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DECODING LEARNING: THE PROOF, PROMISE AND POTENTIAL OF DIGITAL EDUCATION

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About Nesta

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Professor Rosemary Luckin from the London Knowledge Lab has a background in Computer Science and Artificial Intelligence. Her research explores how to increase participation by teachers and learners in the design and use of technologies. This work has a particular focus upon understanding and modelling the impact of the wider context on the process of learning, as explained in her book: Re-Designing Learning Contexts (Routledge). Professor Luckin acts as a reviewer and advisor for UK research councils and International government funding agencies including Singapore, Greece, Cyprus, and Kuwait.

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Professor Richard Noss is co-director of the London Knowledge Lab, Institute of Education, University of London, and director of the Technology Enhanced Learning Research Programme, UK. He has directed some 20 research projects, focussing on a mix of technology–enhanced learning, mathematics, and - for the last ten or so years – workplace learning. He has authored and edited six books, and has published some 200 papers in these fields.

FOREWORD

From its beginning, Nesta has been involved in many projects related to education, including creating and spinning off FutureLab as a centre for innovation in uses of technology. More recently Nesta prepared the *Next Gen*. report with the computing and games industry in the UK which has persuaded the government to put computer science and coding at the heart of the school curriculum.

Through this past work, we have come to recognise an innovation deficit at the intersection of technology and education; students today inhabit a rich digital environment, but it is insufficiently utilised to support learning. Working with researchers at the London Knowledge Lab (LKL) and Learning Sciences Research Institute (LSRI), University of Nottingham, this report seeks to analyse the use of technologies for learning around the world and draw out lessons for innovation in the UK education systems.

The process of this report has involved input and guidance from many individuals. The researchers have consulted a wide variety of stakeholders and experts, who are gratefully acknowledged below. Internally, researchers have been supported by the enthusiasm of inquisitiveness of members within Nesta's Education, and Policy and Research teams. In particular Kathleen Stokes who managed the research, Tom Kenyon, Mark Griffiths, Amy Solder, Helen Drury, Jo Casebourne, and Jon Drori. Nesta's Investments and Communications teams have also provided invaluable support.

This report was initially commissioned to underpin our programme on education in a digital environment. However, as we go forward, we hope that it will continue to act as a tool for discussion and activity within and across the technology and education sectors, so that research, practice and industry can connect and innovate around a common language and imperative.

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CHAPTER 1: INTRODUCTION AND SCENE SETTING

With hundreds of millions of pounds spent on digital technology for education every year – from interactive whiteboards to the rise of one–to–one tablet computers – every new technology seems to offer unlimited promise to learning. Many sectors have benefitted immensely from harnessing innovative uses of technology. Cloud computing, mobile communications and Internet applications have changed the way manufacturing, finance, business services, the media and retailers operate. But key questions remain in education: has the range of technologies helped improve learners' experiences and the standards they achieve? Or is this investment just languishing as kit in the cupboard? And what more can decision makers, schools, teachers, parents and the technology industry do to ensure the full potential of innovative technology is exploited?

There is no doubt that digital technologies have had a profound impact upon the management of learning. Institutions can now recruit, register, monitor, and report on students with a new economy, efficiency, and (sometimes) creativity. Yet, evidence of digital technologies producing real transformation in learning and teaching remains elusive.

The education sector has invested heavily in digital technology; but this investment has not yet resulted in the radical improvements to learning experiences and educational attainment. In 2011, the *Review of Education Capital* found that maintained schools spent £487 million on ICT equipment and services in 2009-2010.[1] Since then, the education system has entered a state of flux with changes to the curriculum, shifts in funding, and increasing school autonomy.

While ring-fenced funding for ICT equipment and services has since ceased, a survey of 1,317 schools in July 2012 by the British Educational Suppliers Association found they were assigning an increasing amount of their budget to technology. With greater freedom and enthusiasm towards technology in education, schools and teachers have become more discerning and are beginning to demand more evidence to justify their spending and strategies. This is both a challenge and an opportunity as it puts schools in greater charge of their spending and use of technology.

This report sets out where proof, promise and potential lie for technology in education. It then identifies the contextual factors and actions needed to ensure current and future opportunities for school children take full advantage of technology for learning.

Our starting point is that digital technologies do offer opportunities for innovation that can transform teaching and learning, and that our challenge is to identify the shape that these innovations take. To aid us in this task, we have rejected the lure of categorising innovations by the type of technology employed. The only answer to questions such as "Do games help learning?" is to say, "It depends." Instead we argue that more progress comes from thinking about the types of learning activities that we know to be effective, such as practising key skills, and exploring the ways that technology can support and develop these effective learning activities in innovative ways.

Many research studies have addressed the impact of particular technological innovations, and many meta–analytic reviews have aggregated these findings. Typically, these synthesising reviews do find some evidence of positive impact. However, there are two important complicating factors that limit the strength of the claims that can be made.

Firstly, the evidence is drawn from a huge variety of learning contexts: the wide range of teacher experience and learner ability means that too often the impact identified is relatively modest in scale. Secondly, these findings are invariably drawn from evidence about how technology supports existing teaching and learning practices, rather than transforming those practices. What is clear is that no technology has an impact on learning in its own right; rather, its impact depends upon the way in which it is used. Accordingly, we have organised our review around effective learning themes:

- **Learning from Experts**
- **Learning with Others**
- **Learning through Making**
- **Learning through Exploring**
- **Learning through Inquiry**
- **Learning through Practising**
- **Learning from Assessment**
- **Learning in and across Settings**

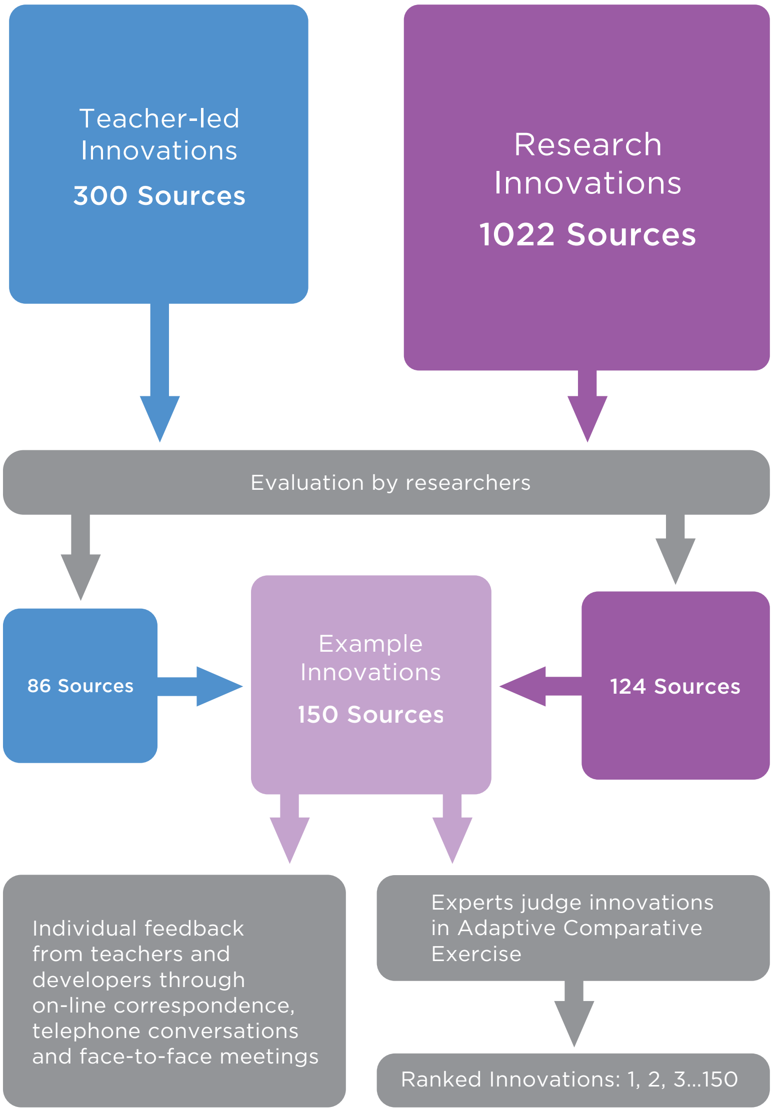
The eight learning themes are based upon an analysis of learners' actions and the way that they are resourced and structured.[2] Chapter 2 of this report discusses the evidence of innovation in each of these learning themes. Chapter 3 considers how the eight themes are related and how they can be linked by technology to produce a rich learning experience.

The context for learning must be taken into account if developers are to design effective technology and educators are to invest their time and money wisely. Chapter 4 looks at the learning context that shapes the impact of new technologies on learning. Learners and teachers have to draw upon a range of resources beyond the technology itself in order to make that technology work. It is important to understand both the role and the availability of these resources. We use the Ecology of Resources framework[3] to categorise these other resources. This framework makes the broad distinction between four different types of resource: *People*: teachers, adults and peers; *Tools*: learning materials; *Environment*: the setting in which learning is taking place; and *Knowledge & Skills*: the expertise of teachers. The availability of each type of resource is constrained, or 'filtered', within a particular context. Some filters are potential barriers – the cost of a learning resource, for example. But filters can also be an important means of structuring learning – such as limiting access to an overwhelming selection of learning materials to help learners make sensible choices.

In Chapter 5 we identify the priorities for action if innovative and effective uses of technology in education are to arise.

CONDUCTING THE REVIEW

Searching for and reviewing evidence on technological innovation in education raises many challenges. On the one hand, academic sources such as research papers, meta-analyses, systematic reviews, and clearinghouse reports offer solid evidence but risk excluding innovations that are too new to have been subjected to rigorous research, or those that seek to innovate in hitherto unexplored areas. On the other hand, the grey literature of informal commentary, blogs, think tanks, and companies' reports may highlight innovations that deserve serious attention, but can lack solid evidence to match their claims. And all information suffers from a degree of bias, whether that is motivated by the need to boost product sales or driven by a competitive research culture.



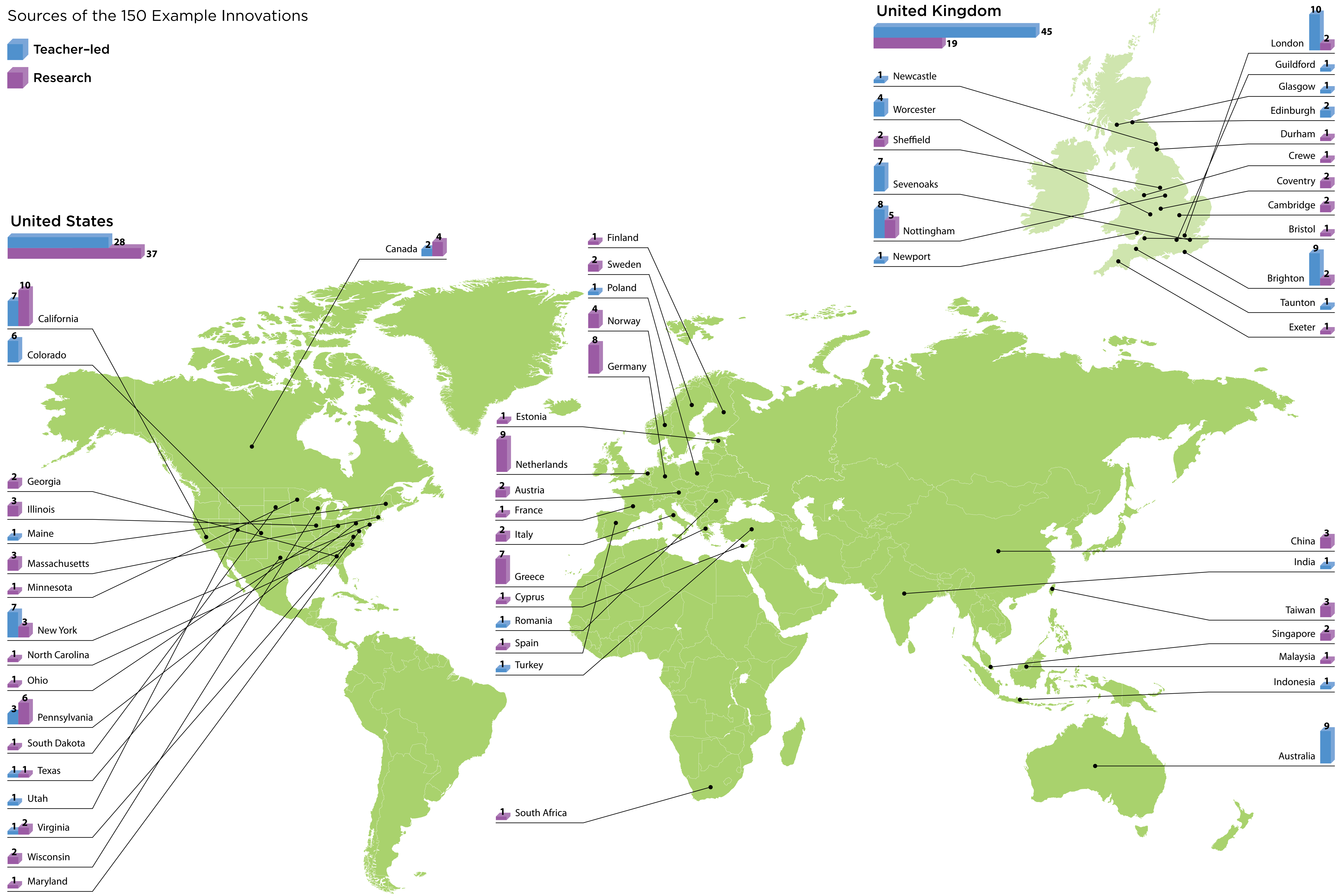
Review Process

The research underpinning this report attempts to address these challenges. We have considered both the quantity and quality of innovations, evidence from formal and informal sources, and proven and promising practice. Through a tailored systematic review of academic sources over the last three years, we collected over 1,000 publications with broad geographic coverage (including Europe, America and Asia) and from multiple disciplines (including education, psychology and technology). From this pool we identified 124 research-led example cases of innovation with sound evidence. In addition, we included relevant reviews and meta–reviews published in the last ten years. Secondly, we reviewed an extensive range of informal literature, including personal blogs and teacher networks. From this material we identified a further 86 teacher-led example cases of innovation from an initial pool of over 300. These 210 cases form the basis of research for this report.

Throughout this review, innovations were evaluated according to the quality of their evidence. Evidence that was anecdotal, superficial, or lacking a clear analytical scheme, was considered to be of low quality, whereas well–designed, fit for purpose analysis that would be appropriate for the highest quality scientific publication was considered high quality.

In order to balance evidence with opinion, and draw upon the wisdom of the informed crowd, a representative sample of 150 innovations were selected from the total pool of 210 and scrutinised by a group of experts comprising teachers, researchers, company representatives and policymakers. In a comparative judgement exercise, the experts were asked to compare two innovations and simply decide which of them was better; each expert was asked to make approximately 30 comparisons. By seeking multiple views on these cases of innovation, we were able to develop a refined ranking of the innovations. The results from the ranking exercise were complemented by on-line correspondence, telephone conversations, and face–to–face meetings with teachers and developers.
The ranking exercise provided a collective view of which innovations offer the greatest potential to advance teaching and learning, if they were to be widely adopted. Interested readers can find further details of the Adaptive Comparative Judgement (ACJ) method in Appendix 2.

Sources of the 150 Example Innovations



CHAPTER 2: LEARNING WITH TECHNOLOGY

INTRODUCTION

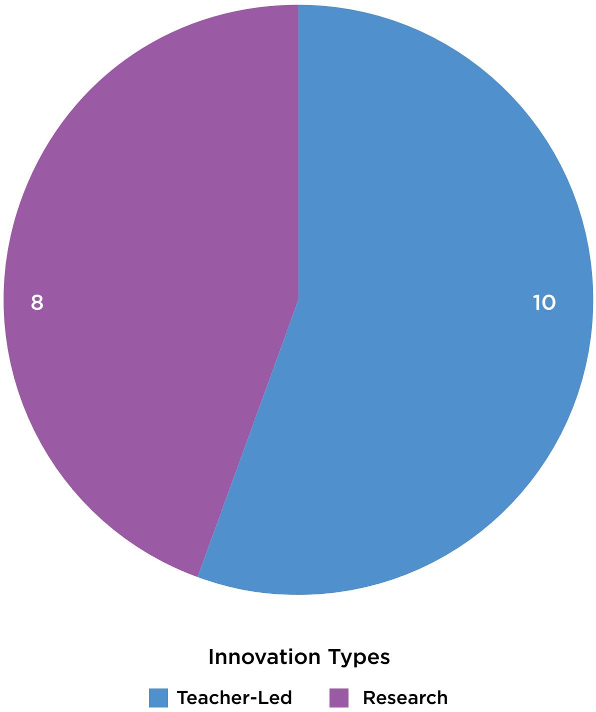
In this Chapter we provide an overview of promising innovations in learning with technology. The Chapter is organised around the eight learning themes discussed in Chapter 1. We consider the type of learning that takes place within each theme; we then present examples of how technology can support those types of learning. We include a set of case studies that provide a snapshot of learning in action.

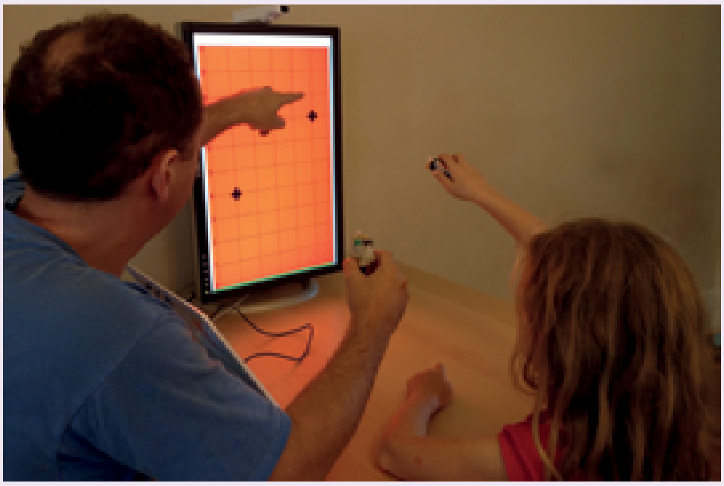
We highlight those innovations we believe offer the greatest potential, drawn from the 124 research and 86 teacher–led examples reviewed.

All the examples quoted are referenced in footnotes. A full list of the innovations ranked in the comparative judgement exercise along with additional resources from the report can be found online at
http://www.nesta.org.uk/assets/features/Decoding_Learning.

2.1 LEARNING FROM EXPERTS

The scope for independent learning has never been higher. There has been huge growth in the amount of information available to learners; and in technology that enables learners to access, structure and package that information. However, the role of teachers in supporting learners to convert information into knowledge should not be underestimated. There has been much technological innovation in the exposition of data; but much less in supporting dialogue between teachers and learners to help learners make the most of that data.





University of California, Berkeley. Photographs used with permission.

Mathematics Imagery Trainer

The Mathematical Imagery Trainer allows learners to develop their understanding of fractions and proportions through physical movement and dialogue. Using a screen and a handheld tracking device – like the Nintendo Wii controller – this tool tracks learners' movements and presents them as a proportion of a total range. As learners reach a preselected proportion, the screen turns from red to green. Rather than teachers giving explicit instructions about achieving different proportions, children are asked to explain what they think is happening. In this way, the design provides a powerful tool to enhance discussion between the teacher and learner.

