case, simultaneously work on an Excel spreadsheet to gather the relevant data collated from the database.

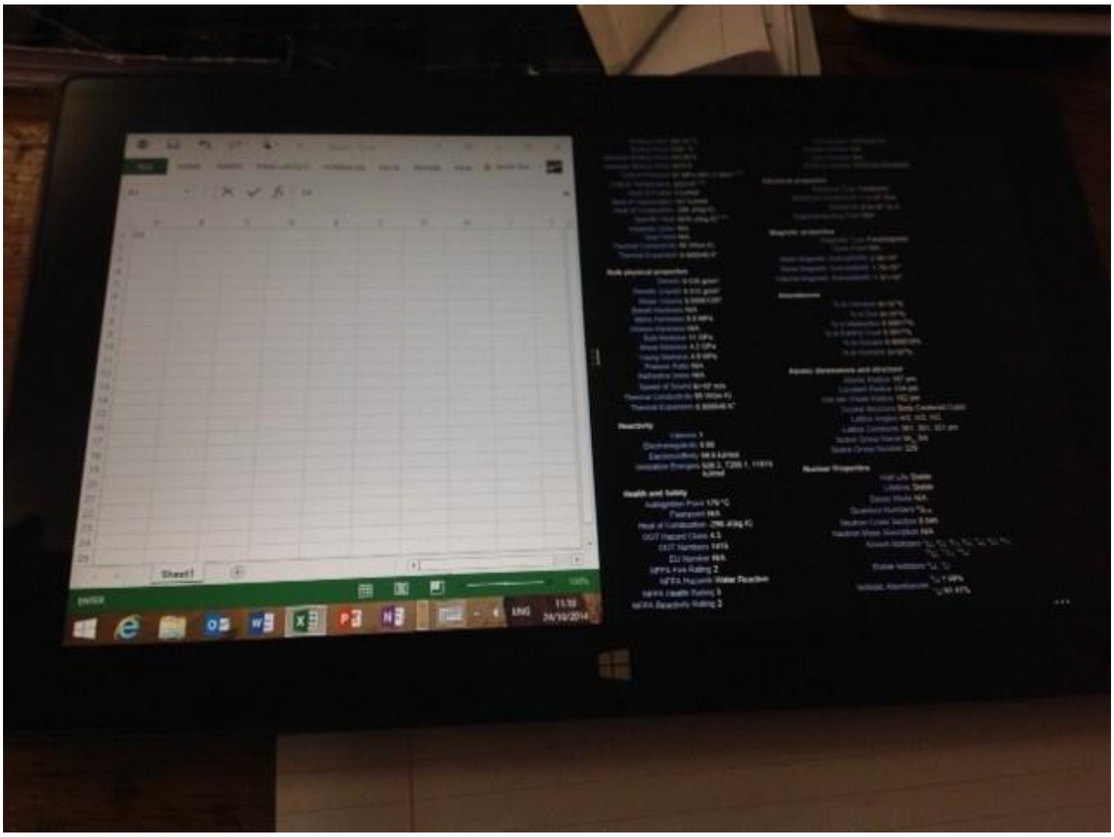


Figure 19. An IB student's own device, used to access an Excel spreadsheet and a database of the periodic table simultaneously

In our observations we also catalogued the use of educational games software, such as 'Zondle[36]', which allowed teachers to run quizzes in class. A class access code was generated by the main site, projected onto a whiteboard. Students then used the code to access the site on their mobile device. In one case observed, the quiz was about definitions of terms in chemistry. The definition was displayed on the board, and students were instructed to select the correct definition from their device. The class view and the student view of this activity can be seen in Figure 20

.

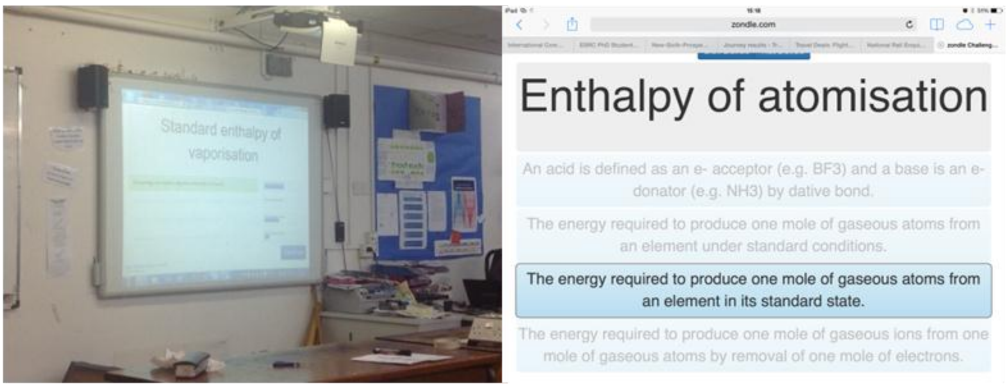


Figure 20. Two views of Zondle used for a quiz on definitions in chemistry

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[36] https://www.zondle.com

iii. Using tablet computers to take photos of whiteboard screens and books

In BYOD rich classrooms, students were frequently observed using their own devices to enable them to see publicly-displayed resources more effectively, or to. retain a permanent record of the resource.

Teachers had reported that this is a use of technology which is particularly useful for students with special educational needs (SEN), but we also observed these actions in students with no disclosure of SEN. Figure 21 shows students working with photos of the whiteboard and photos of a textbook as part of their normal in-lesson activity.

Figure 21. Three views of students working with photos of the whiteboard and photos of a textbook as part of their normal in-lesson activity

6.5.2.2 Inquiry-driven learning and technology integration

In one Year 13 biology lesson (the same lesson as discussed above on auxin generation in roots), students were encouraged to use their personal mobile devices to take photographs of Play-Doh models of shoots reacting to sunlight, in a simulation of time-lapse photography. Whilst such activities are possible with loaned tablet computers, and indeed these were available to students if necessary, by using their own devices, students had ready access to the photographs for further processing after the lesson, and as a record of the class activity. Figure 22 shows the time-lapse simulation in action.

Figure 22. Use of iPads in class for time-lapse simulation photography

In section 6.5.1.4 the use of GDCs by teachers in class was discussed. In observations students were frequently observed using GDCs, often alongside more traditional technologies such as mini-whiteboards and textbooks. The use of GDCs was not limited to mathematics classes, but was also observed in chemistry and physics classes too (Figure 23).

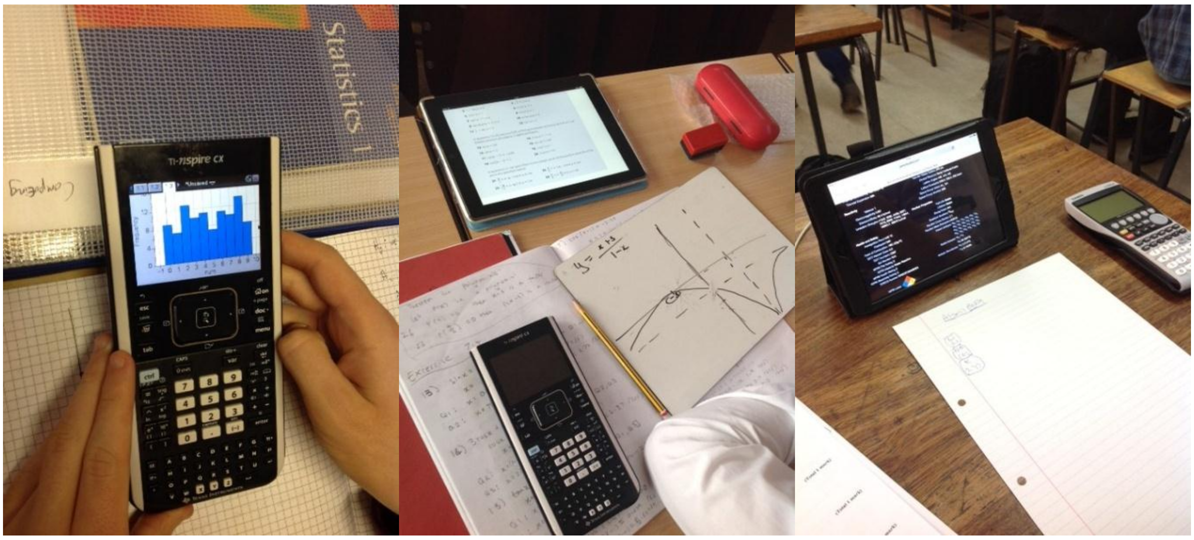

Figure 23. Various uses of GDCs in mathematics and chemistry lessons

One teacher talked about the advantages of GDCs for inquiry-driven learning, and how a simple technology combining GDC calculations, a challenge, and front-of-class integrated projection can prove powerful – if embedded in a clear pedagogic attitude:

> *I wanted to introduce trigonometry. But not using the word 'sine' or 'cosine' etc. I wanted them to see this whole idea of 'opposites' and 'adjacent' and all those sorts of things without any of the technical jargon. To see it in its true essence and concept form…so they discover trigonometry finding their own way orchestrated by passing round materials… what had happened in this previous half hour was that they had discovered what the important things were that had to do with trigonometry and some of them had in fact gone beyond the traditional sine cosine and tangent and were looking at cosec etc. … It just made me realise, depending on how much you package something for delivering to a pupil, it can constrain what they take… opening up allowed them to explore these ideas… what was important was I got them just to play with this geometrical construction then I stopped them I asked them what they noticed from this play time… they told me lots of things (Maths teacher, School J)*

There is an expectation that digital data loggers will be used in IB DP science lessons, and their use by students was either described or evident in all case study schools:

> *And we will use .. you know .. in doing experiments we use .. you know .. data probes and data loggers to .. you know .. to collect things like temperature information or for measuring PH and we use .. you know .. he probes to do that. And then we will use .. you know .. the data logging programmes as well to construct graphs or something like Microsoft Excel if they are .. you know .. they are collecting data .. and it is another way that you can just you know .. import their data and make a graph so .. yeah .. I guess there is a variety of technology that we are using. (Science teacher, School I)*

Figure 24 shows two uses of data loggers in a chemistry lesson. In these cases students were able to engage in inquiry-based learning by forming questions (usually with guidance from the teacher) about what was likely to take place, making predictions about the experiments, forming hypotheses, and testing these out, and then over multiple instances changing the variables of the experiment to help form answers to those initial questions.

