Further Education Learning Technology

A horizon scan for the UK Government Foresight Horizon Scanning Centre

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August 2013

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Executive summary

Introduction

In recent years there has been a renewed public policy emphasis on vocational education and training (VET) mostly as a consequence of disequilibrium in the labour markets of advanced economies. The Department of Business Innovation and Skills has set up a Further Education Learning Technology Action Group (FELTAG) to explore how the Further Education (FE) sector might respond to emerging technologies. FELTAG has commissioned a systematic horizon scan of technologies over the next 10 years likely to be of value to the VET sector.

VET differs principally from compulsory and post-compulsory higher education because it is specifically practiced-based and is at its most effective a “direct line to work”. The market for post-compulsory adult learning is already significant and was estimated in 2007/08 at around £55bn or 3.9% of GDP. Evidence suggests that around 40% of all adults in the UK participate in either informal or formal learning but there are sometimes stark differences based on gender, age, ethnicity and disability.

Successful strategy is a choice that multiplies the effectiveness of effort. The UK Prime Minister has adopted a policy narrative that the nation must develop strategies to compete in “the global race for jobs and for wealth”. In recent years globalisation and technological change have been the major drivers in labour markets. Strategic choices should be underpinned by an appreciation of the level of system uncertainty in which they will play out. For the VET sector, learning technologies may have to be robust to changes in practice.

Prioritising technologies

Prioritising emerging technologies is challenging because policy instruments may falter against powerful social and organisational norms. For technologies with longer lead times, there is the additional complication of ensuring their robustness to future endogenous and exogenous change, and to events that with our existing knowledge we are unable to anticipate.

The specification for this horizon scan sought technologies likely to be of value to improve: (i) personal support for learning, (ii) access to learning, (iii) flexibility of provision, (iv) efficiency and effectiveness of learning, (v) ways of assessing learning, and (vi) data security and identity. In further communications with the experts leading on the workstream, preferences were expressed for technologies that could enable innovation, were learning-centred, could empower teachers, and that were propitious to the concept of a learning system. Understanding the VET sector as a learning system is useful because globalisation and technological change are driving turbulent change that requires increased variation or experimentation in the system. If the system has effective feedback mechanisms the teaching and learning strategies that prove innovative will, increasingly, be selected. The potential of the system to adapt to change rests on this balance between variation and selection.

For technology to be a true ‘game-changer’ in the VET sector it may have to enable new economies of scale. Scale economies, or cost efficiencies, are increased by the density of economic activity and decreased by the distance between economic agents; they also vary according to types of industry. Geography is an important consideration for the VET sector because of its historical relationship with practice and with place. There are possibly two questions to be explored for the VET sector. Firstly what types of scale economies might technology enable within the sector? Secondly, to what extent do the scale economies of the very industries that the sector services increase or decrease the potential of further education learning technologies?

Teaching and Learning Technologies

Massively Open Online Courses (MOOCs) are already available for post-compulsory HE and for compulsory education but they have an immature market and business models are still developing. The expectation is that learners will eventually pay at a minimum for formal accreditation. In many ways MOOCs are a better fit for the FE sector because of their flexibility to adult learners who can learn at their own convenience and pace. VET MOOCs can also very meaningfully 'flip the classroom' so that more time can be spent hands-on learning industry practice. For the less-well funded FE sector, however, MOOCs are a challenge because there is much less opportunity to cross-subsidise the production of content. Processes of variation and selection based on teacher and learner feedback may, therefore, be dependent on the marketing know-how of providers of locked content. This notwithstanding, MOOCs are an undoubted opportunity to improve accessibility to VET. Valuable data is generated by the learner that can be used with learning analytics to enhance learner management systems.

Commercial *social media* platforms such as Facebook, Twitter, Youtube, Linkedin and Google+ are used extensively to develop social and professional networks and to diffuse information and user-generated content. Learners will expect a culture of not only 'Bring your Own Device' but 'Bring Your Own Application' in the future. If providers manage to integrate the applications that learners prefer into their systems, they will be able to better analyse the social behaviour of learners and develop early diagnoses for those lacking social and collaborative skills. Learners are also expected to develop ePortfolios of user-generated content. There are, however, risks in encouraging learners to use popular social media platforms as part of their educational development not least because providers may struggle to protect the privacy of learners and the integrity of learning. And as social media becomes ubiquitous it creates a digital identity that can be assessed in ways that may prove inequitable. The most powerful potential application of social media in the future could be in the distribution of a greater variety of VET teaching and learning strategies and in improving the efficiency of the selection process for success. As teachers develop their digital pedagogy, social media provides a platform for feedback and selection through peer assessment. Peer assessment can also be encouraged among learners to vary and select their own strategies for learning and gain mutually beneficial feedback on user-generated content. For social media to realise its potential in the VET sector, knowledge markets are likely to be necessary.