Developed by Dr Dor Abrahamson and his team at the Embodied Design Research Laboratory, University of California, Berkeley, the Mathematical Imagery Trainer has been tested with 11 and 12 year old children. (Abrahamson, et al. 2011)

Highlights

- The increasing wealth of online resources offers great potential for both teachers and learners; but places great demands on both to evaluate and filter the information on offer.
- Innovations in *Learning from Experts* have tended to focus on the exposition of information rather than fostering dialogue between teachers and learners.
- Digital technologies offer new ways of presenting information and ideas in a dynamic and interactive way. However learners may need the support of teachers to interpret those ideas and to convert that information into knowledge.
- New forms of representation (e.g. augmented objects) offer the potential to enrich the dialogue about information between teachers and learners.

Theories of learning emphasise the role of a more knowledgeable other, or expert, in guiding learners. This could be a peer, but is more usually a teacher.

Digital technology can support two kinds of interaction between learner and teacher. The first is the dialogue between learners and teachers. This is referred to as *tutorial*. A seminal paper by Benjamin Bloom suggested that one–to–one teaching is the most effective way to learn.[4] He found that children who were taught individually performed significantly better than children who were taught in a conventional classroom setting. Technology can support dialogue between learner and teacher, particularly when they are not in the same location; or when they are unable to communicate with each other at the same time. Technology can enhance dialogue with visual aids, such an interactive whiteboard. Technology can even simulate the role of teacher, as seen in intelligent teaching systems.

The other form of interaction concerns the structuring and presentation of learning material. This can be described as *exposition*. There are a range of digital resources that structure and package learning material from podcasts to e–books to videos on YouTube. Digital technologies also offer new ways of presenting information and ideas in a dynamic and interactive way. These resources are accessible and can be engaging; however the learner's role can often be passive. Learners may need the support of teachers to interpret those ideas and to convert that information into knowledge.

Learning through *tutorial* and *exposition* represent traditional approaches to teaching and remain at the heart of much classroom practice. They influenced much of the early work on educational technology, for example the development of Intelligent Tutoring Systems. Today they underpin prominent teacher approaches such as the use of video lectures by Khan Academy.[5] We found many examples of technology building on existing teaching practice, rather than creating new, innovative practices. It is open to question whether simply building on traditional approaches will improve dialogue between learners and teachers in a way that will ultimately improve learning.

A relatively high proportion of research innovations (23) focused on learning from experts, with support for exposition more prevalent than support for tutorial dialogues. Most involved primary and secondary students in the classroom, although several examples considered support for older learners accessing information online. It is also interesting to note how the growth of online courses may extend to younger learners, as exemplified by the American online learning provider, K12.[6] Digital tools ranged from hardware such as interactive whiteboards[7] and mobile devices[8] to visual and audio presentation tools including animations[9] and podcasts.[10] Bespoke tools included a robotic tutor[11] and a desk lantern used to communicate learners' progress on tasks to the teacher.[12]

There were 11 teacher–led examples of innovation under this theme; only two involved support for tutorial dialogue.[13] Examples involved primary and secondary students; and most looked at the use of online resources (such as videos[14] or other 'free' online tools[15]) in the classroom. Non–internet based examples included a gesture–recognition console and game (Kinect Sports)[16] used to provide an engaging context for secondary students working on mathematical problems, such as calculating average speeds. One novel example linked digital information to physical objects using radio–frequency identification (RFID) technology.[17]

Several research papers illustrated how digital technology offers new ways of presenting ideas, through animations,[18] video lectures[19] or podcasts.[20] Research suggests that the benefits of using such technology depend on a range of factors such as the cognition, perception, attitudes and motivations of learners.[21] One example demonstrated how devices can expand access to information in the classroom.[22] This simple, yet effective, project in a UK university used multiple screens to display information over the walls of a classroom to promote discussion. The teacher was able to stimulate debate by presenting a particular argument about materials on display (such as images of historical artefacts) while providing sufficient information around the walls for students to construct alternative explanations.

Two examples show how a simple device like the interactive whiteboard (IWB) can be used effectively to support dialogue between the teacher and learners.[23] Drawing on case studies across the UK, Hennessy explores how the IWB can support student learning through classroom conversation. Teachers can use IWBs more effectively by linking them to digital resources which can be archived and revisited later. This supports the progression of dialogue over time, across settings, and even across groups of learners. Although they may no longer be considered particularly innovative, IWBs are now used in many UK schools. It is therefore clearly timely and useful to find out how best they be used in innovative ways to support learning.

We also found digital technology being used by learners to access information outside of the classroom. In one particular example local students and adults used mobile devices to study environmental issues while on a guided tour of a floodplain conservation site along the Rhine River.[24] However, learners may need support in navigating information. Greene et al.[25] show the benefits of teachers supporting pupils with planning skills before they accessed history content from a hypermedia[26] learning environment. Several examples also looked at blended learning approaches. One study of a learning management system emphasised the importance of including opportunities for constructive dialogue and interactive learning activities.[27] In this regard, technology may support learning by providing a more direct tutorial role. This was also demonstrated in a study of technology that uses sketch recognition and corrective feedback to assist learners drawing human faces.[28]

The examples also showed how technology can be used to provide learners with social support. One social recommender system supported learners with their programming by suggesting solutions previously applied by other learners.[29] Technology is also opening the way for robotic tutors.[30] One such example was Dr Martin Saerbeck's development of a robotic tutor to provide support to learners who are learning a new language. The tutor provides prompts about use of vocabulary. The robot is expressive and can model

A*STAR Institute of High Performance Computing, Singapore. Photographs used with permission.

The iCAT robotic tutor for language learning

Maths Doctor. Photographs used with permission.

Maths Doctor

its interaction with the learner based on the learner's language capabilities. This enables the robot to gradually reduce support and promote independence. While not yet widespread, this shows how technology can increase tutorial dialogue in radically new ways.

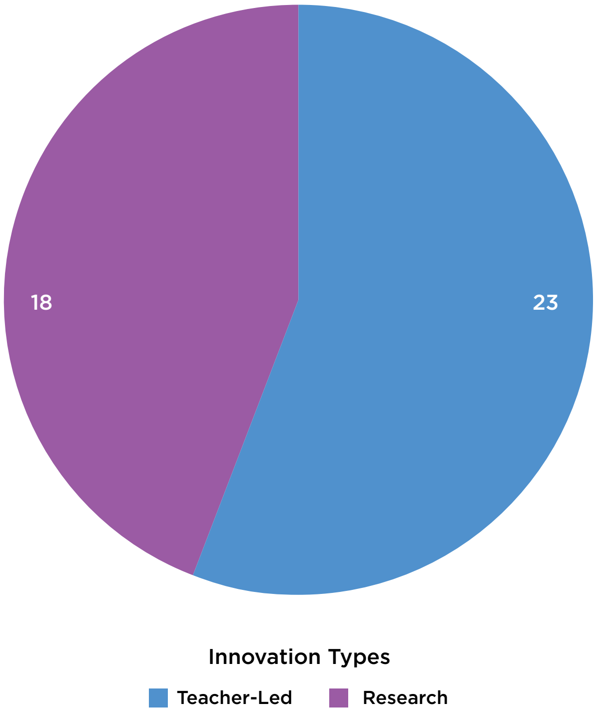
Several teacher-led examples involved the use of multimedia content for learners, such as stop-start animations to discuss story sequencing[31] and game consoles to present mathematics problems.[32] The resources used were predominately online, although one innovation presented at an UnTeachMeet event[33] used near field communication (NFC)[34] so teachers (and learners) could link digital information to physical objects.[35] The Maths Doctor[36] exemplified how technology can support communication between teachers and learners over a distance. Based in Brighton, UK, this online one-to-one tuition service connects highly qualified teachers with learners through videoconferencing software (such as Skype) and tablet devices. Tutors can remotely help their secondary students tackle maths problems in conversation while simultaneously writing and attempting equations on screen. These sessions are also recorded so that students can also go back and review the dialogue afterwards.

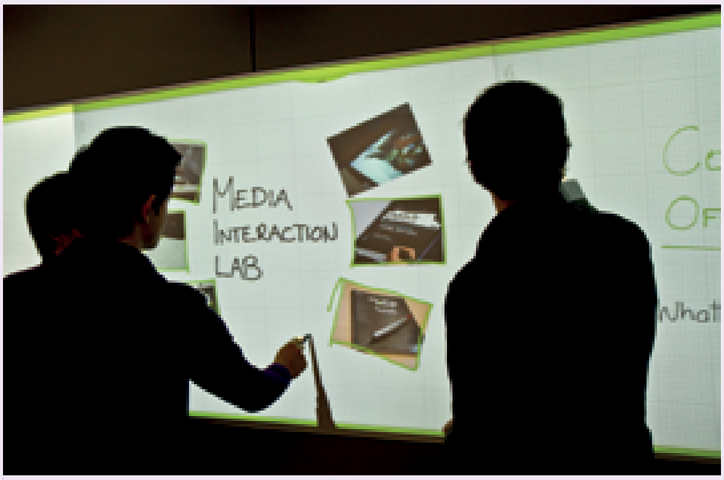
One of the most highly rated innovations[37] supported exposition using the free website and collaborative project, Solar Stormwatch.[38] Created by the Royal Observatory Greenwich, UK, the site provides real-life science information and encourages learners to contribute to the project by helping to identify solar storms. Any information learners gather can be fed into the project by creating an account on the site. Learners can be engaged in topical science issues by being able to: contribute directly to the project; draw on the wealth of information available on the project site; and connect with experts in the field.

Clearly, online technology offers the potential to expand the dialogue between teachers and learners. However, a critical eye needs to be cast over the quality of online materials and any costs associated with accessing those materials, either direct (subscription) or indirect (advertising, data). The development of good quality material requires collaboration between developers, domain experts, teachers, and learners. Finally, as with all online content, it is important to consider whether learners have access to devices, and whether those devices have an adequate connection speed.

2.2 LEARNING WITH OTHERS

There is considerable enthusiasm and commitment to developing innovative approaches that support learning with others. But good ideas developed in academic research are not yet filtering through to the classroom. More could be done to raise teachers' awareness of tools that support learning with others. We would particularly welcome more widespread use of tools that enable learners to capture the progress of an episode of learning with others. Priority should also be given to developing tools that allow teachers to organise and manage episodes of joint learning.





NiCE discussion room

Media Interaction Lab, FH OÖ Forschungs- und EntwicklungsGmbH. Photographs used with permission.

In Austria, the NiCE Discussion Room is a space that supports social learning. This innovation illustrates how the design of both tools and space can be coordinated to create a versatile environment for social learning to create a kind of digital ecology for learning with others. Learners can share learning resources, thoughts and ideas, thereby supporting each other to develop knowledge collectively.

Sharing can be done through different media (e.g. paper and screen) whose contents may be shared or concealed as appropriate during the activity. Emerging knowledge may be captured, annotated, edited, archived and made public – all using the same technical infrastructure. The system provides a versatile single space for socially-organised learning; it emulates workplace conditions that demand brainstorming and team thinking. (Halle, et al. 2010)

Highlights

- There are four social dimensions to *Learning with Others*, each of which can be supported by digital technology:
    - The *collaborative* dimension requires tools that help learners develop mutual understanding.
    - The *networked* dimension requires tools that help learners interact.
    - The *participative* dimension requires tools that help learners to develop a strong community of knowledge.
    - The *performative* dimension requires tools that allow the outcomes of collaborative learning to be shared with others.
- There are three particularly promising areas for development: *representational* tools that enable the activities taking place to be presented to the learners; *scaffolding tools* that provide a structure for learning with others; and *communication* tools that support learners working at a distance from each other to collaborate.

Much of our knowledge arises from social interaction. Whether we learn, and what we learn, depends upon our relationships with others. Sometimes these relationships will be the classic ones of teachers interacting with learners. But they can also involve learners interacting with other learners. Indeed, the role of teachers may be shifting away from managing a teacher–learner dynamic towards coordinating peer learning. Technology can support such a shift. In this section, we consider how.

Biological Sciences 64 pilot classroom, University of Minnesota

Learning with others requires collaboration – this involves learners coming to a mutual agreement or shared understanding in order to solve a problem. Technology can influence the way in which learners collaborate. We suggest there are four distinct, but linked dimensions of learning with others.

First, the *collaborative* dimension refers to learners developing knowledge through mutual interest and understanding. Second, the *networked* dimension refers to the way in which learners organise themselves, especially where they contact each other only intermittently (such as through an online forum). Third, *participation* refers to groups of learners developing a community of knowledge through shared understanding and practice. Finally, the *performative* dimension involves the dissemination of the knowledge gained through learning with others.

Learning with Others was the most frequently considered type of learning in the examples of innovation we reviewed. While the research examples focussed on the collaborative dimension, the teacher–based examples of innovation focussed more on the participative and networked dimensions of learning with others. Few examples looked at the performative dimension – digital resources that might create audiences for the outputs of joint learning are somewhat neglected.

The most highly rated example of innovation in this theme involved pupils in primary school using an online writing tool to build a story collaboratively. BoomWriter is a free "competitive writing platform"[39] that helps engage learners by combining creative writing with social media technology. Learners work together to build a story set up by the teacher. Decisions are taken through blind peer evaluation and voting. Another highly rated research example used online forums to structure learners' discussions. Learners took on a particular role in a scenario. The underlying principle is that structuring discussions in this way can promote critical thinking and higher levels of learning.[40]

National Institute of Education, Singapore. Photographs used with permission.

GroupScribbles

Four teacher–based examples of innovation were also very highly rated. Innovations in learning with others through networks were more frequently cited by teachers and particularly highly rated by the expert panel. Other highly ranked innovations in this theme were those that enabled learners to interact;[41] actively shaped joint activity within some problem solving space; facilitated exchange within learner networks;[42] and opened novel channels of communication between learners.[43]

The research evidence base points to three particularly promising areas for development:

1. Representational tools: tools that enable the activities taking place, or the achievements arising from those activities to be represented. Examples included: tools for integrating representations made using different media;[44] technology–enhanced spaces for acting;[45] tools for capturing and sharing on-going achievements;[46] and tools that represented either the evolving content[47] or learners' progress[48] during an episode of learning with others. The tools used ranged from digital pens and IWBs to more elaborate equipment such as the NiCE Discussion Room (see above). In another example, the concept mapping tool GroupScribbles – software that integrates digital scribbling, sketching and posting – was used on a tablet device to increase collaboration between secondary students in Singapore. To accomplish this, a series of activities were co-designed by researchers and teachers to fit within the curriculum, such as having groups simultaneously co–author a concept map. These activities helped students to become more involved in learning and to communicate better with one another.[49]

2. Scaffolding tools: tools that provide a structure for learning with others. These tools enable learners to manage shared tasks by various kinds of scripting[50] or prompting.[51] One such example is the NumberNet tool, used to promote collaboration within and between groups in maths classes in Durham, UK. While maths classes are often focused on individual instruction, this project organised a three-stage activity in order to promote greater flexibility among learners when using maths. To accomplish this, multiple group activities were set up on table top computers across a classroom. Learners were encouraged to participate and rotate across these activities before being called back for a final sorting and structuring activity.

3. Communication tools: a small number of examples demonstrated the benefit of technology-supported collaboration among learners who were working at a distance.[52] In one example, a multi-user problem solving game was developed to meet increasing demand for informal, collaborative learning in different environments. The project was sparked by a common art exhibition held between two museums in Barcelona and Figueres, Spain. Using a videoconferencing system and multi-touch interactive surface, groups of learners within and across each museum were able to simultaneously explore the exhibitions. One study found that text messaging among pupils, particularly when they began to use abbreviations or 'textisms', was linked to improved literacy and spelling in 9 and 10 year–olds. While it is unlikely that all English classes will be, or should be, conducted in the form of text message conversations, such findings do challenge us to rethink the learning value of certain types of communication activities commonly found outside the classroom (like text messaging).

NumberNet being used to support group activities in maths

University of Durham. Photographs used with permission.

Examples from teachers tended to identify some distinctive, yet familiar, digital resources which had been previously used to support a successful session of learner collaboration. Teachers were also less likely to consider new tools for enhancing networked exchange, again identifying familiar applications like Ning or Google messenger as means of stimulating coordination in learning at a distance or at different times. The consequences of such networking tend to feed into the participative and performative interaction categories.

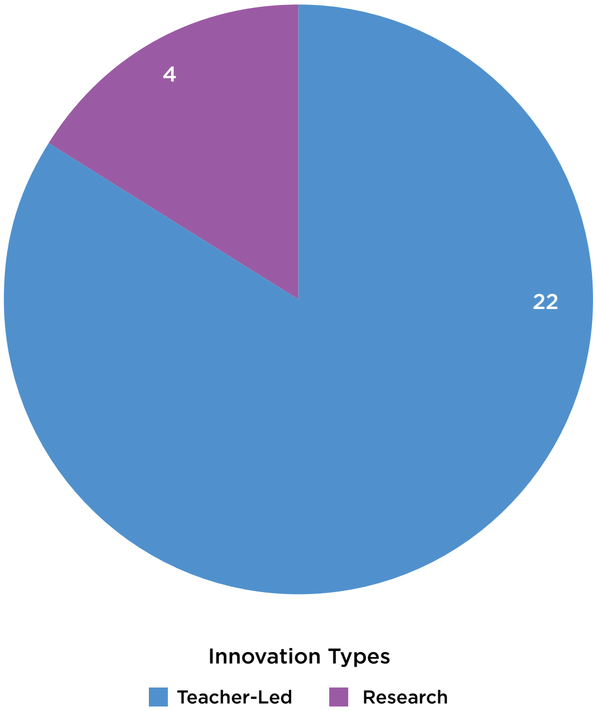
Teachers are certainly enthusiastic about innovation in social learning. However, we believe some of the most innovative practice in *Learning with Others* remains relatively neglected by teachers. In short, the research ideas are not yet filtering through to the classroom. More could be done to raise awareness among teachers of new tools that support learning with others.

We would particularly welcome the more widespread use of tools that capture the progress of an episode of learning with others. These would offer visual records of the progress of a task – designs are likely to be specific to task structures. Representations of both the content and progress of such episodes will be of great value to learners, particularly in terms of the stimulating self–awareness about learning activities. They will also be of value to teachers who can adapt their feedback with the greater insight that such representations can provide.

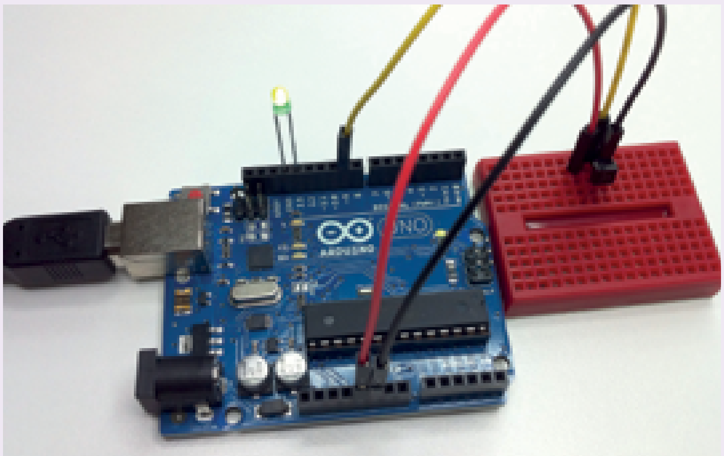
Developing learning with others will often present a challenge of orchestration to the teacher. We have distinguished between *collaborative*, *networked*, *performative* and *participative* dimensions of learning with others. It may be unusual for a single tool to support all of these dimensions. Yet any episode of learning with others will benefit if it is both participative (i.e., it helps build a learning community) and performative (i.e., it helps create audiences for what is achieved). This often requires the teacher to actively manage a variety of tools; some of the most promising innovations we have reviewed have the capacity to orchestrate learning with others (see the case study above for an example).