Figure 24. Data loggers used for experiments in a) colour saturation in a chemical reaction using a colour wavelength data logger and b) naturalisation of an acid with alkaline using a PH probe, both attached to data collection software

6.5.2.3 Using technology in assessments

One of the main reported ways of using data loggers and other scientific probes was in the Group 4 projects, one of the key assessment activities for science students:

> *… in DP they have an internal assessment component which counts for .. towards their final mark which is about a quarter of the mark about 25% and the DP students they also need to do quite a bit of research in terms of their investigations because they have to design investigations first of all and they have to do data collection and processing and so for these activities we use quite a lot of electronic equipment for example we use data loggers and we use calorimeters (Biology teacher, School I)*

The value of using ICT generally in the G4 projects was appreciated by teachers as being a pedagogically useful activity:

> *… last year I had a student and I had set them an internal assessment where they had to look at photosynthesis .. no they were looking at the rate of an enzyme reaction and they were measuring it in various different ways and one student choose do to it using a .. a data logger that measured gas pressure and so as gas evolved from .. from the reaction she could .. she could get that data directly (Biology teacher, School C)*

In many cases the projects were understood as a way in which the IB DP science curriculum prepares students to work with technology in future careers in industry and other science-related areas.

> *I mean one of the good things about it is the way that they include IT in the practical assessment for Chemistry and Physics there is a .. there is a specific element in that .. so you have to carry out investigations at least once using simulation or spreadsheets or a .. database and data logging …exposing the students to those types of activity actually means that they get an appreciation of how ICT*

can be used and how it is used actually in science and technology now .. and you don't do Science and Technology now without a lot of ICT .. and by simply treating everything as if it is a .. a you know .. pen and paper exercise you are not really replicating the real world experience. (Chemistry and Physics teacher, School F)

Not only do the Group 4 projects allow for practical uses of technology, but they require students to collaborate and learn with others. One participant explained how students also engaged in 'learning by making' – in this case video and multimedia presentations, which in turn were used to develop a bank of resources to enable future students to learn from their expert peers:

They do that with the Group four science project that they do. In the last few years we have set up on the model of having .. because we do film studies as well .. having a film studies student in each group who then they have to do edit a video and we used to do it by .. they spend ages doing it and then they presented them all and it took ages and ages and ages and it just went dead after that .. whereas now they edit video .. testing .. whatever they are testing as their hypothesis and they put it together as a little film .. a short film and then they play that at the end and then we put it up onto Moodle and so we have got a back catalogue of them and that has been really good and really high quality actually. (IB Coordinator, School M)

7 Conclusions and Implications

In this section we reflect on the findings reported above. As anticipated in our Introduction, we have been careful to adopt a critical orientation towards our various conversations and observations. Therefore, the interpretative remarks to be gathered in the present section are the outcome of careful negotiation among three seasoned researchers. We have each spent a period immersing ourselves in the practices of educational colleagues working with the IB curriculum and are now able to offer a summary of what has impacted on us.

This summary is organised in the following manner: First, in 'technology sites' we note the nature of the technology provision we have witnessed. We then reflect on the various forces that recruit this technology into practice (or obstruct its application) in 'making it happen'. This is followed by a section entitled 'pedagogy before technology' in which we acknowledge the importance of having pedagogy as the driver of innovations with technology. A position that then allows us to reflect on what we have seen happening in terms of how technology enters into the range of 'learning acts' that constitute a rich educational experience in 'technology and acts of learning'. Next, we offer some remarks on the relationship between digital tools and the particular culture and values that we identify with the IB vision in 'technology and IB fellowship'. Finally, we suggest some implications for the IBO with regard to technology integration in science and mathematics in the DP for UK schools.

7.1 Technology sites

It must be stressed that the IB science and mathematics curriculums are found in a variety of institutional contexts. In many of the schools we engaged with, it was offered alongside a wide range of alternative curriculums, all being delivered by a parent institution. In making any generalisations regarding provision it is therefore necessary to think not in terms of 'IB technology', rather in terms of the 'technology contexts for IB'. Put another way: IB practitioners are often adapting to the technical affordances and constraints of policies formulated in the wider context of a host institution. However, this does not mean that individual practitioners or individual departments were not able to shape their own local preferences and practices: but they will typically be doing so within the frameworks of wider contexts.

We were struck by the central role of two major and somewhat oppositional digital structures: one suggesting an image of centralisation in technology provision and one suggesting an image of fragmentation, or distribution.

The centralising structure is expressed in the various forms of learning platform that are universally present in schools. Usually these are commercial VLEs but in the rare cases where the VLEs not installed, schools had mobilised thinner versions of these environments (such as Edmodo) in order to manage the portfolio of their resources and an infrastructure for internal communications.

The structure of fragmentation took the form of a growing uptake of portable and personal digital devices and a network infrastructure to ensure their greater scope of use. Increasingly, these devices were taking the form of tablets, particularly the iPad.

We found the installation and technical management of the VLE+WiFi configuration (section 6.1.1 and 6.1.2) was typically in good order. However, the extent to which this configuration was being exploited pedagogically varied and this is something we see as an area of great opportunity. For example, the uploading of course support material by individual members of staff was often described as patchy and it was unusual to hear about well-developed practices of homework assessment and feedback taking advantage of this networked infrastructure. In only a few cases had the social networking potential of a learning platform been actively cultivated (through the use of blogs and discussion boards in particular).

Recent consumer enthusiasm for powerful but small digital devices has been embraced by many schools; tablets or laptops therefore were widespread in the schools that we have engaged with. This is undoubtedly a force for coordination and the cultivation of common experience. In some schools it had been institutionalised in the form of a 'bring your own device' (BYOD) policy (section 6.1.3). Broadly, speaking this was welcomed and although familiar concerns were expressed regarding playful multi-tasking with these personal devices, distraction was not regarded as a major challenge to creative application, especially for the students studying the DP curriculum.

Generally speaking, schools and individuals are no longer citing access to useful technologies as the major obstacle to their ambitions, therefore schools could be advised on the advantages of fully-integrated BYOD policies and ways to manage their implementation.

7.2 Making it happen

Although we sought out evidence, we were not aware of any widespread presence in these schools of tightly formulated ICT strategies (section 6.1.4). More common, was a tolerance of mixed pedagogic solutions. It was often stated that there was an expectation for staff to usefully populate the learning platform, yet it was clear that this was a prescription that was not always vigorously actioned.

Informants were often given to noting the challenge (or opportunities) associated with students increasingly presenting as 'digital natives'. This seemed an awareness that was driving the need to recruit technology (particularly personal devices) into pedagogic practice. Some teachers saw the affordances of the technology as a welcome opportunity to handle abstract concepts in a medium that resonated for their students. An awareness of the natural appeal of ICT could therefore be a source of inspiration for teachers to orient their students towards it.

Although the digital native discourse was a common framework for making sense of the need to mobilise technology, it was less common to hear motives expressed in terms of the world of work or the world of life beyond school. This is surprising given the current political imperative around employability, and an argument could be made for the importance of providing opportunities for students to use technology in ways which mimic real-world experiences. For example, in one school we learned how students are punished for using phones, even when they are using them for calendar appointments to help remind them of daily schedules. As one informant from this school noted, "we all use technology in that way now .. and yet schools have a way to catch up with that".

One other distinctive pedagogic perspective on technology arose sufficiently often in our conversations to be worth highlighting here. That is the challenge of student differentiation: or responding to individual learning needs. Technology was regarded as a way of supporting students with individual learning needs, especially in those schools with well-integrated BYOD policies which allowed students to adapt and customise their own technologies for learning support. In schools where the affordances of infrastructure did not make this possible, it was seen as a potentially strong motivation for working on ensuring deeper integration of technology. Whilst policies relating to infrastructure are typically implemented at school level, we feel that there is scope for the IBO to guide schools and teachers towards effective differentiation practices which incorporate ICT, and to offer CPD opportunities in this area.