2.3 LEARNING THROUGH MAKING

One the best ways people can learn is by making and sharing things. There is great enthusiasm for making with digital tools, complemented by a general resurgence in crafts and making. There are growing opportunities for people to integrate physical construction with coding and hacking technology. Innovations in technology-supported learning through making do show great potential. But this potential can only be fulfilled if those required to use that technology are also supported.



Brock Craft. Photographs used with permission.



Arduino and Eclipse Integrated Development Environment and data aggregator

At the London Knowledge Lab, UK, computer science students on a summer internship developed a system to collect environmental data, such as temperature and light levels, on school premises. The environmental sensor unit reported its data to an online data aggregator [cosm.com]. Data was subsequently presented and accessed through a bespoke mobile phone app. This innovation demonstrates how students can put their thinking to action and create remarkable products using affordable and accessible technology through their own initiative. (http://acssummerapp.webr.ly/blog/)

Highlights

- The success of *Learning through Making* rests on two principles: first, learners must construct their own understanding; they must create something they can share with others.
- Digital technology can bring the idea of constructionism alive. Learners can construct anything in their imagination; and they can then share, discuss, reflect upon and, ultimately, learn about that construction.
- Teacher–led examples of innovation frequently cited the motivational aspect and the benefits of producing tangible, 'real world' outcomes of learning through making.
- The success of learning through making depends on the appropriate use of digital tools in suitable environments.
- A review of the use of ICT to support creative and critical thinking in formal education highlighted the key role played by teachers in successful implementation.

One the best ways people can learn is by making and sharing things.

The idea of constructionism was spearheaded by Professor Seymour Papert, an MIT mathematician and computer scientist.[53] Constructionism rests on two main principles: that learners construct their own understanding as they make something, rather than receiving it passively from others; and that this is most effective when they make something they can share.

Digital technology can bring the idea of constructionism alive. Learners can construct anything in their imagination; and they can then share, discuss, reflect upon and, ultimately, to learn about that construction.

Constructionism dates back to developments in computer programming in the late 1960s. The advent of the Logo programming language enabled those with little prior knowledge of programming to start developing programs by using the *turtle*, a programmable screen object or robot. Since those early days, constructionism has provided the framework for a fertile strand of learning research and development, including MIT's Scratch programming language and online community,[54] the "multi–agent programmable modelling environment" NetLogo,[55] and the musical "programming language and environment" Impromptu.[56]

The current enthusiasm for making with digital tools is high; and is complemented by a general resurgence in craft and making. There are growing opportunities for people to integrate physical construction with coding and hacking technology through events and resources such as O'Reilly's Maker Faires,[57] and Make Magazine.[58] But this remains a relatively immature area.

Almost a quarter of all the teacher-led examples we reviewed concerned learning through making. In contrast, there were few research examples, suggesting this is a rising trend in practice that has not yet been subjected to a great deal of research. Examples were found across all levels of education and in a variety of formal and informal settings. They were particularly prevalent in non–traditional subjects. Research examples covered technology not traditionally found in classrooms, including robots and collaborative authoring tools. The subject areas varied from energy saving and the environment, through to computer game development and argumentation.

A number of examples illustrate how technology can help learners construct notes and other materials to improve their learning. Researchers in the University of North Carolina, US, developed the Interactive Shared Education Environment (ISEE)[59] to improve learning while watching videos. ISEE combines a video player and text chat box. While watching videos, learners simultaneously annotated and made notes in a separate box which was automatically connected to the video through hyperlinked timestamps called Smartlinks. Learners took fewer notes and focussed on video content rather than video controls when using ISEE. Another example showed how electronic outlining tools could improve the quality of learners' writing. Learners were able to use outlining tools with little instruction; however, to make the most of the tools, they did require specific instruction on text planning.[60] Finally, the EU–funded MuseumScouts project worked with creative and cultural institutions to develop learner-centred activities within those institutions. Learners designed short, interactive presentations using collaborative authoring tools, such as Evolution, based on the information they collected during visits.[61]

MIT Scratch event

Teacher–led examples frequently cited the motivational aspect of learning through making. These included an interesting approach involving Scratch – a children's' programming language and online community developed by MIT. The aim was to motivate primary-aged pupils to start programming by creating coded animations in informal after–school clubs.[62] Other examples include the use of blogging and storytelling through Web 2.0 applications. One project used digital story telling tool ZooBurst to create 3D pop–up books with augmented reality features. By using exciting effects and creating a product that could be shared online, this project was able to engage many learners who were less enthusiastic about story writing. Similarly, learners have used domo.goanimate.com to create their own short cartoon–style animations,[63] while others have used Storybird.com to write stories that were published in e–book format. Crucially, both applications provide embed codes that allow learners' work to be assembled, published and shared on blogging platforms, like WordPress.org.

The most highly rated teacher-led example also focussed on the motivational aspect of learning through making. In this case, secondary students used Aris – an open–platform for creating geo-location games, tours and interactive stories – to design and create quest games with mobile phones and printed QR codes[64] around the school. Learners were divided into teams, and team members were given defined roles, such as programmers, media collectors, and narrative writers. After creating their storyline, teams designed seven quests and connected them to different locations across their schools using QR codes, which offered clues such as: "Visit both the boys and girls toilets. Then find the toilet and collect toilet paper code. Find the toilet and collect soap code. Then head towards the canteen..."[65] Over the course of five months, learners had successfully designed, tested and debugged their games.

A dragon robot made with the HummingBird Robotics Kit

Other promising teacher–led examples also highlighted the positive effect on learners when they are able to produce tangible outputs with 'real word' applications. Designed in the CREATE Lab at Carnegie Mellon University's Robotics Institute, HummingBird Kits are intended to engage secondary students, particularly girls, in programming by creating artistic, physical designs.[66] Unlike other robotics kits, which provide the materials to make a specific type of robot, the HummingBird kit can be combined with available craft materials to create unique robots based on the learner's interests. Learners were inspired by the ease of creating more artistic and unconventional programming applications, such as animated scenes to accompany a poem.[67]

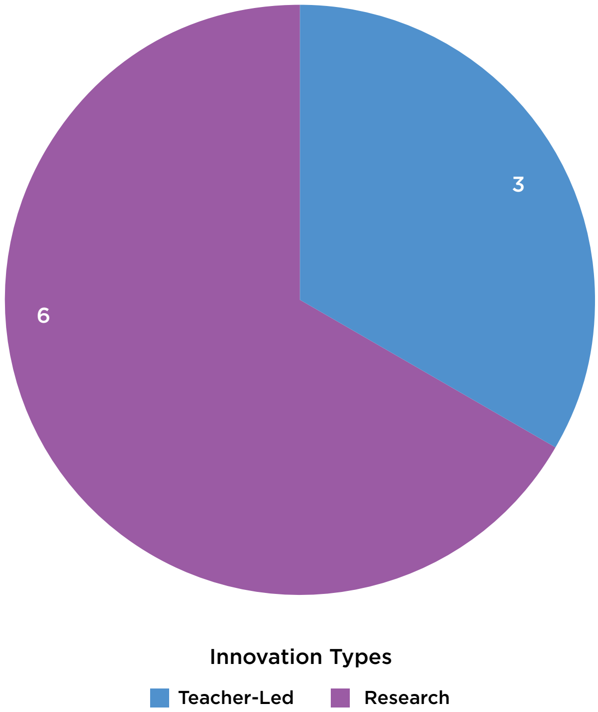
Two other noteworthy examples of learners producing tangible outputs involve weeklong workshops. In the first, learners develop their programming skills by designing digital products, such as mobile apps, alongside local businesses and volunteers.[68] The 'On the Move' project,[69] run by NYU–Poly and MakerBot Industries in Brooklyn, New York, US, provides 10–13 year old learners with a hands-on introduction to 3D printing through a weeklong workshop. Learners gain experience designing and printing objects such as physical gears.

Few examples of innovation in learning through making have been subjected to rigorous academic research; those that have were not seen as particularly promising by the expert panel – the most promising example among the research cases was a project that used computer game development to foster the creative perceptions of secondary students.[70] Meanwhile, there were many teacher-led examples that, while not evidenced, were regarded as highly promising by the expert panel.

Innovations in technology-supported learning through making do show great potential. But this potential can only be fulfilled if those required to use that technology are also supported. Many of the examples we reviewed required some degree of teacher support. The authors of a study into the use of ICT to support the teaching of algebra found some evidence for success, but drew attention to the vital role that teachers played in helping learners to use technology critically, link multiple representations, and build the bridge between individual learners' constructions and whole class understanding.[71] Another review on the use of ICT to support creative and critical thinking in formal education also highlighted the key role played by teachers in successful implementation.[72]

2.4 LEARNING THROUGH EXPLORING

Learners have always browsed information to gain new knowledge. However, in the digital age information is abundant, and can even be overwhelming. Learners need to develop strategies and skills to find and filter the information they need. Technology provides many new opportunities to support learners to develop those strategies and skills, through online multimedia environments, 3D simulations and information visualisations, or technology–augmented physical spaces. However, we found few examples of innovation in this theme.



Queensland University of Technology. Photographs used with permission.

Electronic Blocks

Electronic Blocks are physical building blocks that allow young pupils to begin exploring elements of computer programming and algorithmic concepts. The blocks are embedded with electrical components that allow them to do different things: sensor blocks can see, hear or sense touch; action blocks can produce light, sound, or move; and logic blocks link sensors and actions while adding conditions or commands. Learners can follow their curiosity and combine blocks during extended tasks that resemble free play. As they make their own discoveries about how the different blocks can be combined, they develop their understanding of programming.

These blocks were developed by Dr Peta Wyeth as part of her doctoral thesis at Queensland University, Australia. (Wyeth, 2008)

Highlights

- *Learning through Exploring* rests on two principles: firstly, learners are given freedom to act; secondly, they need to regulate their own actions, which is itself an important skill for learning.
- Digital tools can provide new and engaging ways to explore information, and offer new ways to structure the environment that learners explore.
- The dearth of current research suggests technology–supported exploration is underused and undervalued within educational settings.
- The evidence in the few examples found was of a high quality and suggests that technology does offer the potential to enhance learning through exploration.

Learning through Exploring in this report includes work in which learners search or browse information, or engage in playful, game–like interactions. Exploring can be opportunistic or more structured. Learners may also explore playfully, by experimenting with learning materials in a way they feel is enjoyable.

In some instances, *Learning through Exploring* can be spontaneous – browsing the web for more information about a news item or researching a topic of interest such as a hobby. It can also be deliberately engineered by a teacher, parent, colleague or peer – suggesting a topic of interest, providing some materials to work with or even goals that the learner can work towards. But *Learning through Exploring* is always self–regulated.[73] The learner chooses how and where to explore.

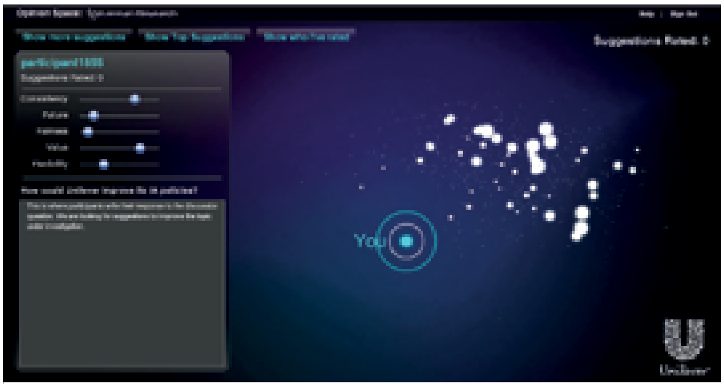
Learners have always browsed information to gain new knowledge. However, in the digital age information is abundant, and can be overwhelming. Learners need to develop strategies to find and filter the information they need. Search engines and recommender systems may be useful in shaping exploration. But if learners do not use such tools well, they can narrow the scope of their exploration too much. It must also be recognised that serendipitous discovery is an important aspect of exploring.

New technology such as online multimedia environments, 3D simulations and information visualisations, or augmented physical spaces provide many new opportunities to enhance learning through exploring. However, we found few examples of innovation in this theme – just ten research examples and five teacher–based examples.

The research examples covered all stages of education and a variety of subjects from mathematics to politics. They tended to involve the use of technology not traditionally found in classrooms, including robots, information visualisation tools and large multi–touch displays. All the teacher–led examples were drawn from primary-level classroom settings, although three also included an aspect of learning in home or community settings.

Given the dearth of examples, learning through exploring appears to be underused and undervalued within educational settings. This is possibly because it is difficult to link exploration – whether it is formal or informal, structured or unstructured, spontaneous or directed – to formal learning objectives. However, the limited evidence available suggests that technology offers great potential to support learning through exploration.

A highly illustrative example of innovation of this theme with sound evidence involved the use of digitally augmented plastic blocks to allow children to explore basic computer programming[74] (described above).



OpinionSpace

University of California, Berkeley and Silverman Research. Photographs used with permission.

Three research examples demonstrated the potential benefits of tools that tailor information in online or computer-based environments. The first of these is Opinion Space,[75] developed at the University of California, Berkeley, US. Opinion Space is a social media technology that self–organises debates into an evolving map that represents trends, patterns, and insights while drawing out emerging key arguments, positions and ideas.[76] Learners discussed politics in the comments section of an online blog connected to Opinion Space, which automatically highlighted and presented those comments found most useful by other learners. Learners were more engaged and exhibited greater respect for the blogs and comments they read, compared to regular blog comments which appear in chronological order. Furthermore, learners were encouraged to interact with more of the comments they read and to argue their points of view in constructive ways.

The second example showed how learners can improve their Internet search skills when presented with a graphical timeline of the progress of other learners undertaking similar tasks.[77] Learners were able to see what information other people had uncovered and so received implicit guidance on search strategies. While this comparison helped point learners in the right direction, it was not intended to provide answers or approaches to copy; instead, learners were required to build on the information present to develop a unique search strategy related to their own goals.

The third example demonstrated how interactive visualisation tools can support the teaching of mathematical concepts.[78] Researchers from The University of Western Ontario, Canada, worked with a diverse group of learners, who explored the mathematical properties of shapes by using tools to move them around and arrange them in patterns. They found that such tools can be effective in supporting learners, but that they need to be flexible to accommodate different learner needs. Interestingly, the researchers reported that (some) learners found the use of the tool addictive.

Another example showed the potential for technology to support exploration in a public setting. A large, multi–touch installation featuring layers of information, including 3D worlds, was used to provide access to science content.[79] Multiple learners simultaneously navigated different ‘layers’ of information in public, leaving their own annotations for others and discussing the issues raised with other learners. The project demonstrated how an environment can be structured so as to gradually ‘unfold’, and how browsing for information can be a social activity – particularly if the technology provides a space where media can be shared.

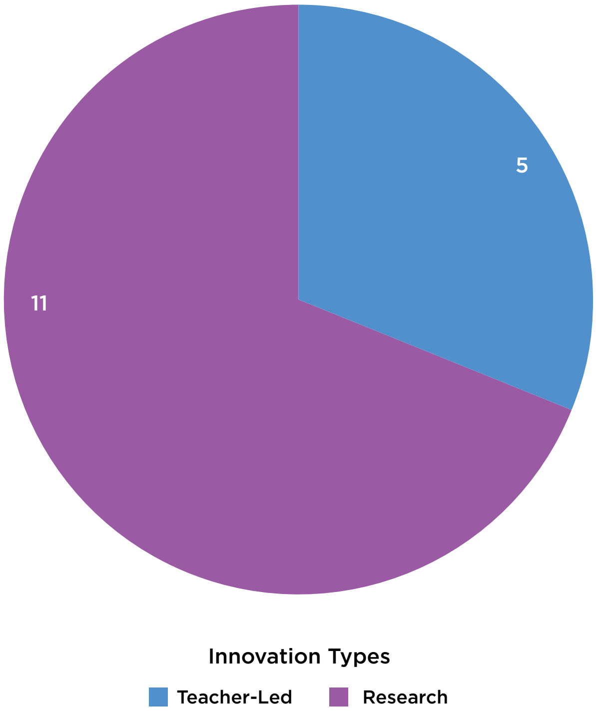
Hole-in-the-Wall

Although these examples presented strong evidence of the effectiveness of technology-enabled learning through exploring, they were not rated highly by our expert panel.

There were also few teacher-led examples of innovation in this theme; and those few were not rated highly by our expert panel. The most highly rated example was the Hole-in-the-Wall[80] – a project that placed computers in a public place to encourage unsupervised learning by exploring the Internet. The project began in 1999 when Professor Sugata Mitra placed a free computer for public use in a hole in the wall separating his university and the neighbouring slum in New Delhi. In the absence of teachers, learners were motivated to teach themselves and one another how to use the computer so they could explore new information. Over time, learners became computer literate and even began to learn other languages, like English, on their own. The impact of this model has been subjected to widespread discussion and research. Ultimately, it shows the immense potential that technology offers to promote learning through exploring – if learners are given time and access to the necessary resources.

2.5 LEARNING THROUGH INQUIRY

Inquiry-based learning involves exploring the natural or material world by "asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding". Technology can be used to organise inquiry that might otherwise be difficult to accomplish, to change how learners look at problem-solving, and to connect learners' inquiries to real world scenarios. There is a great deal of research and teacher-led innovation that provides good evidence of promise for technology-supported inquiry.



RoomQuake

Developed at the University of Illinois at Chicago, RoomQuake is a simulation where learners pretend that their classroom is an active seismic field, and that a series of earthquakes is expected over the course of several weeks within that field.

Over six weeks, learners experience simulated earthquakes using a thin layer of technology consisting of audio subwoofers and fixed position PDAs within the room that simulate seismographs. Learners actively participate, using calibrated tape measures and mathematical trilateration to find earthquake epicentres, and building representations of seismic events. Learners discover underlying rules, develop general skills such as plotting and interpreting graphs and increase their subject-specific knowledge. (Moher, et al. 2005)

Highlights

- Inquiry-based learning is seen as one way of enabling learners to think critically and participate in evidence–based debates.
- Enthusiasm for technology–supported inquiry is high.
- The most highly rated innovation of all involved an online portal that engaged secondary and higher education students in creative challenges set by industry. The major appeal of this project was its ability to connect learning with real-life, industry–based demands.
- A number of high quality examples illustrate the potential of technology to support learning through inquiry in a wide variety of settings, across a range of subjects and with different types of learners.

Successful learners need to be able understand and participate within complex, evidence–based debates. Inquiry–based learning is seen as one way of enabling learners to think critically and participate in such debates.[81] Unlike the open–endedness of *Learning through Exploring*, inquiry-based learning is structured towards an end where something is found, uncovered, or discovered. The US National Science Foundation suggests that inquiry learning "involves a *process of exploring* the natural or material world [...] that leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding."[82] Learners build on their own curiosity through structured actions.[83] *Learning through Inquiry* includes learning with *simulation*, *case–based learning*, *problem–focussed learning* and *scripted inquiry*.