'Making it happen' is something that does arise out of the perception and sensitivity of individual teachers, but innovation is also something that needs to be seeded through the examples and experience of other practitioners. We have discussed this in section 6.1.5. Our strong impression was that provision of technology-related CPD was mixed. In some cases it was very rare or very light touch. In others it was frequent and collegial. Many informants commented that they were conscious of the fast moving nature of the resource field and conscious of their own inability to keep up with that pace of change.

In the face of this problem, the most effective forms of inspiration, encouragement and support comes from trusted colleagues, although they need not be part of the same institutional community. There are clearly opportunities to make use of the technology itself to serve this training and support needs. Some schools had put in place forms of online training provision via their VLE and this was a welcome development. Some teachers made use of external websites where practice was discussed and resources exchanged. These sites included the OCC which could continue to be a useful source of example. Finally, teachers might be encouraged to see the potential of social media as a means of linking with others in the profession and we encountered one example where Twitter was being actively employed in this spirit.

We were not surprised to discover that the two most common obstacles reported concerning innovation were pressures of time and pressures of formal assessment. Not surprised, because these are the most extensively documented obstacles in the research literature. However, one particular gloss on this situation is provided by the particular circumstances of the IB. While it was acknowledged that the IB formal guidance on incorporating technology was a welcome incentive and source of ideas – it was also noted that the overall structure and time-constrained nature of the programme did not readily accommodate design initiatives that went beyond traditional expository formats. Allowing more time within the DP science and mathematics curriculum for students to engage with inquiry-driven uses of technology may have the potential to enhance the contemporary pedagogical experience of those students and, in future, to allow them to reap the rewards of their learning when working in real-world environments.

7.3 Pedagogy before technology

In our introduction we stressed that technology should not become the driving force in a project of the present kind. For example, we invoked arguments that cast technology as a 'carrier' or 'vehicle' for the potent interactions of teaching and learning. This was not to deny the distinctive opportunities arising from adopting new technology – as, often, digital tools provided a more economical or comfortable solution for creating the desired interactions. However, this always should imply that innovation and implementation should be driven by pedagogy itself.

We felt that many of our informants were conscious of this imperative. And we had many conversations where it was apparent that the technology must be seen to be adding value to standard practice and not a fashionable appendage. As one teacher commented: "It's often been: 'here's a tool that you could use and build a lesson around.' But this file itself is not the lesson it's the conversation you have with it. It's the thinking that the students bring to the table." Indeed 'the file is not the lesson' might make a good slogan for stressing the need to put pedagogy in front of technology in the process of innovation.

7.4 Technology in 'acts of learning'

In section 4.6 we offered a framework (adapted from earlier successful work) that did attempt to put a pedagogical emphasis on innovation. We identified a set of 'learning acts' that we suggested would underpin any versatile programme of educational experience. Thinking of the mediating role of technology through this framework, we are able to ask how far the examples of innovative practice shared with us by informants exercised the full range of these learning acts.

Our feeling is that this range is not being fully exploited. It is important to stress that this should not necessarily be taken as a criticism of the imagination or energy of the practitioners who were our informants. They were typically acting within the constraints of one or all of the following: school policies; school priorities; the curriculum; and modes of assessment. Moreover, they were, most evidently, acting within constraints of preparation and delivery time. It remains important to illustrate the shape of the investment pattern of innovating technology across acts of learning. We discuss the most prominent first, and then move towards the most neglected, where this is most potential.

7.4.1 Exposition

It is widely understood that exposition remains a central part of the learner's educational experience. We mean by that term any direct encounter with the voice or text of an 'experienced other' (teacher or expert) for example in presentations by PowerPoint, or video. There were references in our conversations to 'text' in the form of e-books (see section 6.5.1.2) but generally these had not been widely adopted – for example in relation to BYOD contexts. On the other hand, technology was playing a significant role in enriching teacher led demonstration. This was most apparent through examples of enhanced possibilities for *visualising* abstract or multi-dimensional concepts and structures.

7.4.2 Exploration

After exposition, a common form of experience involved creating the conditions for the *exploration* of some science or mathematics topic. This was usually approached in terms of asking students to find and then engage with science and mathematics resources online, or perhaps to engage with resources which teachers directed students towards. As our findings in 6.1 indicate, the internet was readily available in all schools for these exploration activities by teachers and students to be successful, but as also suggested there and in section 7.1, the affordances of BYOD open up exciting and dynamic possibilities in this area.

7.4.3 Inquiry

An 'inquiry learning' experience is a formalisation of exploration in which the student generates hypotheses, collects data, makes interpretations, and develops new hypotheses in an iterative cycle of development. Technology can be very useful in mediating such structures – which are otherwise time consuming and demanding of careful orchestration.

Inquiry was often cast in terms of the importance of transporting students from a space of exposition to a space of "doing things". Often this "doing" took the form of teacher-orchestrated inquiry based upon the principle of simulation. Technology was much admired for the ease with which it brought into the students' reach systems that would be difficult to offer as real-world experiences. Moreover, this contact allowed them to 'inquire' in the sense of manipulating system parameters and observing the impact of their activities. Such experiences can be extended further in the form of what are sometimes termed 'virtual laboratories', meaning that the manipulations that can take place around some simulation are transferred from the realm of mere observation to the structure of a formal experiment. Finally, the importance of inquiry was sometimes expressed in relation to the importance of making it a 'playful' experience, as witnessed in section 6.5.1.4.

Learning through inquiry is a central tenet of the IB DP curriculum, and thus a familiar mode of knowledge-building for DP teachers and students. Our findings suggest that technology is becoming, if it has not already become, a means by which inquiry can be fully embedded into the science and mathematics curriculums. In cases where teachers use technologies to support inquiry-driven learning they express astonishment at the thought of not being able to draw upon these resources. Where there is scope for further adoption of technologies in this realm, schools and parents should be strongly encouraged to do so. Technology-aided inquiry-driven learning is both accessible and commonplace, and is in accordance with the IB DP principles and policies for student development in the 21st century.

7.4.4 Making

Technology offers many opportunities for learning based around the fashionable idea of a school creating a 'maker culture'. Traditionally such construction has been associated with the mainstream computer science activity of coding. However, there are a wider range of digital artefacts that can fall into this category of learning act and in this report we have discussed a small number of compelling examples.

The Group 4 projects in the science curriculum offer opportunities for this type of learning, and these were discussed in section 6.5.2.3, but again, this kind of 'making' investment was often discussed in conjunction with the demand on preparation and learning time. As we have stated elsewhere, a more flexible and less time-constrained DP science and mathematics curriculum may provide important space for both teachers and students to engage in these important skill-building learning activities.

7.4.5 Assessment

It is the *feedback* exchanges of assessment that define value for this 'learning act'. There are such possibilities for stimulating feedback offered by shared access to networked technology. However, we did not find it common to refer to learning platforms as a site for such feedback exchanges, although some teachers did use the school's VLE/CMS/LMS for such purposes. Some teachers were starting to explore more creative possibilities, for example, students making multimedia presentations as part of their Group 4 assessments (see section 6.5.2.3), yet overall creative resources were not mapped as part of a widespread offering. Given the ubiquitous nature of assessment, and the possibilities open to IB World Schools in the form of such approaches as the Group 4 projects, we purport that this aspect of technology integration, arguably more than any other, is ripe for development within the IB DP science and mathematics curriculums.

7.4.6 Learning with others

We were surprised to find relatively few references to the role of technology in organising for *collaborative* work. This is not to suggest that group work was uncommon within these schools: we do not believe this to be so. However, digital technology was not often discussed in terms of this particular affordance.

The form that it might take is not simply the possibility of working at the same device synchronously (although ubiquitous tablet devices make this a less practical, and perhaps less appealing, working arrangement). Technology may also support forms of less synchronous collaboration through network structures. To some extent this may be resisted because of the perceived popular culture (and distractions) of mainstream social networks such as FaceBook or Twitter.

Given the strong collaborative ethos of IB World Schools and the access to international networks available to them, the possibilities offered by technologies to facilitate 'learning with others' is great, and the scope for offering support in terms of network infrastructure and practical guidance is extensive.

7.4.7 Learning across settings

This refers to learning which is extended beyond the classroom setting, and therefore might otherwise often be termed 'mobile learning'. Mobile technologies can offer a valuable means of extending learning outside the classroom, but while we experienced many references to the value of personal handheld devices, these were less often discussed in the context of fieldwork opportunities. In one case this was because fieldwork had been considerably reduced due to financial constraints, and elsewhere because the role of mobile technologies in the management of outdoors fieldwork was regarded as a daunting and unfamiliar possibility. The affordances of handheld technology therefore seemed to be more often contained to the traditional laboratory.

Virtual learning environments are also a form of support for learning in and across settings, as they enable access to traditionally school-centered resources from the home or individual study environment. As shown in section 6.1.2, the use of VLEs was widespread in our participant schools, and science and mathematics teachers talked fairly extensively about their use of these systems. We can conclude that virtual learning environments are being developed and resourced and that the opportunities this gives students for learning across settings are therefore extensive. A detailed understanding of the extent to which students are making use of these opportunities to access learning resources outside school environments is beyond the scope of the present study.