Personal Inquiry Project

The degree to which learners' inquiries are structured varies, as does the degree to which learners are made aware of the structure. For example, learners may be able to manipulate a simulated system without necessarily being aware of its underlying structure. In the Savannah project[84] learners were supported by a mobile game to act as lions in a grassland simulation. Through this experience, learners uncovered the rules of the savannah while also improving their understanding of animal behaviour. In *case-based* and *problem–focussed* learning, structure is provided by particular tasks' content, with the aim of helping learners discover how their knowledge fits within a wider academic subject. In *scripted inquiry*, the steps that learners need to undertake are made explicit. In the Personal Inquiry project,[85] learners used netbook computers with software support to conduct scientific inquiries in different contexts such as classrooms, field trips, and the home. The technology enabled learners to carry out a variety of scientific investigations of personal relevance; one group of learners focussed on healthy eating, for example. The support and direction from the software was useful in alerting learners to, and helping them to meet, the challenges of scientific investigation.

Technology can be used to organise inquiry that might otherwise be difficult to accomplish, to change how learners look at problem solving, and to connect learners' inquiries to 'real world' scenarios.

We found 24 research examples of innovation in *Learning through Inquiry*. They spanned all stages of education. Several involved technology not traditionally found in classrooms, including augmented reality (AR) visualisations, large display environments and motion sensing tools. They usually involved teaching of STEM subjects such as physics, plant science, mathematics, and engineering; though other examples covered English language and architecture.

There were few (six) teacher-led examples in this theme. All were based in primary or secondary-level classrooms; one included an aspect of learning at home. Subjects covered included history, citizenship, antisocial behaviour, business and the creative arts.

Most of the teacher-led examples showed great potential. The most highly rated innovation of all was the I am Creative online portal that engaged secondary and higher education learners in creative challenges set by industry.[86] The major appeal of this project was its ability to connect learning with rea-life, industry demands, such as designing an advert. It is expected that participating industrial partners will provide judges to examine learners' submissions. However, rather than fundamentally change the learning process, this project introduces industry-based challenges to a broader range of learners. Nevertheless, its popularity among experts suggests that the project provides a model that appeals to teachers, industry and learners alike; and is one that is worth replicating in other settings.

Three of the other five teacher-led examples were also highly rated by our experts. They were: a project providing multimedia materials for mathematics problem-solving based on everyday problems;[87] an educational game suite, iCivics, that uses simulations to help secondary students improve their knowledge of US political topics such as governmental structure, legal rights and the constitution;[88] and Literacy Shed, a database of tagged short films and images that aims to engage secondary students with themes such as emotions in literacy.[89]

The research examples received more mixed ratings. However, a number of highly rated examples showed how technology has the potential to support inquiry in a wide variety of contexts. The LECGO tool was developed to motivate learners and promote participation in drawing activities by providing computer-based, problem-driven activities and appropriate feedback.[90] Learners using LECGO made greater learning gains compared to learning using paper and pencil or typical programming environments. Another promising example involved learners at university using game-based tools to tackle complex, open-ended problems, such as designing a city.[91] The planetarium simulation software, Starry Night, was used to help primary-aged pupils develop their understanding of moon phases.[92] The software enabled learners to explore information about space, which helped them to better understand a relatively abstract concept. Finally, the EU-based Science Created By You project, allowed secondary students to work individually and collaboratively to solve socio-scientific questions in a virtual environment.[93]

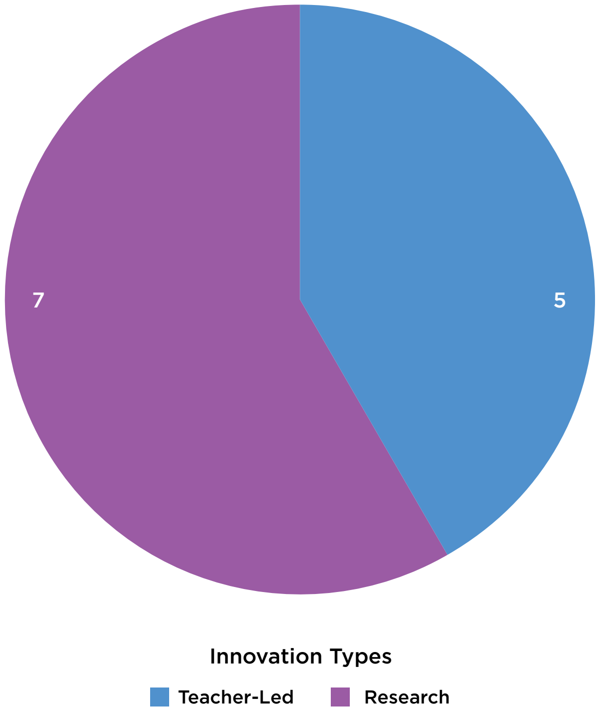
Two examples focussed on learning through simulation. The first involved the use of an online simulation tool, ControlWeb, in a distance-learning control engineering course.[94] Students' online activity and performance was monitored by the learning management system and a fuzzy logic controller.[95] This enabled learners' actions to be regulated and helped learners to regulate their own workload. This example demonstrated how learners can be supported to manage their own time and how their motivation can be maintained by communicating with other learners. The second involved the use of the Starry Night planetarium simulation (see above). A review of the simulation highlighted the importance of predictability and patterns as learners move through different phases of learning – from browsing to reflection. Both of these examples highlighted the time required to gain the skills to usefully manipulate the simulation.

One problem–focussed example involved using a set of 26 bespoke cards containing computing–related concepts to help learners develop programming skills.[96] The cards are a simple tool that supports problem-focussed thinking by illustrating the implications of particular computing concepts in a concrete way. Learners undertook sorting tasks using the cards – acting out a sorting algorithm and considering the cards' meanings – before engaging in open sorting tasks where they developed their own sort criteria and categories. The process was supported by semi–structured discussion with a teacher.

Another interesting research example focussed on supporting scripted inquiry in museums using interactive digital augmentations. Be The Path was designed to illustrate principles of electrical conductivity. Projection technologies directed learners to ask particular questions.[97] The authors suggest their approach could be deployed in other, informal learning settings.

2.6 LEARNING THROUGH PRACTISING

Whatever is being learned, practice makes perfect. There is a long history of technology being used to support learners practising their skills; but it is an activity where innovation is limited. The most effective use of technology enables learners to practise their skills and knowledge using a variety of multi-modal representations and interactions. Where technology is effectively used well to support practice, it does not simply sugar-coat uninspiring or unchallenging activities.



Habgood and Ainsworth. Photographs used with permission.

Zombie Division

Zombie Division is a game designed to help children aged eight to eleven to practise their multiplication and division. They divide skeletons wearing numbers (such as 18) with mathematical weapons (such as 3). Research revealed that successful educational games do not simply provide an opportunity for learners to practise. Instead games that integrate the knowledge and skills to be learnt directly into the structure of the game activity are both more fun for children to play and more effective than those where the game is used as motivation but without connection to the learning content. Zombie Division illustrates how games can be used to implement challenging practice in a motivating form and whose success is based on the integration of learning objectives and game design. (http://zombiedivision.co.uk/)

Highlights

- Practising their skills enables learners to build a solid foundation of knowledge that can then be used in other contexts.
- The use of technology to support practise is rarely seen to be innovative; but promising developments include the use of rich multimodal environments that can create challenging problems and provide appropriate feedback.
- Games are often used as a means of encouraging learners to practise. However, the more highly–ranked examples with our expert panel did not simply use games to disguise an otherwise dull period of practice. They also provided learners with interesting and challenging problems; and with feedback to help learners develop new insights.

Whatever is being learned, practice makes perfect. Practising enables learners to build a solid foundation of knowledge that can then be used in other contexts – such as solving a more difficult mathematical problem, or taking part in conversation in a foreign language.

Practice has a long history in learning; and technology has played a key role in supporting practice. Practice was first systematically studied by Thorndike in 1898. His law of exercise states that practice strengthens connections (and without practice those connections become weakened). Thorndike applied this law to spelling and arithmetic.[98] By 1958 Skinner had developed Teaching Machines which were designed for learners to practice their skills through programmed instruction. The approach became so widespread that, until recently, most educational technology was predominantly used for drill and practice.

Practice still underpins some current theories of learning, particularly where practice till fluency is seen as key to becoming an expert. Learning by practising for examinations has also had a significant influence on education policy and practice.

However, learning by practising is no longer at the cutting edge of learning theory. While commercial products and services using technology to support practising are still in abundance, we found few examples of innovation in this theme – just ten research examples and eight teacher-led examples. They spanned all stages of education, but were predominantly found in traditional subjects (languages and mathematics). They covered all types of settings, including learning in the workplace, home and museum. They typically involved the use of multimedia technology or games, such as the Wii.

As well as being relatively scarce, the examples were not highly rated by our experts. Only two research examples were ranked in the top half of all the innovations reviewed. The first involved learners in a German kindergarten comparing the magnitude of different numbers they generated by making gestures on a digital dance mat. By moving about to demonstrate and compare different numbers, learners were able improve their understanding of magnitude and their basic numerical skills.[99] The second also combined activities for learning in an unlikely way. Two mobile phone apps, Multimedia Word and Drumming Strokes, have been designed by Chinese and American academics to teach groups of young, rural Chinese learners how to write Chinese characters and improve their literacy.[100] To support continued participation and confidence, the app is based on traditional Chinese group games that learners are already familiar with. This culturally sensitive model adds an element of familiarity but, more importantly, the social qualities of the games are suggested to increase engagement.

The most highly rated teacher–led examples illustrated the potential of bots.[101] In one example, artificial intelligence (AI) chatbots – computer programs that can simulate conversations with a learner – helped learners to practice their foreign languages. Learners with limited vocabularies are challenged to ask interesting and different questions to the chatbot, so that its responses create a conversation.[102] Similarly, the online game Light–Bot allows primary–aged pupils to develop basic programming skills as they learn to navigate a bot by choosing a sequence of directions.

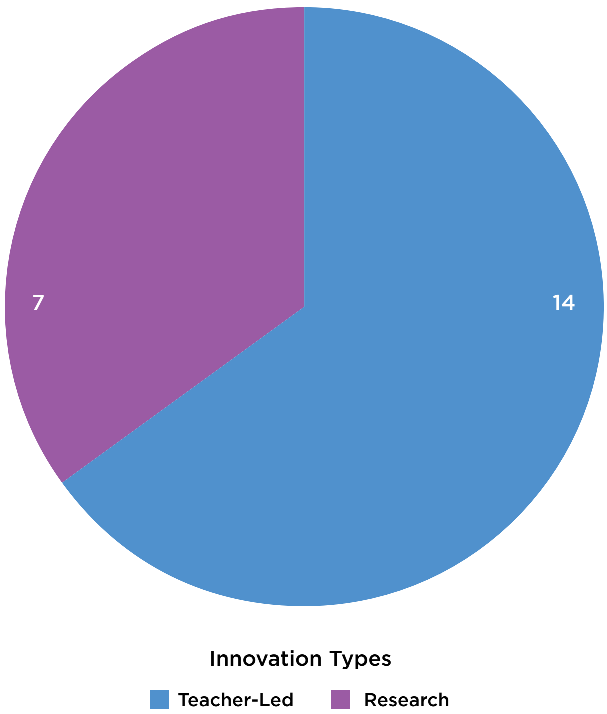
Children playing with mobile games for learning Chinese

Other promising teacher–led examples focussed on practising maths. Motion Math uses the intrinsic features of tablet computers to create educational games designed to engage learners with maths. The apps take advantage of the tablets functionality, such as being able to tilt the device to indicate larger numbers. In this way learners have a physical and visual representation of the concepts they are learning.[103] Tools such as BuzzMath,[104] a US-based online platform, provide practice exercises with instant feedback, visual demonstrations, and detailed solutions to school-aged learners. Teachers can use the abundance of resources or activities with an entire class or assign specific work to individual learners. Although it appeared to be highly promising, it was not rated highly by our experts. This is possibly because the experts thought that technology was being used to simply sugar-coat uninspiring activities.

By contrast, the more highly rated examples – Zombie Division (see case study)[105] and the digital dance mat mentioned above – did not simply use games to disguise an otherwise dull period of practice. They also provided learners with interesting and challenging problems, and with feedback to help learners develop new insights. The evaluation of the digital dance mat showed that improvement comes not simply from the novelty of the experiences, but from developing young learners' mental representations of number magnitude.

2.7 LEARNING FROM ASSESSMENT

Gaining awareness of what a learner understands is fundamental to increasing their own understanding and knowledge. Technology can be used to support assessment in a variety of ways. It can be used to compile learning activities and enable both teachers and learners to reflect upon them; and to track the progress of learning and to present that information about progress in rich and interactive ways. Yet there is little innovation in technology-supported assessment, possibly in part due to the lack of excitement that assessment generates in the education sector.



Madeline Balaam, Newcastle University. Photographs used with permission.

Subtle Stone

There is increasing evidence that emotions affect learning.

The Subtle Stone is a novel use of technology to help learners reflect on the impact of their emotional state upon their language learning, demonstrating that technology-enabled assessment can be used for more than discipline knowledge. The first tool of its kind, the stone is designed to collect learners' self-reported emotional experiences in real time. Equally it can easily be recreated by hacking a commercial juggling ball. The Subtle Stone supports both learners, and their teachers, to consider the emotional impact of learning activities and teaching methods. (http://www.madelinebalaam.co.uk/the-subtle-stone/)

Highlights

- The current level of research innovation in technology–supported assessment is modest; the most innovative work focusses on self-assessment through reflection rather than teacher-led assessment.
- The majority of examples of innovation are based upon summative assessment of traditional subjects. More work is needed to assess the potential for technology to support formative assessment or the assessment of other skills.
- Combining data, captured through a variety of digital tools, with learning analytics appears to offer great promise for assessment.
- Another promising area for development is e-assessment using social networks and read-write technologies such as web 2.0, which can facilitate peer, collaborative and self-guided learning.

Knowing what learners know, and don't know, is crucial to effective learning. If learners attempt tasks that are too complex, they are likely to fail; if they attempt tasks that are too easy they may not progress as they should. Accurate information about learners' current understanding can help us to offer appropriate feedback and increase learners' own awareness of their learning needs. Accurate assessment and analysis also allows learning to be tailored. Learners differ physically, emotionally and cognitively, and in their ability to understand what they know and how they can progress. Recognising these differences can help to ensure that everyone achieves their full potential.

Two important processes underpin how we identify what learners know and understand. *Reflection* involves learners considering their own learning activity. By reflecting learners develop the skills and self-awareness they need to refine their own learning activities. *Assessing* involves teachers considering the learners' learning activity. Effective assessing provides feedback and feed–*forward* advice to a learner about their learning activity: learners must be able to respond to a critical voice. Self–assessment requires the learner to provide that critical voice, which links back to the process of reflection. We must also recognise that at times teachers are also learners, for example, when taking part in professional development activities. The processes of reflection and assessment are no less important for them as they are for any other learner.

Technology can be used to support assessment in a variety of ways. It can be used to compile learning activities and enable both teachers and learners to reflect upon them; and to track the progress of learning and to present that information in rich and interactive ways.

Interest in formative e-assessment is increasing. There are numerous examples of developments in e-assessment using mobile and immersive environments as well as social and collaborative networks.[106] A large amount of development has also taken place on diagnostic testing environments that allow teachers and learners to assess present performance against prior performance.[107]

We found numerous research and teacher-led examples of innovation in assessment. The technologies used in the research examples were notably different from those used in the teacher–led examples. This is possibly due to funding issues and the greater imperative upon academic researchers to seek technological innovation. All the teacher–led examples relied upon 'off the shelf' technology, including free software such as Audacity[108] and Jing (audio and video)[109] and SurveyMonkey (questionnaire design).[110] The research examples more often involved bespoke software, such as an adaptive learning environment,[111] or existing technologies with added bespoke features, such as a system that automatically captures whiteboard images and makes them accessible.[112]

In most examples learners used a web-based or virtual environment via desktop or laptop computers. Exceptions included the Subtle Stone (described above)[113] and a mobile phone app designed to support self-assessment by learners at secondary school and university.[114]

Most examples were in classroom settings from primary school through to university. Many of the research examples focussed on assessment in formal sciences. This is possibly because it is more straightforward to automate assessment in these subjects. However, technology specifically designed to support reflection tended to support general, rather than subject-specific reflection.

Few of the research and teacher–led examples of innovation in this learning theme were highly rated. However, two teacher–led examples were ranked in the top ten innovations. The first involved the use of an audio tool (Audacity) and video mixing tool (Moviemaker) by secondary students to create podcasts reviewing their learning that year, that could be used, for example, to prepare for an exam.[115] By creating audio and visual outputs learners consolidate their learning and produce a resource for other learners. The second example involved learners using digital cameras and a presentation tool, Kidpix, to record, compare, and comment on changes to the environment, for example, how the woods change over seasons. Through this exercise, they learned how to capture and observe long–term changes, and assess them in systematic ways.[116]

Many of the teacher–led examples focussed on using technology to support teachers to work together. For example, technology was used to share information about learner behaviour or teachers' own practice to support community reflection.[117] In one example, teachers used the ClassDojo mobile app to record learner behaviour and achievements in context. The app automatically creates summaries and provides on–going tracking of behaviour which can be shared with learners, other teachers, administrators and parents.

Despite their relatively low ratings, a number of research examples also provide some potentially interesting insights for further developments in technology–supported assessment. One example involved the use of automated feedback to support learners at university with their written assignments. Learners received comparisons with other learners' work by using language technologies that analyse concepts within and between texts and identify any overlaps and gaps. Similarities and differences are then visually represented side by side for the learner to review. An initial study demonstrated that learners were able to identify overlapping and missing core concepts, both in individual texts and in a compiled group text.[118] A second example involved the use of an automated marking system, AssignSim, to support assessment of university learners' programming assignments. This tool measured the similarity of learners' work with examples from a bank of previously marked assignments.[119] Experimental evidence indicates good correlations between system assigned marks and those provided by human markers.

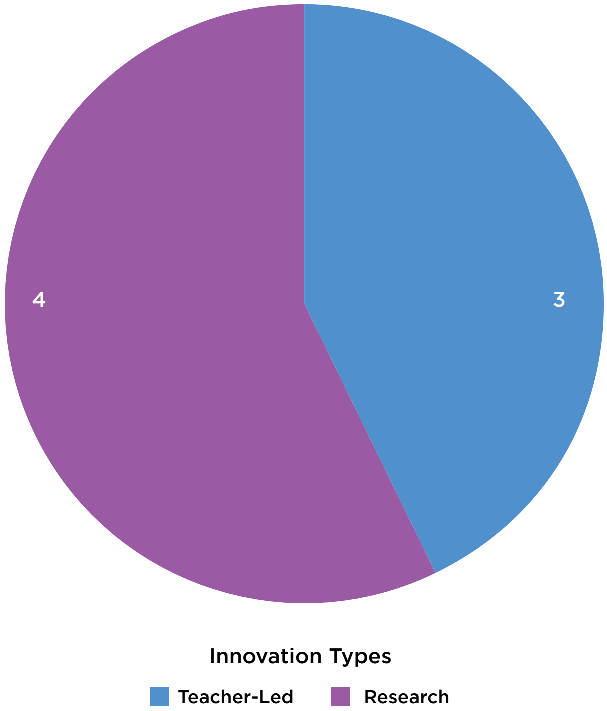
Combining data captured through handheld devices,[120] activity logs, timestamps, version tracking, and target-setting[121] with learning analytics also appears to offer great promise. Another promising area for development is e–assessment using social networks and read–write technologies such as web 2.0, which can facilitate peer, collaborative and self-guided learning (for both teachers and learners).[122] One study by researchers at the Hong Kong

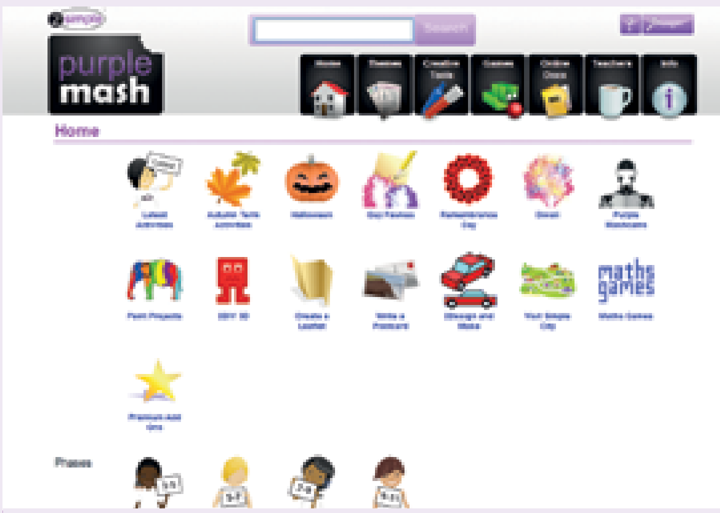
Institute of Education looked at the effects of using video recordings of learner teachers to support their reflection on their teaching.[123] The project used a web cam and online storage for videos so that teachers could easily capture their lessons and review and reflect on their performance afterwards. It was found that video browsing prompted learner–teachers to make more reflective notes, and that they were more deeply reflective about discipline, classroom management, and professional teaching knowledge.

In another example, multimedia materials used to teach computer science were combined with tailored prompts so that learners could explain to themselves what they had understood.[124] Self-explanation is an important part of building learners' understanding of their learning. The results indicated that adaptive prompts can help to address different learner needs, but that learning from these prompts depends upon levels of learner expertise.

2.8 LEARNING IN AND ACROSS SETTINGS

Learners improve their knowledge and deepen their understanding when they apply their learning across different locations, representations and activities. However, it can be difficult for learners to apply learning from one setting, such as a lesson at school, to another, such as a field trip or workplace. Technology can help – teachers and learners can use a variety of devices to capture, store, compare and integrate material from a variety of settings.





PurpleMash

2Simple Software. Photographs used with permission.

Purple Mash takes advantage of cloud-computing technology. It offers a suite of learning tools hosted on the Internet to support primary-aged pupils to transfer learning between school and home. This award-winning site, run by 2Simple Software, contains hundreds of educational projects, games, apps and tools. One such activity explores water use at home and includes video examples, a gallery of clipart and photos, and guidance about how to complete the activity. Learners can develop their schoolwork at home with parents. Schools must pay a subscription fee to use the suite of tools. (www.purplemash.com)

Highlights

- The 'context of learning' has an important role to play in determining the quality of learning – learning across locations can enhance the learning experience.
- Technology can help learners apply and transfer learning from one setting, such as a lesson at school, to another, such as a field trip or the home.
- The variety of locations in which the technologies were used, subjects covered, and ages of the learners suggest that digital tools have the potential to enhance learning in a wide variety of settings.
- Key success factors include: understanding what parents really need in order to get them involved; recognising that activities designed for school are not necessarily transferable to the home, and vice versa; providing on–going support; and ensuring that learners' uses of technology at home are purposeful.

Learners interact with people, places and things as they learn. This context of learning can determine not only the quality of learners' experiences but also their learning outcomes. Learners improve their knowledge and deepen their understanding when they apply their learning across different locations, representations and activities. Solving real–world examples enables learners to develop skills, build knowledge, and apply their understanding. Applying their learning in an integrated and meaningful way can help learners appreciate the usefulness of subject knowledge that might otherwise seem 'academic'.

It can be difficult for learners to apply learning from one setting, such as a lesson at school, to another, such as a field trip or workplace. Technology can help. Learners can capture, store, compare and integrate material from a variety of settings using devices such as mobile recording and communication tools, PDAs, cameras, phones, and GPS–enabled devices.

One research example involved the use of Lifelogs – digital logs of everyday lives and experiences.[125] Learners create Lifelogs by capturing their experiences through pictures, text, and geographical locations using their mobile phone. A tool then displays the information captured at pre-set intervals. By displaying different kinds of information at different times, the tool can prompt memories and stimulate reflection on learning experiences. For example, the location information enables learners to understand habits in their behaviour; while visual cues support the process of recollection. Lifelogs was rated the second most promising example of innovation by our experts, suggesting that it has great potential to further enhance the learning experience.

Technology can also enhance learners' exploration of the 'real world'. There is growing evidence that emerging technologies, such as augmented reality, can support learning by overlaying objects in the real world with digital information. Systems such as EcoMOBILE (Ecosystems Mobile Outdoor Blended Immersive Learning Environment),[126] developed at the Harvard Graduate School of Education, combine augmented reality technology and environmental probes for learners visiting a real ecosystem. They can use their mobile devices to collect data that helps them to solve practical problems and apply scientific concepts to real-life scenarios. For example, EcoMOBILE was used by learners to solve an 'environmental mystery' during a series of field trips to a local pond. Learners collected video, photo, and audio data about the environment while accessing supplementary information and clues through an augmented reality interface on their mobile phone.

New York Hall of Science. Photographs used with permission.

EcoMOBILE

They then gathered real-time scientific data on the ecosystem using environmental probes. The technology created a scientific process that challenged learners to apply theoretical knowledge to a tangible experience outside the classroom. Another well-evidenced and highly ranked research example involved the use of mobile phones to support a history field trip.[127] Learners worked in groups to explore a location and learn about its history. They were able to navigate the area and relate what they were looking at to content provided by the mobile phone.

Technology can also help others support learners as they move between locations, and between physical and digital environments. For example, there is good evidence that technology can support parents to support their children as they transfer their learning between school and home. One highly ranked and promising example of technological innovation in this area is Purple Mash by 2Simple (described above).[128] It was ranked among the top 20 most promising innovations by our experts. Virtual and Managed Learning Environments (VLEs and MLEs), when appropriately designed and used in conjunction with face-to-face courses, were found to help parents understand how to use the technologies and resources available to support their children.[129] These technologies offer great potential to link learning between home and school. Handheld and mobile technologies were found to be particularly valuable for building home-school relationships when little other technology was available in learners' homes.

LocoMatrix. Photographs used with permission.

LocoMatrix

Brighton-based start-up Locomatrix[130] offers teachers and learners an easy way to create location-based games with their application programming interface (API). Using GPS and mobile technologies, location-based games can be developed for use across a variety of environments. Teachers and learners can design their own games that not only reflect but interact with their local environment. We found several similar examples of games-based learning. One particularly interesting example involved learners with Special Educational Needs using cameras in 'digital scavenger hunts' to find words in different areas of their school campus.

It is worth noting that there were relatively few innovations (eight research, and three teacher-led). However, these few examples presented a variety of interesting innovations that showed promise for wider implementation.

The variety of locations in which the technologies were used (from schools to local ponds), the subjects covered (from science to history), and the ages of the learners (from primary school to adults) suggest that digital tools have the potential to enhance learning in and across a wide variety of settings.

Research examples involved the use of both bespoke software and 'off the shelf' products, such as VLEs. Handheld devices and RFID tags were used together to support writing in different environments[131] and smartphones were combined with bespoke knowledge management software.[132] The technologies used in the teacher-led examples were more readily available than those found in the research examples. They included mobile phones, interactive whiteboards, cameras, secure cloud storage and online tools.

The evidence from these examples points to a number of key success factors. They include: understanding what parents really need in order to get them involved; recognising that activities designed for school are not necessarily transferable to the home, and vice versa; providing on-going support; and ensuring that learners' uses of technology at home are purposeful.[133] Technology was most successful in building relationships between home and school when there was already 'cultural harmony between home and school'.[134]

CHAPTER 3: BRINGING LEARNING TOGETHER

In Chapter 2, we looked at ways in which technology is being used to support learners across eight learning themes. However, each theme incorporates a variety of learning activities; and a single episode of learning – such as a lesson, a project, or a unit – is rarely confined to a single learning theme. For instance, learners might explore the application of geometry by watching video lectures (*Learning through Exploring*) and then practice what they have learned through an online adaptive game (*Learning through Practising*). This game might also track learner progress and provide feedback to the teacher (*Learning from Assessment*), so that he or she can adapt the next class to focus on the most challenging concepts identified within targeted group discussions (*Learning with Others*). To achieve a more rich, cohesive, and productive learning experience, we must consider the links that exist between different learning activities within and between themes.

LINKING LEARNING THEMES

Learning Themes are made up of...

Learning Activities – such as creating an animation or playing a maths game – which are connected and embedded across different learning themes into...

Learning Episodes – such as lessons, projects, or units – that are linked and sequenced to create...

Broader Learning Experiences at the classroom, school, and institutional level.

Linking learning activities within and across different learning themes enables learners to create a coherent learning episode. This reinforces learning and creates deeper understanding. It can also strengthen future learning by helping learners establish more versatile approaches to learning.

Learning episodes can be created by coordinating or mutually embedding learning activities. The episode may be structured by teachers; or by the learners themselves. Technology can support both. **In the first part of this chapter we consider how learning themes are linked within learning activities; and we explore the potential role of digital technologies to support the formation of learning episodes.**

Individual learning episodes may themselves be linked. Many teachers strive to link learning episodes across a course, classroom, or entire school in order to create a coherent learning experience. Again technology can help to link learning episodes. To do this effectively, the technology must take account of existing structures and responsibilities within the classroom, an established curriculum, and relevant parties outside the classroom. **In the second part of this chapter we consider how technology can support linking learning episodes at an institutional level.**

LINKING LEARNING ACTIVITIES

We start by considering how technology can support teachers in orchestrating learning – that is, link learning activities within and across learning themes to create episodes of learning. To some extent, this is revealed by the presence of multiple learning activities within the examples of innovation reviewed in this report. Over half (57 per cent) of the research examples encompassed two or more forms of learning. Some featured different learning activities within the same learning theme, for example when *simulation* was being used to support *scripted inquiry* as part of *Learning through Inquiry*. Other examples featured learning activities spanning multiple themes.

Table 3.1 compares the learning themes that we categorised as being the primary focus in the research innovations we reviewed with those that were categorised as being of secondary importance.

Learning theme	Primary Occurrences	Secondary Occurrences
Learning from Experts	23	9
Learning with Others	28	14
Learning through Making	5	19
Learning through Exploring	10	12
Learning through Inquiry	24	6
Learning through Practising	10	4
Learning from Assessment	16	6
Learning in and across Settings	8	3

Table 3.1: Primary and Secondary Occurrences of Learning Themes in Research-led Innovations

Learning through Making, Learning with Others and Learning through Exploring were the most often used in a supporting role, while *Learning through Practising* and *Learning in and across Settings* were least often used in a supporting role. *Learning through Making* was a primary focus for learning activity in only five cases, but played a supporting role in 19. In a typical example, *Learning from Assessment* was supported by *Learning through Making* – learners reflected and prepared for their exams by making podcasts with audio and video tools.[135]

Some patterns emerged within particular learning themes. Where *Learning through Inquiry* was used in a supporting role in six cases, none of these involved *scripted inquiry*. In other words, *scripted inquiry* was usually the dominant form of learning, either being used on its own or providing an overarching structure for other learning activities. Learning activities that occurred most frequently in a supporting role were *collaborative* learning *in Learning with Others* (eight cases) and *browsing in Learning through Exploring* (seven cases). These learning activities play a crucial supporting role in a variety of innovations: in one example of *Learning through Making*, learners that had created multimedia presentations of their visit to a museum were expected to share them with their peers.[136]

Project Noah is an online platform that enables citizen scientists worldwide to collect and share ecological data and document the world's organisms. Described as a "digital butterfly net for the 21st century", this project uses mobile phones to help a community of learners to explore aspects of nature in their local area, for example by identifying types of insects.

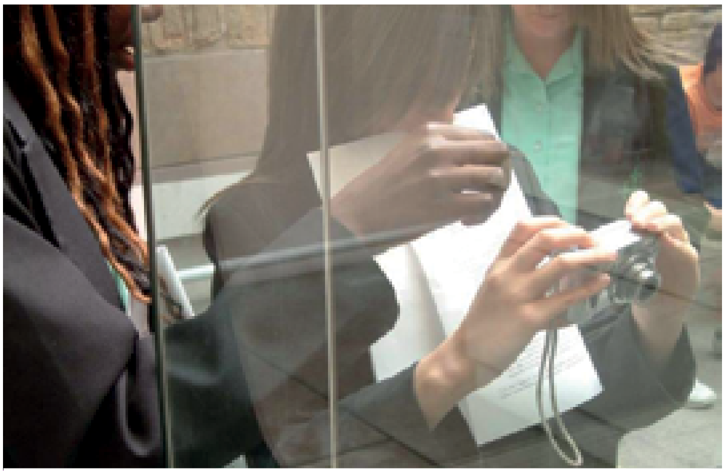
Alongside independently capturing information about local nature, participants can create targeted missions which others can join and contribute to. For example, the Global Urban Biodiversity mission has over 5,700 participants and 23,500 documented spottings of urban wildlife. Project Noah also offers a classroom setting which teachers can use to create curriculum–based missions as assignments and keep track of student activity. A selection of sample course materials is available to support teachers to build activities involving inquiry, exploration, and practice. For instance, in the Tree Tour activity, learners map, locate and identify trees in a local outdoor space, while the Writing Goes Wild activity brings together science and writing by having learners turn their captured observations of wildlife into a descriptive writing activity.

Launched as part of New York University's Interactive Telecommunications Programme in 2010, nearly 340,000 spottings have taken place worldwide to date. (http://www.projectnoah.org)

The tradition of much research design is to isolate and analyse. Therefore it is perhaps not surprising that few research studies consider the ways in which technology can be used to link activities across learning themes. There were even fewer teacher-led innovations that linked learning activities – only 30 (out of over 80) featured activities that crossed two or more learning themes. This may have been a consequence of the limited information available on many of the teacher-led innovations. However, this lack of attention is unfortunate given the considerable potential for technology to create coherent, complex episodes of learning. It is likely that teachers would welcome tools that can link learning activities.

Despite the general lack of evidence, a number of examples have demonstrated the potential of technology to link multiple learning activities into an episode of learning. We have highlighted three particularly promising examples below.

In the European MuseumScouts project,[137] learners undertook research into specific artefacts during museum visits. They used a range of devices (pens, paper, and smartphones and created multimedia presentations in groups using a specially created tool called Evolution. In the Austrian pilot of this project, learners explored an exhibition in small groups, and then captured what they discovered through photographs, drawings and notes. Learners were also invited to meet and interview the curator of the exhibition, who offered additional



Graduate School of Education, Bristol University. Photographs used with permission.

MuseumScouts

multimedia resources about the exhibition. Following the visit, these groups produced timelines of the exhibition using flash animation, combining them with designs they had made in another class. Through this episode of learning, we see that MuseumScouts is primarily about *Learning through Making*; but aspects of *Learning through Exploring*, *Learning in and across Locations* and *Learning with Others* are deployed at different points within the episode.

A suite of web-based learning tools in a highly rated teacher-led example[138] represents one example of *Learning in and across Settings* providing an overarching framework for *Learning through Making*. Small groups of learners were taught web design using collaboration scripts and incomplete concept maps. These tools were designed to allow groups of learners to work together on extended tasks using a scripted inquiry approach. The *cross-setting* opportunities created by the online environment allow classroom support for *construction* projects that mainly occur at home.

Finally, work by Hartmann et al.[139] is particularly interesting because it links different learning themes indirectly – *Learning from Experts* and elements of *Learning through Making* and *Learning with Others*. A learning analytics tool assisted novice programmers who have encountered compiler error messages. The tool acts in a *tutorial* role, since it provided different feedback depending on the particular error message. Yet this tutorial relies on learners *annotating* their own error messages and submitting them to the system. A social recommender system then used a bank of the learners' own annotations to provide help to others. There is no direct collaboration between learners – the relationship between the learning themes is only apparent if learners are considered collectively.

LINKING AT THE INSTITUTIONAL LEVEL

Some commentators argue that fundamental change in learning will only occur if we address teaching practice and resourcing at an institutional level. In other words, we must strive for innovative classrooms and schools, not just innovative episodes of learning. There are many examples of initiatives seeking to achieve such change, including Apple's Classrooms of Tomorrow Today, Quest to Learn, and the Korean Smart Schools. The mission statements in many of these initiatives (e.g., the Q2L learning model[140], the ACOT2 report[141], and Harvard's Project Zero[142]) contain strikingly similar aspirations. In particular, they assert that:

- **Learning should strive for depth and understanding**
- **Learning experiences should be authentic or relevant**
- **Learning should create and disseminate new knowledge**
- **Assessment is important**

New technologies are frequently seen as key to shaping learning in these terms. However, there are few examples of technology being used to produce learning experiences that integrate these aspirations – that is, experiences that have depth, are authentic and create new knowledge, while at the same time acknowledging the role of assessment.

In 1999 the Malaysian Ministry of Education introduced the Smart School Policy as part of a range of policies aimed at developing a more knowledge–based economy. While Smart Schools embraced digital technology, the more fundamental change related to the curriculum. Teaching became less driven by textbooks; learning became more structured around personal inquiry; and assessment occurred more frequently but was managed by learners themselves. The success of the initiative has depended on establishing a communications network within and between schools. Emphasis has been placed on adopting learning management systems, access to Internet sources, and extensive use of multimedia devices. The initiative has successfully taken the school system to a state of digital maturity. It illustrates how technology can be a catalyst for curricular innovation: achieving radical change in teaching and learning through investment in infrastructure.

(Ghavifekr, S., Hussin, S. and Ghani, M.F.A. (2011) The process of Malaysian smart school policy cycle: A qualitative analysis. 'Journal of Research and Reflections in Education.' 5(2), 83-104)

Technology is often seen as a means of delivering depth and understanding through its capacity to provide easy access to information. Authenticity or relevance may often be achieved by *Learning in and across Settings*. Yet examples of innovation in this theme were relatively rare and not always highly rated by our experts. We found more examples of technology being used to create and disseminate; yet *Learning by Making* was most often only used in a supporting role. And we found few examples of technology being used to support the *performative* dimension of *Learning with Others* (i.e., creating audiences for learning outputs).

The situation with assessment is particularly interesting. Assessment is by far the single most unpopular learning activity. None of the cases involving assessment was ranked highly by our expert panel; particularly when assessment was used to support other learning activities. Yet much of the assessment seen in the innovations reviewed was not summative, with its (often negative) association of judgement and examination. Assessment can also be formative: that is, it can be used to monitor learner progress and provide feedback that guides and supports, rather than judges and examines. It is this broader sense of assessment that offers greater scope for innovation and perhaps deserves more recognition.