8 Endnote

Technology integration in the IB DP science and mathematics curriculums was a feature of all the schools which participated in this study. Hardware and software infrastructures were generally robust and the importance of maintaining strong systems was a given in all schools we had contact with. We identified affordances and challenges of technology integration in schools, which may help inform IB policy with regards to ICT, not just in science and mathematics, but possibly across other DP subject areas. We identified a range of teaching and learning activities around and through technology, and patterns of use associated with these. And, finally, we portrayed how technology is used in the classroom by teachers and students through a range of data-driven examples drawn from our case study observations.

Part of our goal within this project was to identify innovative practices. Whilst technology integration was a feature of the schools we visited, it was not typically and consistently innovative. For example, we did observe the use of technology to support feedback and assessment procedures in the form of the online and interactive quiz shown in section 6.5.2.3. However, we struggled to identify what might be called exciting pedagogical practices, such as using technology to enable collaboration between students in different parts of the world or within the UK, or the use of programming as a way of helping students to actively construct knowledge (although we did observe the making of Lego Mindstorm robots within one school but not as part of the IB DP). Whilst we had hoped for greater surprises in this regard, the outcome was perhaps not unexpected. As we discussed in section 4.1 there is a long history of relative disappointment in this field, and although we did in that section refer to 'a new level of anticipation and optimism' (p. 14) regarding the educational potential of new technologies, realistically it may take some years for this to emerge in everyday practice.

Given the emphasis within the IB culture on international linking, we were particularly surprised not to find technology more often implicated in the cultivation of such links. It is possible that the central organisation of the IB could do more to seed this possibility. Although when we discussed this we were made aware of the practical obstacles that might be encountered in making this an inclusive activity, such as available bandwidth for synchronous communication with schools in other parts of the world, particularly developing countries (Uganda was given as an example, by one participant, as a country where the school has a partner, but where bandwidth issues would be problematic). However, there is another sense in which technology might be involved in strengthening the fellowship of the IB community – that is in relation to schools *within* a country context. In the UK, the relatively dispersed and diverse nature of the community of IB sites could make this a practical solution for some.

Nevertheless, there is cause for celebration in the potential for considerable advances in technology integration for an organisation, such as the IBO, with a stated dedication to embedding such practices. The fact that access to useful technologies does not seem to be an impediment for teachers and students in DP schools could be taken as an opportunity for increasing both the guidance on how technology can be used and the requirements for its use. Examples of appropriate guidance could consist of frameworks for allowing teachers to easily connect with teachers in other schools and countries in order to set up collaborative work projects, or individual or group communications amongst students. These frameworks could exist either through a resource such as 'Global Exchange' or through new developments. Other examples of appropriate guidance could take the form of 'video solutions' for GDCs to support the teaching of mathematics. Ways in which ICT integration could be further required, or strongly encouraged, could be to increase the likelihood of students working together to support each other in their learning through the adoption of stylus-type technologies for use with tablet computers for 'writing' scientific and mathematical notation. Just as GDCs are currently a requirement within the mathematics curriculums, so could stylus technologies become a requirement for coursework and assessment within chemistry, physics and mathematics. Students could then be empowered to record their own solutions to mathematical or scientific problems and exchange them with others through a shared network. Another supportive framework is to encourage teachers to reflect on the breadth of learning activities with which they wish their students to engage, such as the framework of learning acts used in this report. In this way, they could consider how technology could support their learners to move beyond expository activities so commonly observed into more innovative pedagogical practices such as learning by inquiry and across contexts.

We conclude by noting in our direct contact with IB practitioner colleagues and their institutions, we encountered circumstances and individuals that were receptive to innovation and development. Technical infrastructures were typically in good order for such innovations, and attitudes were receptive and creative. The challenge is to address the design and deliver of the curriculums to make the necessary space – for invention, reflection and sharing. We would urge the IB organisation to support such opportunities.

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10 Appendices

10.1 Appendix 1: Examples of Group 4 documentation referring to technology use

The aims of Diploma Programme Group 4 Subjects (IBO, 2011)

Through studying any of the group 4 subjects, students should become aware of how scientists work and communicate with each other. While the "scientific method" may take on a wide variety of forms, it is the emphasis on a practical approach through experimental work that distinguishes the group 4 subjects from other disciplines and characterizes each of the subjects within group 4. It is in this context that all the Diploma Programme experimental science courses should aim to:

1. provide opportunities for scientific study and creativity within a global context that will stimulate and challenge students

2. provide a body of knowledge, methods and techniques that characterize science and technology

3. enable students to apply and use a body of knowledge, methods and techniques that characterize science and technology

4. develop an ability to analyse, evaluate and synthesize scientific information

5. engender an awareness of the need for, and the value of, effective collaboration and communication during scientific activities

6. develop experimental and investigative scientific skills

7. develop and apply the students' information and communication technology skills in the stud of science

8. raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology

9. develop an appreciation of the possibilities and limitations associated with science and scientists

10. encourage an understanding of the relationships between scientific disciplines and the overarching nature of the scientific method.

Chapter on The Use of ICT from Group 4 subject guides

Group 4

The use of ICT

In accordance with aim 7—that is, to "develop and apply the students' information and communication technology skills in the study of science"—the use of information and communication technology (ICT) is encouraged in practical work throughout the course, whether the investigations are assessed using the IA criteria or otherwise.

Section A: use of ICT in assessment

Data-logging software may be used in experiments/investigations assessed using the IA criteria provided that the following principle is applied.

The student's contribution to the experiment must be evident so that this alone can be assessed by the teacher. This student's contribution can be in the selection of settings used by the data-logging and graphing equipment, or can be demonstrated in subsequent stages of the experiment.

(When data logging is used, raw data is defined as any data produced by software and extracted by the student from tables or graphs to be subsequently processed by the student.)

The following categories of experiments exemplify the application of this principle.

1. Data logging within a narrowly focused task

Data-logging software may be used to perform a traditional experiment in a new way.

Use of data-logging software is appropriate with respect to assessment if the student decides and inputs most of the relevant software settings. For example, an investigation could be set up to monitor a person's breathing capacities while on an exercise bike using a spirometer sensor linked to a calculator-based data logger in which the student controls the level of exercise (speed or workload). Data-logging software that automatically determines the various settings and generates the data tables and graphs would be inappropriate with regard to assessment because the remaining student input required to investigate the breathing capacities would be minimal.

If the experiment is suitable for assessment the following guidelines must be followed for the DCP criterion.

Data collection and processing: aspect 1

Students may present raw data collected using data logging as long as they are responsible for the majority of software settings. The numerical raw data may be presented as a table, or, where a large amount of data has been generated, by graphical means. For example, the student should set the duration and rate of the sampling, and the generated data in the form of lists of measurements from the calculator or computer could be downloaded by the student into a computer spreadsheet. Students must organize the data correctly, for example, by means of table or graph titles, columns or graph axes labelled with units, indications of uncertainties, associated qualitative observations, and so on.

The number of decimal places used in recorded data should not exceed that expressed by the sensitivity of the instrument used. In the case of electronic probes used in data logging, students will be expected to record the sensitivity of the instrument.

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Data collection and processing: aspects 2 and 3

Use of software for graph drawing is appropriate as long as the student is responsible for most of the decisions, such as:

- what to graph
- selection of quantities for axes
- appropriate units
- graph title
- appropriate scale
- how to graph, for example, linear graph line and not scatter.

Note: A computer calculated gradient is acceptable.

In the example of the investigation to monitor breathing capacities, the student could process data by drawing a graph in the spreadsheet and measuring the breathing frequency from the data. By inspecting the graph or spreadsheet data, the maximal and minimal lung volume values could be identified and used to calculate the mean tidal volume at rest. The mean volume of air breathed per minute and recovery rate after exercise could also be calculated.

Statistical analysis carried out using calculators or calculations using spreadsheets are acceptable provided that the student selects the data to be processed and chooses the method of processing. In both cases, the student must show one example in the written text. For example, the student must quote the formula used by or entered into a calculator and define the terms used, or the student must write the formula used in a spreadsheet if it is not a standard part of the program's menu of functions (for example, mean, standard deviation).

2. Data logging in an open-ended investigation

Data-logging software can enhance data collection and transform the sort of investigations possible. In this case fully automated data-logging software is appropriate with regard to assessment **if** it is used to enable a broader, complex investigation to be undertaken where students can develop a range of responses involving independent decision-making.

For example, a task could be set to investigate a factor that affects the rate of photosynthesis. If an oxygen sensor with automatic pre-programmed software to monitor the amount of oxygen released by an aquatic plant is used, the student could use the program to develop a broader, complex investigation, for example, comparing rate of photosynthesis in different species of aquatic plants at different light intensities.

Design: aspect 1

The student must state a focused problem/research question, for example: "What is the difference in the rate of photosynthesis at different light intensities, as measured by oxygen release, between *Elodea canadensis* and *Myriophyllum spicatum*?"

Relevant variables must also be identified, for example:

- independent variable—species of aquatic plants
- dependent variable—rate of oxygen production
- controlled variables—temperature, mass of plant, leaf surface area, time, light quality (wavelength).

Design: aspect 2

The student must design a method to monitor and control the variables (for example, a water bath for control of temperature), use an electronic balance to determine the mass of the plants, and use the same light source to control light quality.

Design: aspect 3

The student must design the method for the appropriate collection of sufficient raw data. The student would select the species of aquatic plants to use, and measure the amount of dissolved oxygen in the water using the oxygen sensor program. The student would also decide on the range and number of different light intensities and the number of experimental replicates.

Data collection and processing: aspect 1

Appropriate raw data would consist of the rates of photosynthesis derived from the graphs of the experimental runs generated by the program using the oxygen sensor. These rates of photosynthesis may be calculated by the student using a function on the program that analyses the graphs. This must be done without prompting by the teacher. The derived data for rates of photosynthesis could be annotated on a series of graphs or presented in a table with an appropriate title, column headings and units. Calculation of uncertainties would not be expected in this experiment. In addition, other important data should be recorded, for example, water temperature.

Data collection and processing: aspect 2

The graphs showing changes in oxygen concentration would not be assessed, as these would have been generated automatically by the pre-programmed software on the data logger, without input from the student. However, the rates of photosynthesis derived from these graphs could be plotted against light intensity for each species using graph-plotting software where student input is possible, for example, choice of type of graph, x and y axes, range and scale.

Data collection and processing: aspect 3

The student would generate graphs of light intensity versus rates of photosynthesis for each species, which should have clear titles, correctly labelled axes, a legend for the data of the different species of plants, and trend lines to reveal the degree of uncertainty.

Section B: use of ICT in non-assessed practical work

It is not necessary to use ICT in assessed investigations but, in order to carry out aim 7 in practice, students will be required to use each of the following software applications at least once during the course.

- Data logging in an experiment
- Software for graph plotting
- A spreadsheet for data processing
- A database
- Computer modelling/simulation

There are many examples of the above in the ICT resources for biology, chemistry and physics on the OCC.

Apart from sensors for data logging, all the other components involve software that is free and readily available on the Internet. As students only need to use data-logging software and sensors once in the course, class sets are not required.

The use of each of the above five ICT applications by students would be authenticated by means of entries in the students' practical scheme of work, form 4/PSOW. For example, if a student used a spreadsheet in an investigation, this should be recorded on form 4/PSOW. Any other applications of ICT can also be recorded on form 4/PSOW.

10.2 Appendix 2: Examples of Group 5 documentation referring to technology use

The aims of Diploma Programme Group 5 Subjects (IBO, 2012, p. 8)

The aims of all mathematics courses in group 5 are to enable students to:

1. enjoy mathematics, and develop an appreciation of the elegance and power of mathematics
2. develop an understanding of the principles and nature of mathematics
3. communicate clearly and confidently in a variety of contexts
4. develop logical, critical and creative thinking, and patience and persistence in problem-solving
5. employ and refine their powers of abstraction and generalization
6. apply and transfer skills to alternative situations, to other areas of knowledge and to future developments
7. appreciate how developments in technology and mathematics have influenced each other
8. appreciate the moral, social and ethical implications arising from the work of mathematicians and the applications of mathematics
9. appreciate the international dimension in mathematics through an awareness of the universality of mathematics and its multicultural and historical perspectives
10. appreciate the contribution of mathematics to other disciplines, and as a particular "area of knowledge" in the TOK course.

Statement of technology use from IB DP Group 5 subject guides (e.g. IBO, 2012, p.12)

Technology

Technology is a powerful tool in the teaching and learning of mathematics. Technology can be used to enhance visualization and support student understanding of mathematical concepts. It can assist in the collection, recording, organization and analysis of data. Technology can increase the scope of the problem situations that are accessible to students. The use of technology increases the feasibility of students working with interesting problem contexts where students reflect, reason, solve problems and make decisions.

As teachers tie together the unifying themes of **mathematical inquiry, mathematical modelling and applications** and the **use of technology**, they should begin by providing substantial guidance, and then gradually encourage students to become more independent as inquirers and thinkers. IB students should learn to become strong communicators through the language of mathematics. Teachers should create a safe learning environment in which students are comfortable as risk-takers.

Teachers are encouraged to relate the mathematics being studied to other subjects and to the real world, especially topics that have particular relevance or are of interest to their students. Everyday problems and questions should be drawn into the lessons to motivate students and keep the material relevant; suggestions are provided in the "Links" column of the syllabus. The mathematical exploration offers an opportunity to investigate the usefulness, relevance and occurrence of mathematics in the real world and will add an extra dimension to the course. The emphasis is on communication by means of mathematical forms (for example, formulae, diagrams, graphs and so on) with accompanying commentary. Modelling, investigation, reflection, personal engagement and mathematical communication should therefore feature prominently in the DP mathematics classroom.

10.3 Appendix 3: Ethics documentation

Surveys

ICT provision in your school

Welcome to the survey! Information on our project

What is the project about?

The focus of this project is on the integration of technology in the 'Diploma Programme' provided by International Baccalaureate Organization (IB). We have been asked by the organising body for this programme to look specifically at the use of Information Communication Technology (ICT) in science and maths courses, including any examples of innovation in those areas.

What are the aims of the research?

This project has three broad aims regarding technology and science and maths courses in the Diploma Programme:

1. We want to find out how technology is integrated with (IB) teaching and learning.
2. We want to find out about teachers' and students' experiences with any such integration.
3. We want to identify examples of good practice.

Who else is involved?

We are inviting a number of IB schools across the UK to be involved.

What sorts of methods are being used?

The present survey will be administered to the person most familiar with ICT provision in the school. There will be a second survey administered to teachers of Diploma Programme Science and Maths classes.

What are you being asked to do?

We are asking you to complete this online survey to help us learn about the ICT infrastructure in your school. We estimate that it will take around 5 minutes of your time.

Do you have to take part?

Your participation is entirely voluntary. It is important you understand that you do not have to participate in the project at all, and that you can decide to withdraw from any participation at any point. Your survey responses will be electronically and securely stored. We are committed to carrying out our research according to the ethical guidelines provided by the British Educational Research Association (online at http://tinyurl.com/6r5juen).

Who is paying for this research and who is carrying it out?

The research has been commissioned by the International Baccalaureate Organization in order to help them evaluate the effectiveness of their programme. It is hoped the research will help teachers further integrate technology in IB schools. The work is being undertaken by researchers from the University of Nottingham School of Education. The team is led by Professor Charles Crook -- if you have any questions or concerns about the research you can contact him or other members of the project team by email or by phone:

Professor Charles Crook (Principal Investigator)
e: charles.crook@nottingham.ac.uk
p: 0115 8466453

Professor Shaaron Ainsworth (Co-Investigator)
e: shaaron.ainsworth@nottingham.ac.uk
p: 0115 846 7671

Dr Lucy Cooker (Co-Investigator)
e: lucy.cooker@nottingham.ac.uk
p: 0115 951 4437

Dr Natasa Lackovic (Research Assistant)
e: natasa.lackovic@nottingham.ac.uk
p: 0115 84 67672

You can also raise issues with the Research Ethics Committee, University of Nottingham School of Education
educationresearchethics@nottingham.ac.uk

On the next page, we will ask you to give your consent to participating in this pilot survey.

Your agreement to participate

Conditions of consent to participate

By proceeding with this survey and submitting a return of your responses you confirm the following. That:

_ I have read the 'Information for potential participants' and the nature and purpose of the research project has been explained to me.

_ I understand the purpose of the research project and my involvement in it.

_ I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.

_ I understand that information gained during the study may be published.

_ I understand that data will be stored in a way that does not reveal my identity on a password protected machine and that only the research team will have access to this data. It will not be held longer than 2020.

_ I understand that I may contact the Principal Investigator or other researchers if I require further information about the research, and that I may contact the Research Ethics Committee of the School of Education, University of Nottingham, if I wish to make a complaint relating to my involvement in the research.

Technology in science and maths

About this study

What is the project about?
The focus of this project is on the integration of technology in science and mathematics classes. We have been asked by the International Baccalaureate Organization to look specifically at the use of Information Communication Technology (ICT) in science and maths courses, including any examples of innovation in those areas.

What are the aims of the research?
This project has three broad aims regarding technology and science and maths courses:
1. We want to find out how technology is integrated with teaching and learning.
2. We want to find out about teachers' and students' experiences with any such integration.
3. We want to identify examples of good practice.

Who else is involved?
We are inviting a number of IB Diploma Programme schools across the UK to be involved.

What sorts of methods are being used?
Data will be collected in a number of ways. We want to understand the experiences and views of both teachers and students. In particular this will involve the present survey that will be administered to teachers in a number of IB schools.

What are you being asked to do?
We are asking you to complete this online survey. We estimate that it will take around 10-15 minutes of your time.

Do you have to take part?
Your participation is entirely voluntary. It is important you understand that you do not have to participate in the project at all, and that you can decide to withdraw from any participation at any point. Your survey responses will be electronically and securely stored and will contribute to summaries of findings that we may publish or circulate. But your own responses will not be identified and will not be shared with any third party, including members of your own institution. We are committed to carrying out our research according to the ethical guidelines provided by the British Educational Research Association (online at http://tinyurl.com/6r5juen).