Research on 'blended learning' suggests that combining face–to–face and online learning may be beneficial. Flipped learning (see case study) requires teachers to build lessons upon material presented online beforehand. But this may underestimate teachers' roles in preparing learners to use the available information effectively. For example, Greene, et al.[143] have shown the benefits of teachers supporting learners with planning skills before accessing history content from a hypermedia learning environment. One study of 595 learners who used a course management system as part of a blended learning approach[144] found that the system encouraged deeper learning and enhanced understanding by promoting constructive dialogue between learners and enabling interactive learning. The findings from the study suggest that learners gain more when they are provided with opportunities for dialogue along with the learning material.

Flipped classrooms, or inverted classrooms, use technology to allow learners to view teacher exposition (*Learning from Experts)* before the start of a lesson. This allows more time for other forms of learning to flourish during lessons, such as *Learning through Practising* or *Learning with Others*. To 'flip' their classroom, teachers present learning materials online, perhaps created using screen–casting technology, which learners use to prepare in advance. This relatively under–researched idea has mainly been driven by teachers. Proponents argue that learners develop a more open attitude towards cooperative learning and new teaching methods, but become more critical of typical classroom learning. As such, a core concern is maintaining coherence online and face–to–face teaching.

(Strayer, J.F. (2012) How learning in an inverted classroom influences cooperation, innovation and task orientation. 'Learning Environments Research.' 15(2), 171-193.)

With this in mind, an important challenge for future innovation in educational technology is the design of tools at an institutional level: that is, tools that will enable institutions to deliver those aspirations highlighted earlier in an effective, joined-up way. The VLE is commonly used to join up learning; but it is primarily used for dissemination purposes only. One example of innovation in this area is the Knowledge Forum,[145] in which original project work is researched, co-ordinated and shared. However, such innovations are rare. Perhaps the most promising development in whole–school resourcing is the EU-funded KP lab initiative.[146] Based in Helsinki, this cross-Europe consortium seeks to create new theories, tools and models of collaborative technology for education. The lab brings together researchers, enterprises and end users to collectively design new technologies and services. Research into its efficacy is on-going.

The examples highlighted in this report show that technology can link learning activities within and between learning themes and thereby provide more coherent episodes of learning. However, there has been much less consideration of how technology can be used to join up learning in a coherent way within and between institutions. This is an area that warrants further research.

CHAPTER 4: CONTEXT IS IMPORTANT

INTRODUCTION

In the previous two Chapters we have highlighted many technological innovations that hold real promise to improve learning. But new technologies cannot, in themselves, improve learning. The context within which they are used is crucial to their success or otherwise.

It is important to guard against the assumption that new technologies will smoothly and effortlessly improve learning. Evidence clearly suggests that digital tools offer opportunities that are still to be realised; and that realising them is contingent on how we use them and the *context of learning*.

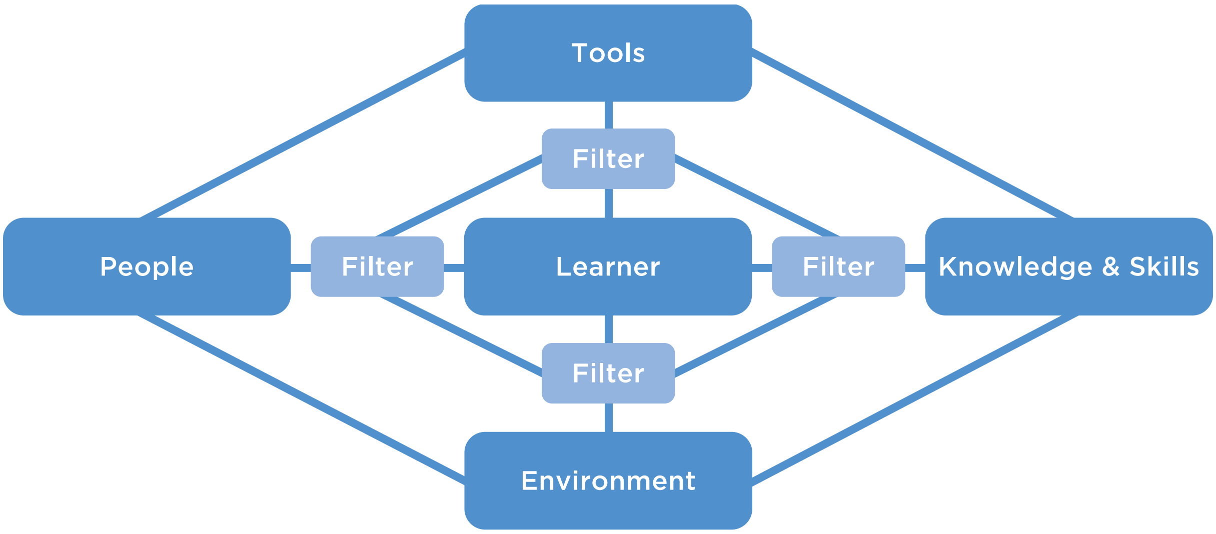


Fig. 4.1 The Learning Context, based on Luckin's Ecology of Resources.

With this in mind, this Chapter considers the learning context within which technological innovation takes place. We draw upon the Ecology of Resources framework introduced in Chapter 1 to organise our discussion - *Environment*, *Knowledge and Skills*, *People*, and *Tools*.[147] Understanding the nature, role and availability of these resources, beyond the technologies themselves, can help us predict their likely impact. It also helps us to offer guidance about how innovations can be most effectively rolled out. It must be noted that very few examples we reviewed considered this context in great detail. As a consequence, we can only provide very general guidance and must stress the need for future evaluations to take greater account of context.

ENVIRONMENT

Most of the examples reviewed for this report took place in formal learning environments: primary and secondary schools or universities. We did find examples of technology-supported learning in other environments, including field trips, museums, and the home. Understandably, these were most prevalent in the *Learning in and across Settings* theme. We found almost no examples of technological innovation in pre-school settings such as nurseries. Technology may be effective in supporting very young learners; but caution is required when applying the findings of our review to learners and settings outside those covered by the evidence.

It is clear that some learning activities are more easily conducted in the classroom because, for example, of the availability of specialist equipment or expertise. Nevertheless there is clearly room for further technological innovation that looks beyond the classroom. Indeed, one of the key benefits of many digital tools is that they can be used in many learning environments. But the particular learning benefits of digital tools are not automatically transferrable from one learning environment to another. For example, many of the resources we reviewed were available online and could be accessed from any location with an Internet connection. But, if they are to be used successfully in different learning environments, they have to be adaptable; and learners need to know how to adapt them.

As digital tools become cheaper, more powerful and ubiquitous in the home, learners of all ages have increasing access to learning resources outside of the classroom. It will be important to find ways to help them make the most of these – what works well in the classroom may not automatically work well in the home.[148] Although several research examples considered learning at home,[149] there were few teacher-led examples. As we discussed in Chapter 2, the key to success is the care and inclusiveness with which technologies have been designed and implemented.

Whether they are inside or outside the classroom, all learning environments contain a set of formal and informal rules that shape the behaviour of teachers and learners. These rules may have a profound impact on the use of technology to support learning; while the use of technology may have a profound impact on those rules. However, we found little information about the effect of these rules on the use of technology, and vice versa. Greater attention to the reporting of these factors would provide practical guidance for those trying to develop and apply innovations in different environments.

Sometimes existing infrastructure may limit the use of technology. Many examples required access to electricity[150] or the Internet. The introduction of faster broadband speeds gives learners greater access to multimedia resources in many areas, but this will be a gradual process. This has important implications for VLEs, where quality of experience is filtered by the speed of connection.

It is clear that environmental factors can limit the use of technology; but technology can be used to expand learning environments.

Several innovations promoted connections between classrooms within schools. One example involved using QR codes and mobile devices to create treasure hunts around a school.[151] Technology can also support learning in outdoor areas, by, for example, guiding a tour of a floodplain.[152] And it can connect learners: from across museums in Europe;[153] to cities and villages across India.[154] Finally, many innovations described virtual spaces that could be considered a distinct type of learning environment. They include various learning management systems,[155] as well as more informal gaming environments such as World of Warcraft.[156]

KNOWLEDGE AND SKILLS

The way knowledge and skills are categorised shapes learning. Education in the UK is currently organised around subject headings that have been used for over a century. Today's subjects are comparable to those listed in the 1901 Orders (England): English, Maths, Science, History, Geography, Modern Language, Drawing, PE, and Housewifery.[157] Many of the innovations we have reviewed focussed on using technology to support teaching of the traditional 'core' subjects of Maths, English, and Science. Some forms of learning activity may lend themselves to certain subjects, particularly subjects that can be easily codified and assessed. However, the rather limited set of subjects covered by much of the innovative practice we have reviewed, and the lack of emphasis upon skills, is a concern.

Research is beginning to question whether traditional conceptions of 'knowledge' are appropriate for contemporary society. Many commentators advocate shifting the focus away from developing subject–based knowledge to developing skills such as collaborating, problem solving, or critical thinking. Throughout this report, we have highlighted a number of examples of technology–driven innovation that support learners to acquire those skills. Many examples in the *Learning with Others* and *Learning through Exploring* themes show how technology can support collaborative learning; while examples in the *Learning through Inquiry* theme show how technology can support learners to think critically.

Shifting our approach to learning towards the acquisition of skills and competencies presents a challenge – it does not fit comfortably within current assessment systems. Learners cannot get an A* in collaboration or inquiry–based learning; nor can learners really take a final examination on creativity. All of those involved in education recognise the importance of these skills, both in purely educational terms and in life. But such a radical change in the approach to learning requires radical change in the approach to assessment. There are signs that this shift is beginning to take place – as seen in the case of the Malaysian education system highlighted in Chapter 3. Interestingly, these evolving approaches to teaching and assessment appear to be driving new and more integrated uses of technology. While far from a causal link, it could be suggested the willingness to adopt more contemporary approaches to learning can help to open the door for more innovative tools.

PEOPLE

Much of the evidence on innovation looks at the way in which technology supports the role(s) of teachers, for example by enabling them to manage resources and interact with learners or other teachers more effectively.

Teachers have a crucial role in ensuring that promising innovations do not fail in practice. Developers of technology must also consider the role of appropriate teacher skills and attitudes. Yet approaches to training vary and have had mixed success. Our experts did not highly rate innovations designed to improve teachers' training. Two examples that received low ratings were: providing teachers with access to videos about technology for learning; and providing new ways for teachers to record, share and reflect on their teaching with video cameras and a video tagging database tool. The latter was not rated highly because it was felt to impose significant time demands. Digital tools may reduce teachers' workloads or improve their teaching practice in the long term; but there will inevitably be an initial cost to the teachers as they learn to use those new tools. Take–up is likely to be poor if the perceived future benefits do not outweigh the initial costs.

Peer learners can also have a significant impact on individual learners. Digital networks create new possibilities for such peer learning. These networks bring together learners with different skills, knowledge, attitudes and interests. Technology can be used to enhance the effectiveness of peer learning: for example, by allowing peers to be grouped by ability; or by creating anonymous discussion forums to encourage more open debate.

The level and type of support that learners receive from other individuals will be determined by the knowledge, skills, and attitudes of those individuals. For example, parents' skills and attitudes will influence learners' use of technology at home. Those with limited technology skills and knowledge may feel unsure or unable to provide appropriate support. However, several examples we reviewed have demonstrated how technology can help parents support learners at home. One example showed how grandparents living away from their grandchildren can support their learning with a digital storybook and video conference application, such as Skype.[158]

Although rarely identified in the examples reviewed, other people within schools – such as senior managers, teaching assistants, technical staff and network managers – also influence teaching and learning. Again, it is important to take their skills and attitudes into account when developing technological innovations in learning.

We should also consider the role of people in the wider community, such as business people. The most highly ranked innovation by our expert panel was one in which companies presented learners with creative challenges (often using technology) through an online portal.[159] Another example involved businesses providing space and organisation for a programming workshop.[160] Businesses can provide resources and expertise not normally found, or that are extremely limited, in schools, while also offering a real life context for learning.

TOOLS

The resources considered above will undoubtedly influence the success, or otherwise, of technological innovation. But, ultimately, technological innovation is driven largely by the technology itself. Clearly non–digital tools will shape learners' experiences. However, for the purposes of this report, we retain our focus on digital tools. We have looked at specific tools in detail in Chapters 2 and 3; below, we discuss more general trends.

The tools used in most of the cases we reviewed were standard desktop and laptop devices; but mobile phones were also prevalent. As mobile devices, including tablets, become ever more powerful and incorporate ever more features, they are likely to become an increasingly important tool for learning.

Most of the innovations focussed on the use of hardware or applications – few looked at the role of networks or platforms. Nevertheless, networks and platforms are required to manage and link the hardware and applications; they therefore perhaps warrant greater consideration. Many technology companies highlight the crucial role of infrastructure in managing learning with technology; connecting users while keeping access secure. One significant development is the move toward cloud–based computing, which allows learners to access storage and applications from any device connected to the Internet. The benefits of cloud computing were illustrated in one case[161] where primary-aged pupils accessed a range of applications through a web browser and link learning activities, such as making an animation, between home and school. Another example showed how multiple learners could access and comment on a web–based presentation via instant messaging.[162]

Another interesting development is the move from traditional desktop computers to 'thin clients', where learners simply access material on a screen linked to a central server. This allows learners to access material from different locations while any technical problems can be addressed centrally. However, it is not yet clear how the central management of devices will affect teacher ownership and efficacy.

A wide range of software was used in the examples we reviewed; from highly bespoke applications to more generic writing or communication tools. We found a wide range of web–based tools being used to support learning; and, accompanying the growing trend in the use of mobile devices noted above, there is a growing market in apps for learning. The teacher–led cases tended to involve the use of readily available, off the shelf – and often free – software, while many of the research cases used bespoke software. Such software can be expensive to produce, but is invaluable in driving innovation. Yet the value of such investment will only be realised if such bespoke software can be used to develop better technology and practices that can be made widely available.

As we showed in Chapter 2, digital tools are driving innovation in learning in a variety of new, exciting and interesting ways. However, we also found three factors that, if not addressed, could potentially constrain their wider adoption.

Cost: Adopting new technologies can be expensive, especially when considering the total costs of ownership that include installation, training, upkeep, and (ultimately) replacement. One particular difficulty is considering the costs of using 'free' online programs and apps. Signing up for a 'free' program usually requires teachers to provide basic information, such as name and email address, that can be highly valuable to companies for marketing purposes. Once access is given to a 'free' program, there may be charges associated with extending provisions: extra features or storage space, for example. This requires teachers to make a judgment about the cost effectiveness of different programs, often without having had the time to fully evaluate them. There are added difficulties when learners are required to provide their information.

Complexity: Resources for learners are becoming increasingly complex. A teacher may be confident in making their own digital worksheet or interactive presentation and sharing these with other teachers and learners. The TES Connect website[163] is an excellent innovation that enables teachers to share digital resources. However, it seems unreasonable to expect material developed by teachers to compete with the more aesthetically pleasing commercially available materials from developers of digital tools. On the other hand, many developers lack understanding of teaching. As a result teachers have to filter and adapt digital tools in order to make them suitable for learning. This can be time–consuming and tedious. Building effective tools for the future will require effective collaboration between developers, teachers and learners.

Safety: A challenge faced by developers and teachers is providing learners with the freedom to browse information and communicate with one another safely. Given the responsibility for safety within schools, it is perhaps inevitable that access to digital tools is often tightly constrained. An obvious tension involves the use of mobile devices in the classroom where schools may feel that the potential for distraction outweighs the potential learning benefits. This tension is likely to increase as mobile devices become ever more powerful.

CHAPTER 5: BRINGING RESEARCH INTO REALITY

INTRODUCTION

Throughout this report we have presented a wide range of evidence on how technology can support learning. We have highlighted innovative practice from the traditional academic research literature and the growing body of informal online practitioner reports. But understanding how technology can be employed to improve learning is only part of the equation. If these innovations are to enter the mainstream, and if they are to fulfil their obvious potential, there are a number of systemic challenges to be addressed.

In this final Chapter we highlight the greatest opportunities for technology to support learning. We then set out three key priorities for achieving better use of technology for learning.

LEARNING FROM THE EVIDENCE

One of the greatest challenges of this report has been assembling our findings into a short, definitive set of recommendations. Having focussed on learning practices instead of the technologies themselves, we would be missing the point if we were to prescribe a ‘top ten’ list of technological innovations. A tablet, mobile device or an augmented reality environment won’t improve learning on their own – we need to make better, and more creative use of them. However, we have identified certain trends and opportunities grounded in effective practice. These are highlighted within each of the learning themes in Chapter 2. Below we set out what we believe are the most compelling opportunities to improve learning through technology.

IMPROVE ASSESSMENT

Assessment has a drab reputation. However, there is a significant opportunity to consider how technology can make assessment more efficient, effective, and supportive. This potential is not going unnoticed – but there is too little innovative technology-supported practice in the critical area of *Learning from Assessment*. Technology-supported assessment does not need to be restricted to the end of a learning episode; and it need not be dull or dispiriting. Emerging learning analytics technologies, that capture data about learning within and beyond formal learning settings offer enormous potential for assessment. Research innovations, as well as popular models like Khan Academy’s[164] adaptive assessment tool, highlight the scope of applications for technology in assessment and self–assessment. Its potential extends to instant statistics, knowledge maps, class data and badges. Further consideration should also be given to how technology can be used to enable the assessment of knowledge and skills not usually distinguished within current curricula – such as collaboration and leadership.

LEARN BY MAKING

Making is an effective way of learning. There is much excitement around mending, mashing, and making with digital tools, making it an area ripe with possibility. Given the relevance of such tools to current trends, it comes as no surprise that a high proportion of the innovations we reviewed concerned the cultivation of digital skills, such as coding and design. Robotic kits, authoring tools, and multimedia production tools are just some examples of the technologies that can support learning through making. To learn effectively through making, careful consideration needs to be given to how the process of making leads to the desired learning outcome. It is important that learners work within appropriately designed environments, using suitable personal devices and flexible web tools to achieve clearly articulated goals.

UPGRADE PRACTISING

Technology has been used to facilitate practice longer than most other learning themes. An immense number of resources are available, but not all types of practice are equally beneficial – and even fewer are making creative use of technology. Practice is most effective when time is spent on rich, challenging problems accompanied by appropriate feedback, rather than misdirected on easy, but ultimately unrewarding, activity. Learners benefit from practice using a variety of multi-modal representations and types of interaction. Adaptive technologies that take advantage of learning analytics can be used to offer problems of appropriate difficulty and provide suitable feedback. However, there is relatively little innovation in this area. The challenge here lies not in identifying technology–supported practice, but determining which ones are most effective, for whom, and in what context. To that extent, further innovation in this area would be welcome.

TURN THE WORLD INTO A LEARNING PLACE

While most learning occurs in school, new digital technologies invite us to break institutional bonds and get learning into the wild. Building effective learning that escapes the traditional constraints of location is not simple, but it is possible – and potentially very beneficial. Technology can link learners with other learners, experiences, and settings much more easily and, often, cost effectively. Connecting learners to other spaces – like labs, workshops, and even the high street – can also offer access to tools and experiences currently unavailable in most school settings. We need to stop thinking of learning taking place in isolation, in schools. Technology can enable schools to tap into the wealth of expertise that exists within their communities. Structural differences between environments must be recognised, as they influence which tools will be effective in which circumstances. Some learning activities will remain most effective when they take place inside a school classroom; but we are a long way from realising the undoubted potential that technology holds to turn the whole world into a learning place.