Who is paying for this research and who is carrying it out?
The research has been commissioned by the International Baccalaureate Organization in order to help them evaluate the effectiveness of their programme. It is hoped the research will help teachers further integrate technology in IB schools. The work is being undertaken by researchers from the University of Nottingham School of Education. The team is led by Professor Charles Crook -- if you have any questions or concerns about the research you can contact him or other members of the project team by email or by phone:

Professor Charles Crook (Principal Investigator)
e: charles.crook@nottingham.ac.uk
p: 0115 8466453

Professor Shaaron Ainsworth (Co-Investigator)
e: shaaron.ainsworth@nottingham.ac.uk
p: 0115 846 7671

Dr Lucy Cooker (Co-Investigator)
e: lucy.cooker@nottingham.ac.uk
p: 0115 951 4437

Dr Natasa Lackovic
e: natasa.lackovic@nottingham.ac.uk
p: 0115 84 67672

You can also raise issues with the Research Ethics Committee, University of Nottingham School of Education
educationresearchethics@nottingham.ac.uk

On the next page, we will ask you to give your consent to participating in this survey.

Technology in science and maths

Data protection: your agreement to participate

Conditions of consent to participate
By proceeding with this pilot survey and submitting a return of your responses you confirm the following. That:
_ I have read the 'Information for potential participants' and the nature and purpose of the research project has been
explained to me.
_ I understand the purpose of the research project and my involvement in it.
_ I understand that I may withdraw from the research project at any stage and that this will not affect my status now
or in the future.
_ I understand that while information gained during the study may be published, my responses to this pilot survey will
not be included in the main study findings.
_ I understand that data will be stored in a way that does not reveal my identity on a password protected machine and
that only the research team will have access to this data. It will not be held longer than 2020.
_ I understand that I may contact the Principal Investigator or other researchers if I require further information about
the research, and that I may contact the Research Ethics Committee of the School of Education, University of Nottingham

Telephone interviews

Technology Integration in the

International Baccalaureate Diploma Programme

What is the project about?

The focus of this project is on the 'Diploma Programme' provided by International Baccalaureate. It is looking specifically at the use of technology in the science and maths courses and examples of innovation in those areas.

What are the aims of the research?

This project has three broad aims regarding technology and the science and maths courses of the Diploma Programme:

We want to find out how technology is integrated.

We want to find out about teachers' and students' experiences.

We want to identify examples of good practice.

Who else is and can be involved?

We are inviting a number of IB schools across the UK to be involved, although some schools will be more involved than others.

What sorts of methods are being used?

Data will be collected in a number of ways. We want to understand the experiences and views of both teachers and students. This will involve a survey, analysis of documents from schools and the International Baccalaureate Organisation, photos taken by teachers and students of how they use technology, and interviews based on use of technology for teaching and learning.

What are you being asked to do?

You are being asked to participate in short telephone interview. It will last for approximately 20 minutes. The discussion will be recorded using voice recording software.

Will your participation in this study be kept confidential?

The data we collect will be treated confidentially, and only members of the research team will have access to the raw data. All information collected while carrying out the study will be stored on a database which is password protected and strictly confidential. The digital and textual data resulting from the interviews will be kept in a secure and confidential location. Your name will not appear on any database or any information which is then published. Instead, a number will be used as an identifier on all data associated with you. The master copy of the names associated with each number will be kept in a secure and confidential location.

We will report the results anonymously. When results are reported all individuals and institutions (individual schools) will be anonymised, so neither you nor your school will be identifiable. You will have the opportunity to look at the results of our study before we publish them, and ask us not to include the information you have given us if you so wish.

We are committed to carrying out our research according to the ethical guidelines provided by the British Educational Research Association (online at http://tinyurl.com/6r5juen).

Do you have to take part?

Your participation is entirely voluntary. It is important you understand that you do not have to participate in the project at all, and that you can decide to withdraw from the project at any point. We will not ask you to participate without you formally providing your consent.

Who is paying for this research and who is carrying it out?

The research has been commissioned by the International Baccalaureate Organisation in order to help them evaluate the effectiveness of their programme. It is hoped the research will help teachers further integrate technology in IB schools. The work is being undertaken by researchers from the University of Nottingham School of Education. The team is led by Professor Charles Crook – if you have any questions or concerns about the research you can contact him by email: charles.crook@nottingham.ac.uk or by phone: 0115 8466453.

You can also raise issues with the Research Ethics Committee, University of Nottingham School of Education educationresearchethics@nottingham.ac.uk

Technology Integration in the

International Baccalaureate Diploma Programme

Agreement to Participate – Telephone interview

Please check your responses below.

I understand the nature and purpose of this research.

Yes ☐ No ☐

I have received enough information to make an informed decision about participating.

Yes ☐ No ☐

I understand that I can raise questions, offer criticisms and make suggestions about the project.

Yes ☐ No ☐

I understand that I can decide *not* to participate in this project at any time after agreeing to.

Yes ☐ No ☐

I understand that I can withdraw from this project at any time.

Yes ☐ No ☐

Do you agree to contribute to this research? Yes ☐ No ☐

Do you agree the conversation can be audio-recorded? Yes ☐ No ☐

Please check below to indicate your preferences

I would like to be involved in/informed about this project:

☐ just for this interview, and prefer not to be contacted again

☐ for this interview, but would be happy to be in touch for follow-up discussion

☐ beyond this interview, such as for workshops or collaborative work

Your consent indicates that you have decided to take part in this project after considering the information provided, and that you know you can raise questions and decide not to participate at any time.

Signature/verbal consent ______________________________ **Date** ____

Name ______________________________

Email/contact (optional)______________________________

For more information, contact Professor Charles Crook (Principal Researcher), University of Nottingham School of Education, charles.crook@nottingham.ac.uk.

You can also raise issues with the Research Ethics Committee, University of Nottingham School of Education educationresearchethics@nottingham.ac.uk

Grounded interviews/interviews during case study observations

Technology Integration in the International Baccalaureate Diploma Programme

What is the project about?

The focus of this project is on the 'Diploma Programme' provided by International Baccalaureate. It is looking specifically at the use of technology in the science and maths courses and examples of innovation in those areas.

What are the aims of the research?

This project has three broad aims regarding technology and the science and maths courses of the Diploma Programme:

We want to find out how technology is integrated.

We want to find out about teachers' and students' experiences.

We want to identify examples of good practice.

Who else is and can be involved?

We are inviting a number of IB schools across the UK to be involved, although some schools will be more involved than others.

What sorts of methods are being used?

Data will be collected in a number of ways. We want to understand the experiences and views of both teachers and students. This will involve a survey, analysis of documents from schools and the International Baccalaureate Organisation, screenshots taken by teachers of how they use technology, and interviews based on use of technology for teaching and learning.

What are you being asked to do?

You are being asked to participate in an interview at your school. It will last for approximately 30 minutes. We will also ask you to share with us screenshots or photographs of the technology that you use in your science and mathematics classes. The interview will be recorded using a digital voice recorder, and we may ask you to use a particular app to take photographs of the technology you use in class.

Will your participation in this study be kept confidential?

The data we collect will be treated confidentially, and only members of the research team will have access to the raw data. All information collected while carrying out the study will be stored on a database which is password protected and strictly confidential. The digital and textual data resulting from the interviews will be kept in a secure and confidential location. Your name will not appear on any database or any information which is then published. Instead, a number will be used as an identifier on all data associated with you. The master copy of the names associated with each number will be kept in a secure and confidential location.

We will report the results anonymously. When results are reported all individuals and institutions (individual schools) will be anonymised, so neither you nor your school will be identifiable. You will have the opportunity to look at the results of our study before we publish them, and ask us not to include the information you have given us if you so wish.

We are committed to carrying out our research according to the ethical guidelines provided by the British Educational Research Association (online at http://tinyurl.com/6r5juen).

Do you have to take part?

Your participation is entirely voluntary. It is important you understand that you do not have to participate in the project at all, and that you can decide to withdraw from the project at any point. We will not ask you to participate without you formally providing your consent.

Who is paying for this research and who is carrying it out?

The research has been commissioned by the International Baccalaureate Organisation in order to help them evaluate the effectiveness of their programme. It is hoped the research will help teachers further integrate technology in IB schools. The work is being undertaken by researchers from the University of Nottingham School of Education. The team is led by Professor Charles Crook – if you have any questions or concerns about the research you can contact him by email: charles.crook@nottingham.ac.uk or by phone: 0115 8466453.

You can also raise issues with the Research Ethics Committee, University of Nottingham School of Education educationresearchethics@nottingham.ac.uk

Technology Integration in the International Baccalaureate Diploma Programme

Agreement to Participate –Interview

Please check your responses below.

I understand the nature and purpose of this research.

Yes ☐ No ☐

I have received enough information to make an informed decision about participating.

Yes ☐ No ☐

I understand that I can raise questions, offer criticisms and make suggestions about the project.

Yes ☐ No ☐

I understand that I can decide *not* to participate in this project at any time after agreeing to.

Yes ☐ No ☐

Do you agree to contribute to this research? Yes ☐ No ☐

Do you agree the conversation can be audio-recorded? Yes ☐ No ☐

Your consent indicates that you have decided to take part in this project after considering the information provided, and that you know you can raise questions and decide not to participate at any time.

Signature/verbal consent ___________________________ **Date** ___________

Name

____

Email/contact

____

For more information, contact Professor Charles Crook (Principal Researcher), University of Nottingham School of Education, charles.crook@nottingham.ac.uk.

You can also raise issues with the Research Ethics Committee, University of Nottingham School of Education educationresearchethics@nottingham.ac.uk

10.4 Appendix 4: Survey - Technology in science and maths

The document reproduced below is a word-processed version of the online survey. Thus formatting that was in the original online version is omitted from this version.

Technology in science and maths

1. Please select the name of your school from the dropdown box.

If you selected Other, please specify:

Using ICT

2. Using hardware or software in your classes

So far this school year, how often have you or your students used the following hardware or software in your classes?

	Never	Occasionally	Monthly	Weekly	Daily
a. 3D printers	○	○	○	○	○
b. Classroom voting systems	○	○	○	○	○
c. Digital probes/sensor	○	○	○	○	○
d. Interactive whiteboard	○	○	○	○	○
e. Laptop or desktop computer	○	○	○	○	○
f. Mobile device (smartphone/tablet computer (e.g.iPad))	○	○	○	○	○
g. Programmable objects such as robots or vehicles	○	○	○	○	○

h. Real time communication tools (Skype, Mikago,ooVoo)	◯	◯	◯	◯	◯
i. Short messaging systems such as Twitter, WhatsApp	◯	◯	◯	◯	◯
j. Social networking sites such as Edmodo, Facebook	◯	◯	◯	◯	◯
k. Touch tables	◯	◯	◯	◯	◯
l. Virtual learning environment (VLE/LMS)	◯	◯	◯	◯	◯
m. Visualiser	◯	◯	◯	◯	◯

3. Turning now to thinking about your teaching - we will ask about your students' learning later.

So far this school year, how often have you engaged in the following activities when preparing or teaching? (Remember to think about your teaching. We will ask about your students' learning later.)

	Never	Occasionally	Monthly	Weekly	Daily
a. Browsing the internet to find learning resources for students	◯	◯	◯	◯	◯
b. Browsing the internet to find information yourself	◯	◯	◯	◯	◯
c. Digital communication with a wider community of teachers	◯	◯	◯	◯	◯
d. Digital communication with parents	◯	◯	◯	◯	◯
e. Digital communication with students	◯	◯	◯	◯	◯
f. Posting homework for students	◯	◯	◯	◯	◯
g. Using ICT for feedback and/or assess students' learning	◯	◯	◯	◯	◯

4. Are there
other teaching activities using ICT that you have engaged with? Please specify.
(Optional)

Learning in your classes

5. Turning now to your students' learning

	So far this school year, how often have the following learning activities taken place in your classes?				
	Never	Occasionally	Monthly	Weekly	Daily
a. Browsing the internet to find information	◯	◯	◯	◯	◯
b. Capturing or measuring data in class using ICT	◯	◯	◯	◯	◯
c. Capturing or measuring data outside class using ICT	◯	◯	◯	◯	◯
d. Communicating with experts	◯	◯	◯	◯	◯
e. Contributing to blogging or discussion forums	◯	◯	◯	◯	◯
f. Contributing to collaborative projects using ICT	◯	◯	◯	◯	◯
g. Developing and presenting multimedia	◯	◯	◯	◯	◯
h. Developing electronic portfolios of personal work	◯	◯	◯	◯	◯
i. Engaging with dynamic maths visualisations	◯	◯	◯	◯	◯

j. Engaging with simulations using ICT

k. Experimenting in virtual or remote labo ratories

l. Participating in peer to peer exchanges using ICT

m. Playing educational games

n. Programming objects such as robots or vehicles

o. Representing data visually(charts/grap hs) using ICT

p. Using geo-learning or augmented reality (AR)

q. Using immersive virtual worlds (e.g. Se cond Life)

r. Watching digital video

6. Are there other learning activities using ICT that you think are important, missing from the list above? Please specify. *(Optional)*

Exploring the good/bad sides of ICT

7. Briefly identify the ICT resources (if any) that you regard as most valuable for either teaching or learning

8. Is your use of ICT in teaching and learning adversely affected by the following?

	Is your use of ICT in teaching and learning adversely affected by the following?				
	No t at all	A little	Partially	**Yes**	Yes, a lot
a. Appropriate content/material does not exist	○	○	○	○	○
b. Inadequate internet bandwidth or speed	○	○	○	○	○
c. Insufficient technical support	○	○	○	○	○
d. Lack of funds to purchase content/material	○	○	○	○	○
e. No, or unclear, benefit in using ICT for teachi ng	○	○	○	○	○
f. Not enough computers	○	○	○	○	○
g. Pressure to prepare students for exams and t ests	○	○	○	○	○
h. School space organisation	○	○	○	○	○
i. School time organisation	○	○	○	○	○
j. Unsatisfactory pedagogical support	○	○	○	○	○

9. Are there other ways that your use of ICT is adversely affected? Please specify.
(Optional)

10. During the past two school years, how much time (e.g days or hours) have you spent in professional development opportunities that concern ICT?

11. Have you used ICT for professional development (e.g. Twitter)?

- Yes
- No

12. In this final question, we'd like you to consider an ideal world _ or your personal vision for how ICT can best support learners.

	How far do you think ICT is important for students performing the following learning activities?				
	Not important	Somewhat important	Important	Very important	Crucial
a. Browsing or exploring information in an open_ended way	○	○	○	○	○
b. Collaborating with others	○	○	○	○	○
c. Coordinating learning across settings (in-class/out-of-class)	○	○	○	○	○
d. Creating or making things	○	○	○	○	○
e. Making discoveries/solving problems through inquiry	○	○	○	○	○
f. Practising some skill or rehearsing existing knowledge	○	○	○	○	○
g. Receiving assessment and its feedback	○	○	○	○	○
h. Watching demonstrations or listening to experts	○	○	○	○	○

13. Is there another personal vision you have for how ICT can support learners missing from the list above? Please specify.
(Optional)

10.5 Appendix 5: Survey - ICT provision in your school

The document reproduced below is a word-processed version of the online survey. Thus formatting that was in the original online version is omitted from this version.

ICT provision in your school

1. Please select the name of your school from the dropdown box.

Your role

2. Please tell us what role you perform regarding ICT in the school: briefly summarise your main responsibilities

About wireless internet access in your school

3. Who has access to WIFI in your school?
(select all that apply)

Staff only

Some students

All students

Local community

Other *(please specify)*:

Bring your own device

4. Are students in your school permitted to bring their own device?

Yes

No

It depends

If you answered 'it depends', please explain what it depends on

VLE/CMS/LMS

5. Does your school use a virtual learning environment (VLE), course management software (CMS), or a learning management system (LMS) such as Moodle or Blackboard?

Yes

No

If "yes", please tell us which VLE/CMS/LMS your school uses

6. Please indicate which of the following are available for teachers and students in science and mathematics Diploma Programme classes

	Teachers	Students
a. 3D printers		
b. Classroom voting systems		
c. Desktop computer		
d. Digital probes/sensor		
e. Interactive whiteboard		
f. Laptop computer		
g. Mobile device (e.g. smartphones or tablets such as iPad)		

h. Programmable objects such as robots or vehicles

i. Real time communication (e.g. Skype, Mikago or ooVoo)

j. Short messaging systems (e.g. Twitter, WhatsApp)

k. Social networking sites (e.g Edmodo, Facebook)

l. Touch tables

m. Visualiser

7. If there is other ICT available for teachers and students not listed above, please specify it. *(Optional)*

ICT pros & cons

8. Briefly identify the ICT resources (if any) that you regard as most valuable to either teaching or learning *(Optional)*

9. In your opinion, is the use of ICT in teaching and learning in your school adversely affected by the following?

	Not at all	A little	Partially	Yes	Yes, a lot
a. Insufficient Internet bandwidth or speed					

b. Insufficient number of computers

c. Insufficient pedagogical support

d. Insufficient technical support

e. Lack of adequate content/material

f. No or unclear benefit to use ICT for teaching

g. Pressure to prepare students for exams and tests

h. School space organisation

i. School time organisation

10. If there are other significant issues that are not listed above, please specify them. *(Optional)*

10.6 Appendix 6: Semi-structured telephone interview schedule

1) Role in school: to start with establishing the role of the interviewee

2) ICT context: to understand ICT teaching resources (the internet access, VLE, available digital resources)

3) Success story: to record an example of particularly interesting/successful use of ICT

4) Support: to understand ICT support provided and ICT professional development

5) ICT strategy: to understand the school's strategy and professional roles in relation to the use of ICT for teaching

6) Connectivity with other schools: to find out whether the school uses digital means to link with other schools

7) Vision: to understand the "ICT for teaching" ambitions of the teacher and /or the school

10.7 Appendix 7: Tables mapping the research method on to the analysis rationale for each question. (The numbers of individual questions in the 'specific details' column refer to the numbers in the relevant inquiry instruments)

1. How do IB DP schools plan for, and implement, the integration of technology into the science and mathematics curriculums?		
Method	Specific Details	Analysis Rationale
Survey	The survey 'ICT provision in your school', which was sent to the ICT professional in the school, addresses this question. Specifically, the follow items: About wireless internet access in your school 3. Who has access to WiFi in your school? Bring your own device 4. Are students in your school permitted to bring their own device? VLE/CMS/LMS 5. Does your school use a virtual learning environment (VLE), course management software (CMS), or a learning management system (LMS) such as Moodle or Blackboard? Resource access 6. Please indicate which of the following are available for teachers and students in science and mathematics Diploma Programme classes 7. If there is other ICT available for teachers and students not listed above, please specify it. ICT pros & cons 8.Briefly identify the ICT resources (if any) that you regard as most valuable to either teaching or learning (Optional)	These survey items provide information about general IT infrastructural characteristics of the participating schools allowing quantitative descriptions and comparisons.
Telephone interviews	Analysis of the following questions, included in the telephone interviews with both teachers of science and mathematics and the ICT professional, also contribute to exploring this question: (2a) Can you tell me about how readily you have internet access for your teaching?	Analysis of the interview data provides more nuanced insight that might lie behind quantitative responses– for example, it can determine the difference between who uses the internet and whether people do so easily and frequently.