MAKE LEARNING MORE SOCIAL

Learners have access to an ever-expanding amount of information. However, the role of the teacher in supporting strategies for transforming that information into knowledge should not be underestimated. Technologies that support dialogue between teachers and learners will play an important role in ensuring that online resources are used efficiently and effectively. This can be as simple as using Twitter to engage in live discussion and feedback in the classroom,[165] or through more complex combinations of audio, chat and drawing applications that make personal tutorial significantly more accessible (and affordable) than ever before. Technology can facilitate conversations that can enhance learning – whether they are between teachers and learners, or among learners themselves. Investment is required in technology that enables teachers to organise participative and performative activity; and to create audiences for the outcomes of those activities. A similar need was highlighted in *Learning through Inquiry* – technology can be used to organise forms of inquiry that would be difficult to undertake otherwise due to the number of resources that need to be manipulated.

KEY PRIORITIES FOR TECHNOLOGY IN LEARNING

LINK INDUSTRY, RESEARCH AND PRACTICE

Throughout this report, we have been continually reminded of the significant disconnect between educational technology's key partners – industry, research, teachers and learners. Too often, researchers operate in isolation from the developers whose products grace our schools and homes. This situation makes little sense.

Industry, researchers and teachers need to work closely together to test ideas and evaluate potential innovations *before* they are taken to market. Such a process would benefit industry by providing clear evidence of effectiveness that would potentially boost sales; it would benefit teachers who would have access to better products on the market; and, ultimately, it would benefit learners. To realise this, new channels of communication are needed through which:

- **Researchers can get a feed forward from the educational technology industry about what they are developing, the current market needs and the problems to be addressed;**
- **Industry can get hold of accessible research that addresses the challenges they currently face; and**
- **Schools and teachers can gain clear and evidence–based guidance on effective uses of technology for learning, and access to the training and resources need to realise it.**

Connections need to be made and sustained. Industry organisations, professional bodies, funders and public bodies, including the Departments for Education and Business, Innovation and Skills, can bring together different stakeholders to drive technological innovation in education. Networks can be fostered through events such as TeachMeets[166] and the TechHeads[167] meetups. However, more formal cross–stakeholder networks or dedicated spaces for technological innovation for learning must also be created and supported.

Additionally, we need to develop a consistent and accessible evidence base that can be applied to practice. Much of the research we have reviewed is based on the isolate and analyse tradition. It is rare to find detailed information about contextual factors in research on particular innovations, yet many of the barriers to success relate to the learning context that we considered in Chapter 4. These 'filters' need to be explicitly recognised, reported and addressed by all stakeholders if technology-driven innovation is to produce real benefits.

MAKE BETTER USE OF WHAT WE'VE GOT

Technology-driven innovation is clearly dependent upon access to technology. But the mass distribution of digital tools is not necessarily a precondition to innovation. In fact, at times, an emphasis on hardware may draw the focus away from other potential opportunities.

Initiatives to equip every child with a mobile, laptop or tablet serve a purpose and they are likely to continue where funding and political will are aligned. Yet we must also consider how the existing resources at our disposal can be used more creatively, and effectively. We need to change the mindset amongst teachers and learners: from a 'plug and play' approach where digital tools are used, often in isolation, for a single learning activity; to one of 'think and link' where those tools are used in conjunction with other resources where appropriate, for a variety of learning activities. Teachers have always been highly creative, creating a wide range of resources for learners. As new technologies become increasingly prevalent, they will increasingly need to be able to digitally 'stick and glue'.

To achieve this, teachers will need to develop and share ways of using new technologies – either through informal collaboration or formal professional development. But they cannot be expected to do this alone. They need time and support from school leaders to explore the full potential of the technologies they have at their fingertips as tools for learning. School leaders can further assist teacher development by tapping into the expertise available in the wider community.

CONNECT LEARNING TECHNOLOGIES AND ACTIVITIES

Digital technologies offer opportunities for innovation in teaching but to achieve impact it is important to concentrate on the way technologies can be used by pupils – the learning activities. Linking learning activities and using a variety of technologies and approaches to achieve this gives a far richer experience. Focussing on individual learning activities with single use technologies will not achieve maximum impact.

It is clear technologies that support learning activities can be powerful. But digital tools with apparently single functions are too often used in isolation without linking to support complex, rich learning activities. With a little creativity, learners could use these tools to complete a more fulfilling learning episode rather than a set of discrete learning activities. However, this requires further development of digital tools that can facilitate learning episodes. These would be particularly valuable in stimulating collaborative learning, promoting learner self–awareness, and enabling teachers to adapt their feedback.

We need more inclusive tools and, more importantly, inclusive ways of using them. Multi–function tools, especially in the themes of collaboration and inquiry, can enhance learning and unlock new types of learning in schools – and out. Likewise, tools that can facilitate and connect different learning activities are greatly needed. There is a considerable incentive for industry to design such tools, but design of such new technologies needs to shift focus towards the variety of possible uses based on research and practice.

CONCLUSION

We looked for proof, potential and promise in digital education.

We found **proof** by putting learning first. We have shown how different technologies can improve learning by augmenting and connecting proven learning activities. This approach gives us a new framework for evaluating future innovations in education.

The numerous examples of good practice identified in this report show that there is also a great deal that can be done with existing technology. It is clear that there is no single technology that is 'best' for learning. We have identified technology being used effectively to support a variety of learning activities and learners across a wide range of subjects and learning environments. Rather, different technologies can be used to support different forms of learning, either individually or in conjunction with others.

There is a growing body of invaluable evidence that demonstrates how technology can be used effectively to support learning. However, if that evidence is going to be useful in practice it needs to address the contexts within which the technology is used; and it needs to be presented in ways that are accessible to industry, teachers and learners.

We found clear **potential** to make better use of technologies that are widely available and that many schools have already purchased. But this potential will only be realised through innovative teaching practice. Teachers may require additional training that enables them to use technologies in new ways.

There is enormous potential for further innovation in digital education. Success will come from commercial developers, researchers, teachers and learners working together to develop, test and spread imaginative new technologies.

We also found many areas of **promise**; that is, areas where technology is currently undervalued and underused. We found relatively little technological innovation in some of the more effective learning themes we considered in Chapter 2. For example, the market is saturated with drill and practice games (particularly for maths) to support *Learning through Practising* despite being regarded as one of the less powerful learning themes. Meanwhile, there has been relatively little technological innovation aimed at supporting *Learning through Assessment* – which can be a powerful aid to teaching and learning.

Over recent decades, many efforts to realise the potential of digital technology in education have made two key errors. Collectively, they have put the **technology above teaching** and **excitement above evidence**. This means they have spent more time, effort and money looking to find the digital silver bullet that will transform learning than they have into evolving teaching practice to make the most of technology. If we are to make progress we need to clarify the nature of the goal we want to satisfy through future innovation. Much existing teaching practice may well not benefit greatly from new technologies. As we continue to develop our understanding of technology's proof, potential and promise, we have an unprecedented opportunity to improve learning experiences in the classroom and beyond.

APPENDICES

APPENDIX 1: TABLE OF INFORMATION SOURCES

	Source	Description, issues	Locations
A	Opinion, anecdotes, fears, word of mouth	Wikis, blogs, commentaries	Websites, email lists, professional networks and groups (e.g. LinkedIn), newspapers/media
B	Professional journals	What innovative practices are professionals being informed about / invited to take up?	Websites of associates (NCSL, NIACE, ALT, NCETM...)
C	Expert think-pieces, attempts at foresight	Expert views, Think tank reviews (e.g. Futurelab, Demos, (JISC, OECD)	Sponsored publications, assume availability through sponsor's website
D	Casestudies and self-reports	Proof of existence. Illuminative. Can multiple case studies be considered as some form of triangulation? Sponsorship bias, one-sidedness of evidence	Publications, websites
E	Interviews	Structured, semi-structured, unstructured? With individuals or focus groups?	Project reports
F	Surveys, questionnaires	Robustness and publication venue. Sampling, return rates, baseline, question balance	Journals, conference proceedings, theses, etc.
G	Design interventions, comparative studies, RCTs, research prototypes	Structure of underpinning aims and objectives. Methods: testing, scales, observational methods and associated analysis	Journals, conference proceedings, theses, research programmes (e.g. TEL)
H	Meta-reviews, systematic reviews	Authority of publication? Basis of review protocols?	Peer-reviewed literature
I	Policy statements & documents (central/ local government, official bodies)	Policy statements in favour of change, reports and white papers, policy review committees, consultations	Policy websites
J	Commercial marketing materials	Information on products and perceived markets. Future launches?	Company websites, product literature, trade magazines, websites, etc.
K	Grant applications	Sample limited to successful funding applications by necessity	Websites of funding bodies

APPENDIX 2: THE ADAPTIVE COMPARATIVE JUDGEMENT (ACJ) METHOD

METHOD

Our method for comparative judgement of innovations of educational innovation involved several stages.

Firstly, we produced short paragraphs of text that summarised our understanding of a particular case of innovation. The paragraphs of text provided a brief outline of how the case of innovation worked, some idea of the underlying justification provided by the information source that described the innovation (such as an academic journal paper, or a teacher's blog post), and an idea of the resources that needed to be in place if the innovative practice was to be feasible. The following is one example of such a paragraph of text:

> *This project uses a mobile phone app to help learners navigate around a particular geographical location during History field trips. The underlying idea is that peers are guided to work in teams to explore the location and to relate what they are looking at to content knowledge provided by the mobile device. Constraints include timetabling and fit with the curriculum, and the requirement to create content so that the software can guide learners around an accessible local place.*

In total, we produced 150 such paragraphs of text (86 drawn from informal information sources and 64 from the academic literature). Since our own coding of these innovations, in terms of the forms of learning that were evident and how exciting and promising we thought the work was, occurred concurrently with this process we were unable to produce summaries based on particular 'quotas' of types of learning or quality of innovation. Instead, these paragraphs were sampled from across the full range of cases of innovation derived from the research and practitioner literature; later we cross-referenced these cases back to our spread sheets of research and teacher-led innovation cases so that we could produce statistics about how the cases related to the learning themes and to particular learning acts. Some proofreading by team members was utilised to check that the paragraphs were comprehensible and not phrased in ways likely to 'lead' judges. A small sample of ten paragraphs was printed out onto pieces of paper at an early stage of the exercise and used in a small-scale pilot where the judges were postgraduate students from one of our research labs.

Secondly, we worked with a commercial partner to import these paragraphs of text into an existing, online ACJ system, *e–scape*.[168] This tool had been developed to support awarding bodies' work investigating how the ACJ technique could be used to support educational assessment, and so our summaries were entered into the system as different exam 'scripts'. The system would adaptively present pairs of these scripts to judges, as illustrated by the screenshot in Fig. A2.1

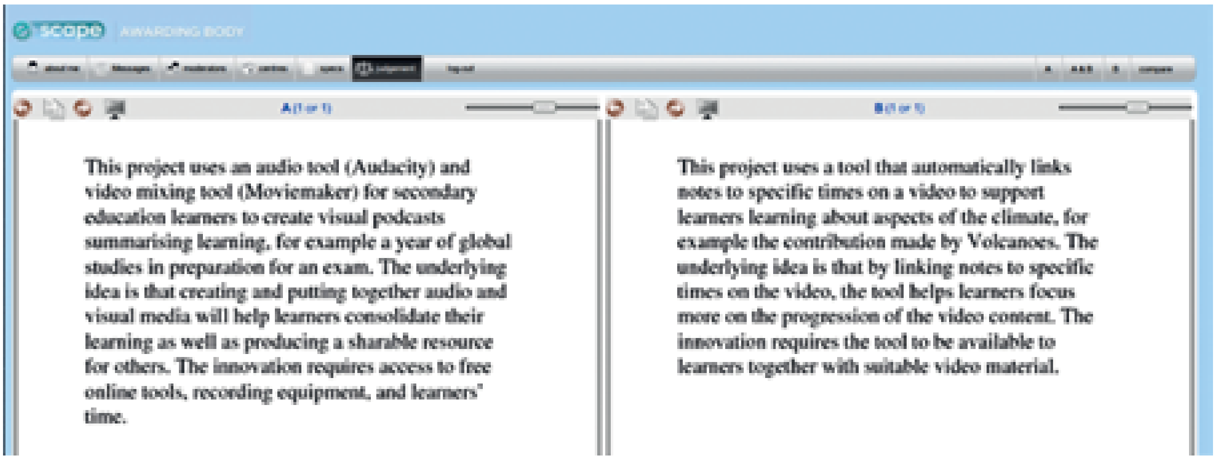


Fig. A2.1: Screenshot of the e-scape ACJ system. A judge selects which example of innovation they prefer: A or B.

Thirdly, we recruited an expert panel of judges from a range of specialisms: researchers specialising in technology–enhanced learning, innovative teachers, commercial sector partners and policymakers. Those people who agreed to participate were shown a short help video that explained how to log onto the system and make judgements, and were allocated a unique username and password within the system. Each particular judge was allowed to first make judgements on a 'practice' session so as to familiarise themselves with the interface and the process of making judgements, but was aware that 'practice' judgements would not contribute to our analysis. When they felt ready, judges could log into the 'live' session and make judgements that would contribute to our analysis. Judges were allowed to contribute a maximum of 36 judgements each by the system, and were requested to make at least 20 judgements.

For our final analysis, we note that 48 expert judges made a total of 1,568 judgements (comparisons). Judges made a mean average of 32.6 judgements each (standard deviation 8.83).

Finally, we exported the raw judgement data from e-scape and subjected it to analysis using the *Facets* software[169] that supports many-facet Rasch analysis. Based on all the judgements that had been made in the live session, this software was used to produce the final rank order for the items as well as their corresponding 'parameter' (numeric scores) and 'SE' (the standardised amount of error in how an item had been judged).

RESULTS

The final distribution of items can be represented as in Fig. A2.2. It can be seen that around 14 cases of innovation were judged to be significantly better than all other candidates, that approximately ten were particularly unpopular, and that the innovations ranked between positions 15 and 140 display a gradual decline in parameter score, with some particularly noticeable drops in score around positions 55 and 96.

When considering how these top-ranked cases of innovation relate to the categories of learning that we highlight in this report, it is clear that a broad spectrum of forms of learning were rated highly by our expert judges. *Learning through Making* is the most frequently occurring category, with three appearances in the top 14. Conversely, *Learning through Exploration* appears only once in the table, while *Learning through Practising* does not appear at all. All of our other categories appear twice each.

A clearer picture of the relative popularity of the innovation cases can be obtained by looking at Figs. A2.3 and A2.4. Fig. A2.3 shows that the most popular category *on average* (mean average) was *Learning in and across Settings*, though the standard error bars show that the cases of innovation in this category were less closely clustered than those in many of the other categories. Cases of *Learning through Inquiry* were also popular, while a 'middle tier' consisted of cases from: *Learning from Experts*, *Learning through Exploring*, *Learning through Making* and *Learning through Practising*. Cases of *Learning through Understanding Learners* were the least popular within the exercise. Fig. A2.4 shows that, of current cases of innovation in learning that were entered into the ACJ, cases of *Learning with Others* were by far the most numerous.

We can usefully glean some idea of the forms of learning within each theme that judges preferred by expanding the learning themes into their constituent learning activities. Fig. A2.5 provides a summary of this information. The most immediately striking statistic displayed in this table is the comparative unpopularity of assessment, one form taken by *Learning from Assessment*. Cases of innovation that involved assessment were by far the most unpopular in the exercise, and were largely clustered toward the bottom of the ranking. It should be noted that the unpopularity of assessment has had an overall effect on the popularity, in Fig. A2.3, of *Learning from Assessment*; cases of innovation within this category that called upon self-understanding through *reflection* as the primary form of learning were not nearly so unpopular within the exercise.

Among the more popular learning themes, it can be observed that all forms of *Learning through Inquiry* are reasonably popular. The component forms of learning within the *Learning through Making* category, however, exhibit very different levels of popularity: forms of making that involve *construction* (actually creating artefacts) tend to be very popular indeed, while those involving *representing* or *annotating* information are relatively unpopular.

Rank	Script	Parameter score	Standard error	Text	Primary learning theme
1	48	6.803	1.489	This project uses an online portal (I am Creative) to engage secondary and higher education learners with creative challenges set by industry, for example, a challenge to design an advert. The underlying idea is that that the service can engage learners in real-life examples of creative projects. The innovation requires access to the portal, and judges for the work, paid for by the participating industry.	Learning through Inquiry (Problem-focussed)
2	27	5.2823	1.18	This project involves a tool to capture 'lifelogs' of people's capture 'lifelogs' of people's experiences, including pictures, text, and geographical locations taken from their mobile phone, and another tool to prompt later reflection by displaying the information at pre-set intervals. The underlying idea is that different kinds of information display can be used to prompt different kinds of reflection, such as reflection on learning experiences. This innovation requires time to look at and reflect upon information presented.	Learning in and across Settings (Cross-contextual)
3	60	4.8558	0.7819	This project uses a website (Solar StormWatch) for learners to engage with and actively con tribute to real-life science projects, for example, identifying solar storms. The under-lying idea is that contributing to the project will empower learners to engage learners with topical science issues. The innovation requires access (and possibly signing up) to this free website tool.	Learning from Experts (Exposition)
4	71	4.5525	0.7161	This project uses a geo-location game (using Aris) to let secondary-aged learners design and create a game, such as a quest game around the school. The underlying idea is to motivate learners to design a game narrative for for other learners. The innovation requires the game platform, teacher support for understanding how to generate a game, mobile devices and printed QR codes.	Learning through Making (Construction)
5	109	4.4823	0.6953	This project uses an educational robotics kit (HummingBird) to engage secondary-age learners (girls in this case) into programming, for example, by creating artistic, physical designs. The underlying idea is that the tool inspires learners by facilitating more artistic, tangible applications of programming. The innovation requires the educational robotics kit, a nascent understanding of programming and teacher support.	Learning through Making (Construction)
6	74	4.4475	0.6662	This project uses an audio tool (Audacity) and video mixing tool (Moviemaker) for secondary education learners to create visual podcasts summarising learning, for example, a year of global studies in preparation for an exam. The underlying idea is that creating and putting together audio and video media will help learners con-solidate their learning as well as producing a shareable resource for others. The innovation requires access to free online tools, recording equipment and learners' time.	Learning from Assessment (Reflection)
7	113	4.2958	0.6773	This project uses digital cameras and a simple presentation tool (Kidpix) to support learners with learning about changes to the environment, for example, how the woods change over seasons. The underlying idea is that this innovation encourages learners to focus upon the environment and use technology to record, compare and comment on changes. The innovation requires a camera and software, travel to a local wood, and teacher guidance to encourage reflection.	Learning from Assessment (Reflection)
8	132	4.1412	0.6636	This project uses a very large display technology (Multi-Slides), where information in a PowerPoint file is projected over multiple walls within a classroom, to support richer	Learning from Experts (Tutorial)