	(2b) And do you have access to a VLE (what is it – is it widely used) (2c) Can you tell me what digital resources you have reliably available in your own teaching area (6) Does the school have a distinctive strategy for ICT?	It also allowed us to ask about ICT strategy directly where a more extensive conversation provides much richer data than that which would have been possible through survey.
Document analysis	During the case study observations, we will request ICT policy documentation and examine VLEs, samples of teachers' lesson plans, and students' work	This will shed light on the planning of technology integration into science and mathematics curriculums. By examining VLEs, lesson plans, and students' work we can seek evidence of the implementation of such planning
Grounded Interview/ Visit	The conversations with the ICT professional, and teachers of science and mathematics, will explore the practices around planning for, and implementation of, technology integration. These conversations will be informed by the data from the surveys and telephone interviews, and, where possible, will be 'grounded' in examples of digital practices or products.	These data can bring to life practices which are otherwise difficult to ascertain essentially helping to explore the gap between intention and reality.

2. What are DP teachers' perceptions of enablers and challenges of technology integration in DP science and mathematics courses?		
Method	Specific Details	Analysis Rationale
Survey	The survey 'Technology in science and maths', which was sent to teachers of those subjects, addressed this question. Specifically, the follow items: Exploring the good/bad sides of ICT 8 Is your use of ICT in teaching and learning adversely affected by the following? 10. During the past two school years, how much time (e.g days or hours) have you spent in professional development opportunities that concern ICT? 11. Have you used ICT for professional development (e.g. Twitter)? (LMS) such as Moodle or Blackboard?	These survey items provide quantitative information about which specific factors adversely and positively affect the responding teachers' perceptions of using technology.
Telephone interviews	Analysis of the following questions, included in the telephone interviews with both teachers of science and mathematics and the ICT professional, also contribute to exploring this question: (4) Visions: is there any digitally-dependent activity that you would like to do more of or develop. (5) Support: Are there any difficulties in pursuing these "visions", are there any obstacles to using digital tools more (if he/she wants to)?	Analysis of interview data will shed light on individual teachers' perceptions as it provides opportunities for them to express their personal vision. Data will not be quantified but will shed light on specific enablers and challenges.
Sound Photos	Teachers who are owners of smartphones or tablets will be asked to take photos and videos related to enablers and challenges of technology integration in science and maths classes, with a spoken interpretation and evaluation commentary.	This combination of concrete instances, together with interpretative commentaries, is ideal for capturing nuanced perceptions of technology.
Grounded Interview/ Visit	The conversations with DP teachers of science and mathematics, will explore their perceptions of enablers and challenges of technology integration in DP *science and mathematics* courses. These conversations will be informed by the data from the surveys and telephone interviews, and, where possible, will be 'grounded' in examples of digital practices or products.	These data are particularly valuable for exploring the wider context of specific issues.

3. What types of teaching and learning activities occur around and through technology in DP science and mathematics courses? Do DP students use technology for academic purposes? How do DP students communicate with their teachers and is technology a part of this?		
Method	Specific Details	Analysis Rationale
Survey	The survey ‘Technology in science and maths’, which was sent to teachers of those subjects, will address this question. Specifically, the follow items: Using ICT 3. So far this school year, how often have you engaged in the following activities when preparing or teaching? (Remember to think about your teaching. We will ask about your students' learning later.) Learning in your classes 5. So far this school year, how often have the following learning activities taken place in your classes? Exploring the good/bad sides of ICT 12. How far do you think ICT is important for students performing the following learning activities?	These questions allow quantitative description and comparisons concerning the use of ICT. By focusing on the activities we move beyond approaches that simply document which technologies are used. Question 12 interrogates teachers directly about how ICT can support the different learning activities we use to frame our understanding of how technology is used.
Documentary analysis	During the case study observations, we will request ICT documentation which may shed light on the types of teaching and learning activities occurring around and through technology in DP science and mathematics courses, whether DP students use technology for academic purposes, and how DP students communicate with their teachers. We will then examine VLEs, videos, wikis, blogs used and produced in class, other forms of technology use such as Word documents and samples of teachers’ lesson plans and students’ work,	These data enhance understanding of how ICT is intended to be, and then actually, used for teaching, learning, and communication.
Sound photos	Teachers who are owners of smartphones or tablets will be asked to take photos and videos related to teaching and learning activities occurring around and through technology in DP science and	Specific examples with commentaries will be sought wherever possible, but it should be noted that sound photos relating to DP students’ communications with their teachers will not be requested or permitted, in

	mathematics courses, and DP students' use of technology for academic purposes, with a spoken interpretation and evaluation commentary.	compliance with our ethical clearance.
Grounded interviews/Visit	The conversations with teachers of science and mathematics, will explore activities relating to teaching, learning, and communication. These conversations will be informed by the data from the surveys and telephone interviews, and, where possible, will be 'grounded' in examples of digital practices or products.	As data concerning activities can be difficult for teachers to recall out of context, and then abstract and summarise, these data will be crucial to fully understand how ICT is being used to support teaching, learning and communication in practice.

4 What are the *general* patterns in the DP teacher and student use of technology in the classroom (frequency, tools/applications, preferences)?		
Method	Specific Details	Analysis Rationale
Survey	The survey 'Technology in science and maths', which was sent to teachers of those subjects, will address this question. Specifically, the follow items: Using ICT 2. So far this school year, how often have you or your students used the following hardware or software in your classes? 3. So far this school year, how often have you engaged in the following activities when preparing or teaching? (Remember to think about your teaching. We will ask about your students' learning later.)	By asking participants to indicate their frequency of engagement with different kinds of technology we can provide quantitative analysis of which are the most commonly used technologies and which are the least commonly used across the IB World schools. By asking participants to indicate their frequency of engagement with teaching activities with ICT we can provide quantitative analysis of which are the most/least common practices for which ICT is used by teachers in IB World Schools.
Documentary analysis	During the case study observations, we will request documentation which may shed light on the general patterns of teachers' use of technology in the classroom. We will examine VLEs, samples of teachers' lesson plans, and samples of students' work for evidence of such use.	These data provide illustrations of the data described in the survey.

5. How do DP teachers and students in the case study schools use technology in the classroom (activities, functions)?		
Method	Specific Details	Analysis Rationale
Telephone interviews	Analysis of the following questions, included in the telephone interviews with both teachers of science and mathematics and the ICT professional, will also contribute to exploring this question: (3) Your success: Can you tell us about any of your activities with digital tools that feel have been particularly successful? (4) Visions: is there any digitally-dependent activity that you would like to do more of or develop?	These questions are particularly useful to identify case study schools.
Sound photos	Teachers who are owners of smartphones or tablets will be asked to take photos and videos related to their use of technology in DP science and mathematics courses.	Where it is not possible to visit schools directly, these data are the best ways to capture the rich examples of practices we require to understand the actual ways technology is used.
Grounded interviews/Visit	The conversations with DP teachers of science and mathematics, will explore their use of technology in the classroom. These conversations will be informed by the data from the telephone interviews, and, where possible, will be 'grounded' in examples of digital practices or products.	By examining directly with teachers examples of practice we are in the best position to understand the use of technology in teaching and to identify and document innovative practices.

10.8 Appendix 8: Minimum requirements for calculators

(taken from IBO, OCC http://occ.ibo.org/ibis/occ/Utils/getFile2.cfm?source=/ibis/occ/home/subjectHome.cfm&filename=dp%2Fgr5%2Fd_5_gen5d_sup_1202_1_e%2Epdf)

Minimum requirements for calculators from May 2014

Statistical tables are not allowed in DP group 5 mathematics examinations from May 2014.

Candidates must have access to calculators which are able to find relevant statistical values.

Different courses have different requirements, but the minimum requirements listed below are for

all the mathematics courses. Some of these may not be relevant to every course.

Examiners will set questions assuming that all candidates have a GDC with the minimum

functionalities listed here. Candidates using calculators which do not meet these requirements will

be at a disadvantage.

Minimum requirements

draw graphs with any viewing window

solve equations numerically

find a numerical derivative at a point

find a numerical definite integral

financial package

add and multiply and find inverse matrices (further mathematics HL only)

find statistical values including

- normal distribution
- binomial distribution
- Poisson distribution
- t-distribution
- binomial coefficient

n , nPr

r

- 1 and 2 var stats
- chi squared values (including p values)