Rank	Script	Parameter score	Standard error	Text	Primary learning theme
				forms of discussion in university small-group teaching. The underlying idea is that the teacher presents a particular argument about some materials (e.g. images of of historical artefacts) but provides sufficient information around the walls for students to construct alternative explanations, so encouraging debate. The innovation requires the presentation tool to have been installed within a seminar room and a confident teacher who can respond positively when their argument is challenged.	
9	59	4.1167	0.719	This project uses an online writing tool (Boomwriter) for primary- aged learners to build a collaborative story, for example, by assessing which chapter written by peers to include. The underlying idea is that this tool provides a way to engage learners in writing and to manage blind peer evaluation. The innovation requires access to the tool and teacher time to set up the story and decide the number of chapters, as well as peer time to read and vote.	Learning with Others (Participative)
10	118	4.0388	0.9976	This project uses digitally augmented plastic blocks (Electronic Blocks) to let pre-school children explore basic electronic ideas, for example, attaching sensor blocks to an action block (e.g. a light). The idea is that this tool facilitates interaction and engagement, making important ideas accessible for younger learners. The innovation requires learners to have access to the prototype technology.	Learning through Exploring (Ludic)
11	26	3.8589	0.9716	This project uses special software on laptops to support learners with autism and teachers working together to create visual representations of the activities they are going to undertake in the classroom. The underlying idea is to provide special support to learners, who may have problems understanding, structuring and predicting activities, while also involving them in the creation of visual representations to support their understanding. This innovation requires time of the teacher and learners as well as support for learning this particular tool.	Learning from Experts (Tutorial)
12	105	3.8557	0.6326	This project uses a week-long workshop with businesses and volunteers to develop learners' (under 18) programming skills through making, for example, digital products such as a mobile application. The underlying idea is that the workshop engages learners by providing access to tools and local expertise to build personal projects. The innovation requires free programming tools, rudimentary programming ability physical space from local businesses, volunteer time and expertise.	Learning through Making (Construction)
13	15	3.6354	0.6806	This project uses a mobile phone app to help learners navigate around a particular geographical location during History field trips. The underlying idea is that peers are guided to work in teams to explore the location and to relate what they are looking at to content knowledge provided by the mobile device. Constraints include timetabling and fit with the curriculum, and the requirement to create content so that the software can guide learners around an accessible local place.	Learning in and across Settings (Cross-contextual)
14	152	3.6297	0.9263	This project uses a computer based problem solving environment based around drawing activities to motivate high school-aged learners who are beginning to learn programming, for example, learning the 'C' prog ramming language. The underlying idea is that the tool adopts a holistic approach, providing representations, meaningful activties in a drawing context, and feedback. The innovation requires the tool to be made available to learners.	Learning through Inquiry (Problem-focussed)

Table A2.1: The highest ranking 14 cases of innovation

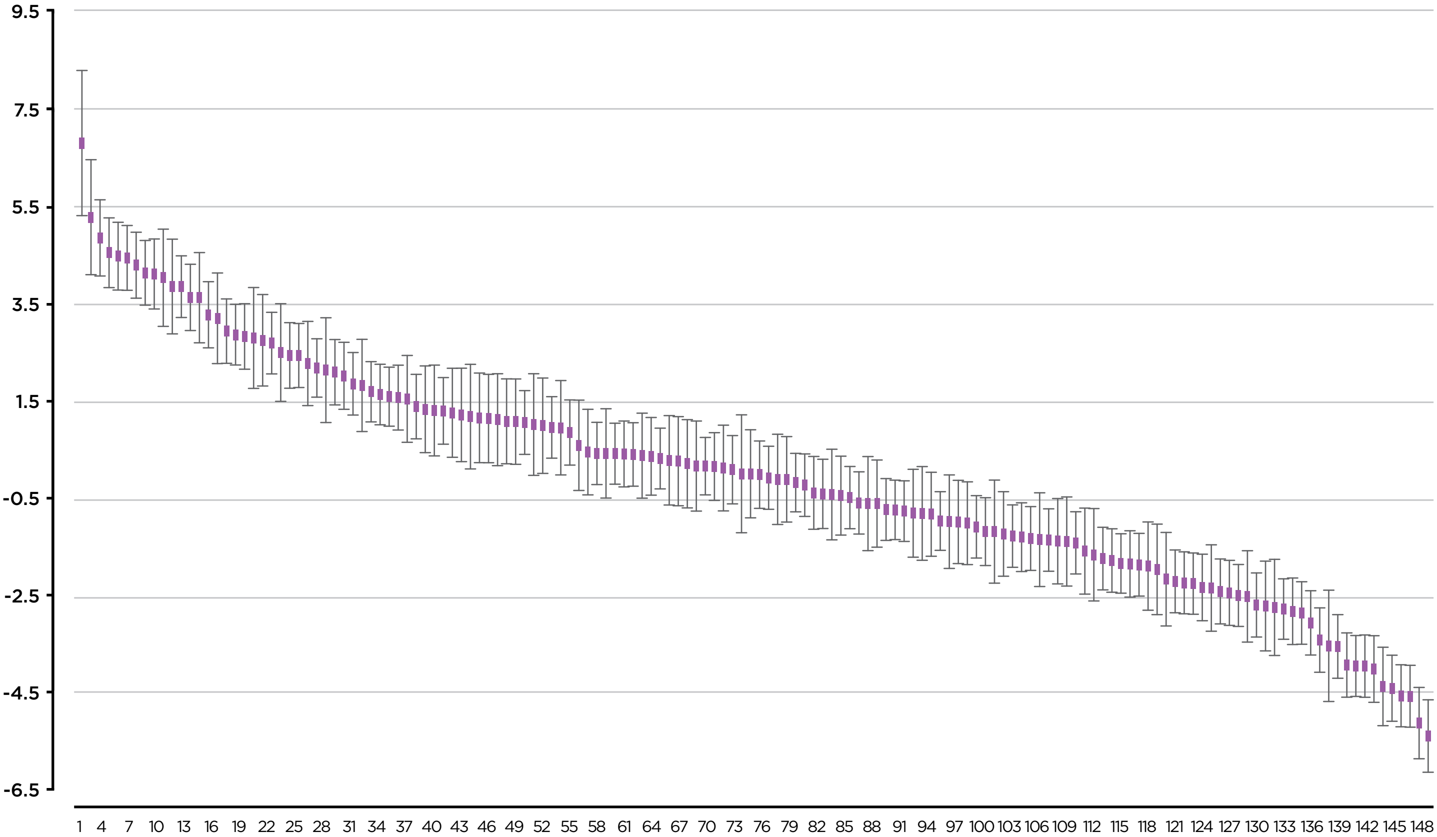


Fig A2.2: Parameter score vs. item rank. Bars show standard error.

MEAN RANK IN ACJ BY THEME

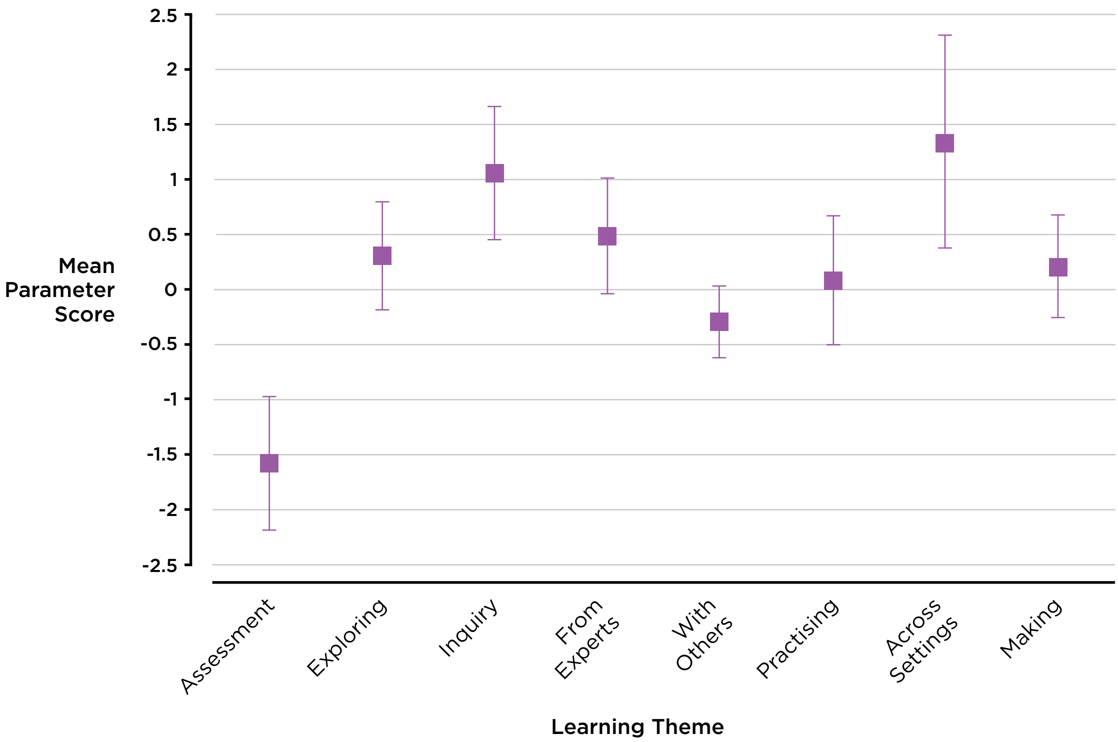


Fig. A2.3: Mean parameter score vs. learning theme. Bars show standard error.

NUMBER OF INNOVATIONS IN ACJ BY THEME

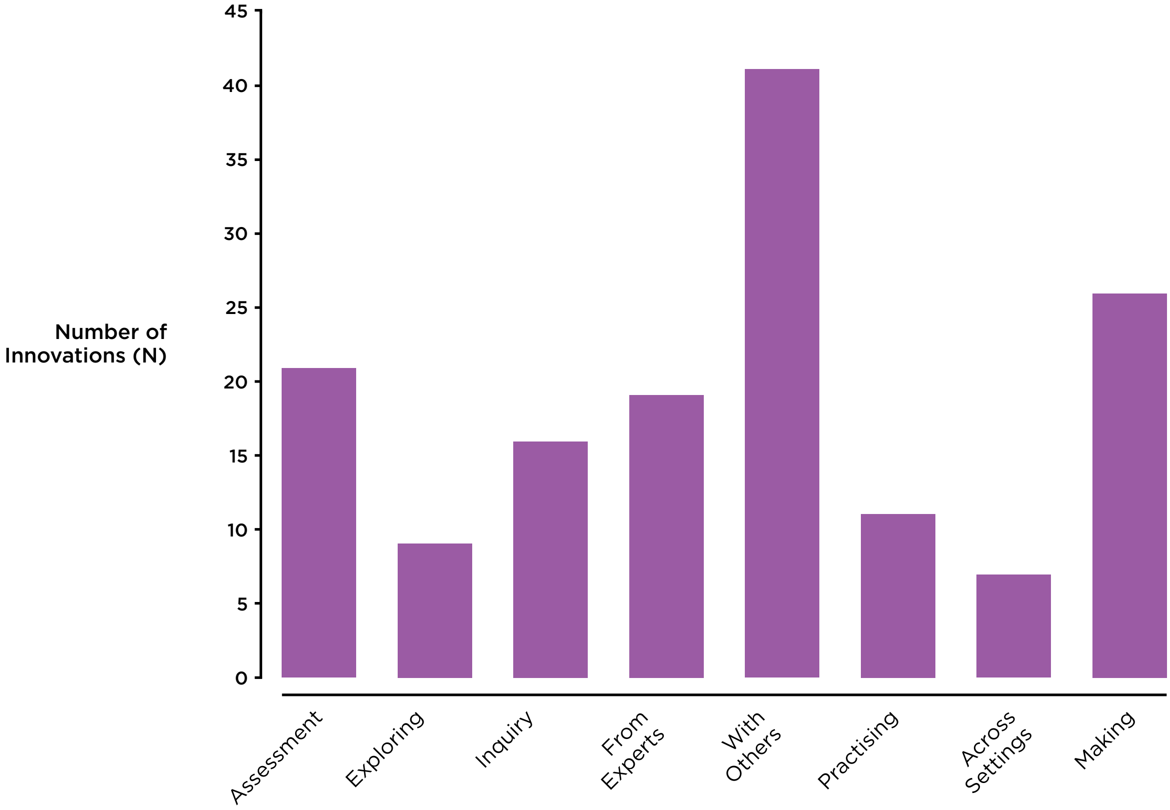


Fig. A2.4: Number of cases by learning theme.

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6. See http://www.k12.com/
7. Hennessy (2011); Lopez (2010).
8. Greene, Bolick and Robertson (2010).
9. Fischer, and Schwan (2010); Schmidt-Weigand, Kohnert, and Glowalla (2010); Watson et al. (2010).
10. Heilesen (2010).
11. Saerbeck et al. (2010).
12. Alaviand and Dillenbourg (2011).
13. See http:// http://www.mathsdoctor.tv/ and https://www.remind101.com/
14. See http://yoursmarticles.blogspot.co.uk/2011/04/video-sequencing.html; http://www.l4l.co.uk/?p=2656; and http://www.youtube.com/user/Vihart
15. See http://digitaltoolsforteachers.blogspot.co.uk/; and http://www.educationeye.org.uk/
16. See http://tbarrett.edublogs.org/2009/10/14/nintendo-wii-golf-subtraction/
17. See http://digitaleducationbrighton.org.uk/?cat=3
18. Watson et al. (2010); Fischer and Schwan (2010).
19. Wieling and Hofman (2010).
20. Heilesen (2010).
21. Ainsworth (2008).
22. Bligh and Sharples (2010); Lanir, Booth and Hawkey (2010).
23. Hennessy (2011); Lopez (2010).
24. Ruchter, Klar and Geiger (2010).
25. Greene, Bolick and Robertson (2010).
26. Just as hyperlinks link digital information through text, hypermedia is the linking of digital information using multimedia, such as video, audio, or graphics. This is a common feature of many websites and social networking platforms, such as Twitter.
27. Kember et al. (2010).
28. Dixon et al. (2010).
29. Hartmann et al. (2010).
30. Saerbeck et al. (2010).
31. See http://yoursmarticles.blogspot.co.uk/2011/04/video-sequencing.html
32. See http://tbarrett.edublogs.org/2009/10/14/nintendo-wii-golf-subtraction/
33. An event where educational businesses share ideas with teachers. For further information please see: http://digitaleducationbrighton.org.uk/?p=229
34. Near Field Communication (NFC) uses radio communication or small chips to enable two or more pieces of technology to connect when nearby. This technology has become increasingly popular for such things as public transit passes and touch transactions using mobile phones. New uses of NFC continue to be developed and adapted for a variety of other purposes.
35. See http://digitaleducationbrighton.org.uk/?cat=3
36. See http://www.mathsdoctor.tv/
37. See http://www.educationeye.org.uk/
38. See http://www.solarstormwatch.com
39. See http://www.boomwriter.com/home/about
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44. Alvarez et al. (2010); Haller et al. (2010).
45. Brooks (2011); Haller et al. (2010).
46. Looi (2010); Hennessy (2011).
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49. Looi (2010).
50. Hatch et al. (2011).
51. Loll and Pinkwart (2011).
52. Arroyo et al. (2011); Wood et al. (2011).
53. See http://www.papert.org/
54. See http://scratch.mit.edu/
55. See http://ccl.northwestern.edu/netlogo/
56. See http://impromptu.moso.com.au/
57. See http://makerfaireuk.com/
58. See http://makezine.com/

59. Mu (2010).
60. de Smet et al. (2011).
61. Wishart and Triggs (2010).
62. See http://www.bbc.co.uk/news/technology-17740143
63. See http://www.boxoftricks.net/2011/12/teaching-and-learning-with-social-media-a-case-study/
64. QR (Quick Response) codes are easy to create barcodes which can be read by image sensors, such as cameras on digital devices. Originally created for the automobile industry, they are now used widely to link people with digital information for everything from advertising to airline tickets.
65. See http://missaliceleung.wordpress.com/category/geolocation/
66. See http://www.hummingbirdkit.com/
67. See http://www.fastcoexist.com/1680168/hummingbird-an-educational-robotics-kit-designed-to-get-girls-into-engineering#1
68. See http://youngrewiredstate.org/
69. See https://www.poly.edu/node/7544
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71. Goulding and Kyriacou (2010).
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73. Steffens (2012).
74. Wyeth (2008).
75. Faridani et al. (2010).
76. See http://opinion.berkeley.edu/
77. Moraveji et al. (2011).
78. Liang and Sedig (2010).
79. Jacucci et al. (2010).
80. See http://www.ted.com/talks/lang/en/sugata_mitra_shows_how_kids_teach_themselves.html
81. Anastopoulou et al. (2012).
82. National Science Foundation (2000) our emphasis.
83. de Jong (2012).
84. Facer et al. (2004).
85. Anastopoulou et al. (2012).
86. See http://digitaleducationbrighton.org.uk/?cat=3
87. See http://www.mathalicious.com/about/
88. See http://ilearntechnology.com/
89. See http://ilearntechnology.com/
90. Kordaki (2010).
91. Shaffer (2006).
92. Trundle and Bell (2010); see also http://www.starrynight.com/
93. de Jong et al. (2010).
94. Méndez and González (2010).
95. Fuzzy logic controllers are devices used to control mechanical devices and software. Using a unique mathematic system, they are able to better capture and react to the fuzzy implications of human situations and thought than traditional logic systems in mechanical and digital devices.
96. Dorn and Guzdial (2010).
97. Yoon et al. (2011).
98. Thorndike (1922).
99. Fischer and Schwan (2010).
100. Tian et al. (2010).
101. Bots, or Internet robots, are a form of software program that provides automated responses to repetitive tasks and queries on the Internet. Bots have become particularly popular for commercial uses, such as online assistants and advertising.
102. See http://nikpeachey.blogspot.co.uk/
103. See http://motionmathgames.com/about/
104. See http://www.buzzmath.com/
105. Habgood and Ainsworth (2011); see Case Study.
106. Beevers (2010); Elliot (2007); Pachler et al. (2009).
107. Winkley (2010); Ripley (2007); Bull and Kay (2007); Zapata-Rivera et al. (2007).
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116. See http://edtap.psu.edu/video/outdoors/
117. See http://www.classdojo.com/about#how
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119. Naudé et al. (2010).
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121. Jewitt et al. (2010).
122. Luckin et al. (2008); Elliott (2007).

123. Kong (2010).
124. Yeh et al. (2010).
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126. See http://ecomobile.gse.harvard.edu/
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132. Liaw et al. (2010).
133. Lewin and Luckin (2010).
134. Grant (2009).
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144. Kember et al. (2010).
145. http://www.knowledgeforum.com/
146. See http://www.kp-lab.org/
147. Luckin (2010).
148. Grant (2011).
149. For example, Lewin and Luckin (2010).
150. For example, Brusilovsky, Hsiao and Folajimi (2011).
151. See http://missaliceleung.wordpress.com/category/xbox/
152. Ruchter, Klar and Geiger (2010).
153. For example, Arroyo et al. (2011); Yoon et al. (2011).
154. See http://www.ted.com/talks/lang/en/sugata_mitra_shows_how_kids_teach_themselves.html
155. For example, Greene, Bolick and Robertson (2010).
156. See http://www.livescience.com/5109-world-warcraft-video-game-succeeds-school.html
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