Telepresence, which enables teaches and learners to have a virtual presence in other locations, is widely used in social networks and in business. The technology is steadily progressing towards more realistic presences using higher resolution video and audio, and more reliable networking, with a direction of travel towards 3D and holograms. In the education sector frontier technology is being adopted predictably by business schools like the University of Pennsylvania's Wharton School. Telepresence is also being innovatively deployed in practice-based workplaces. Skype is used in classroom settings to improve access to experts and other settings for learning so much so that the company has set up a website devoted to the exchange of innovative teaching and learning strategies.

Telepresence robots are now appearing in office environments, hospital wards and on the military battlefield principally to widen the reach of expert opinion. For some the next development will be towards more lifelike robots with prosthetic limbs but another promising direction of travel is for the technology to get smaller. It is also possible to successfully integrate telepresence with whiteboards to offer ‘parallel teaching’ to adult learners. There are internal and external scale economies because such technology produces more profitable classroom sizes and enables multiple classrooms to connect.

The *modelling and simulation* of systems is a powerful form of adaptive learning and in many ways is the apogee of cognitive skills development. Innovation in computation together with big data – which has been called the “new raw material of the 21st century” – vastly increase the opportunity. Digital modelling and simulation is increasingly being used in the VET sector to support practice-based adaptive learning. Virtual labs are useful when developing concepts and practice that are either costly to teach (in resources and in time) or are constrained by health and safety issues. In the future, the internal scale economies of cloud-based services are likely to decrease the cost of digital modelling and simulation. Haptics, an internet of things, and robotics could drive a trend towards remote labs, which would give learners remote access to workplace equipment and machinery in controlled environments. In education the pedagogical theory of constructionism takes modelling and simulation one step further by encouraging learners to ‘construct’ knowledge with tangible objects rather than receiving it passively in a transfer from others. Constructionism may also hold for the creation of digital objects. As innovation improves the accessibility of 3D printers and robotics, modelling is likely to become a bona fide multi-sensory personalised learning experience. Serious games and apps, increasingly put forward as new tools for adaptive learning, may also unburden teachers from some aspects of formative and summative assessment. Several of the most popular current gaming apps are serious but they are costly to develop and their benefits are likely to be limited if the gaming model is received passively. The use of digital modelling and simulation in education is not without its critics. Learners may become indifferent to the inherent limitations of the computer as a learning instrument. Sensor technology based on an emerging ‘internet of things’ might be a way to reduce this risk by embedding constructionism in modelling and simulation.

Human-computer interfaces (HCIs) that incorporate tactility (touch) and kinesthetics (motion) are widely used in gaming and they have pedagogical potential for practice-based VET. Haptic interfaces have already been used to increase authenticity to classroom learning in medicine, dentistry, and animal welfare. Many people rely on tactility and kinesthetics to learn and they can be disadvantaged by formal education and traditional computing. The most significant developments in HCI are arguably in natural language and visual processing. Synthesising natural language and visual processing together with kinesthetics is leading irresistibly to augmented reality, which is likely to be the near future of HCI. Consumer devices such as Google Glasses massively increase the opportunities to learn in and across settings but they may present challenges for pedagogy, educational inequality, and the integrity of learning. More immediately, designing learning environments with effective HCI can stimulate collaborative skills.

Neuroscience, the study of the brain and the nervous system, could be the most revolutionary and far-reaching area of scientific research of the 21st century. Although learning outcomes are also modulated by environmental factors, neuroscience research has provided new insights into the enduring plasticity of the brain and the transience of skill. One of the early breakthroughs in *neuroeducation* has been a deepening in the understanding of 'reinforcement learning' and further insights into adaptive learning are expected. Neuroeducation will also have a future role in understanding the neural basis of the mental representations important for literacy and numeracy, in improving knowledge of executive function, which is the brain's mechanism for self-regulation, and in guiding teachers towards the development of a multi-sensory education enabled by new learning technology. The application of neuroscience to education has been constrained so far by a lack of inter-disciplinary connectivity between educators, psychologists and neuroscientists. One of the unfortunate consequences of this lack of connectivity has been the rise of 'neuro-myths'. In 2012, the cognitive training market surpassed $1bn despite being based on flimsy scientific evidence; and the market is expected to grow to $6.2 bn in 2020. Pharmacological cognitive enhancers such as Ritalin or Modafinil are already being used to improve motivation and concentration; but the long-term effects of cognitive enhancing drugs are under-researched and, furthermore, ethical issues of access and fairness surround their consumption.

The ongoing development of neuro- and bio-markers for educational risk in early years and cognitive decline in older age suggests a growing role for genomics in education. There has been remarkable research into the relationship between genes and the environments that activate them but there is much that is as yet poorly understood particularly in education. For experts, a highly personalised education based on genetics is not expected in the next decade. Even if major innovations in '*edugenetics*' are expected in the future, but not within a decade, the profound ethical and identity issues surrounding their use may emerge prematurely.

The promise of enabling technology will dissipate quickly without a new *digital pedagogy* that explores a variety of teaching strategies and selects for success using enhanced forms of e-assessment. Realising the innovation potential of the flipped classroom, new HCIs, multi-sensory learning, neuroeducation, modelling and simulation, social media, telepresence, and other as yet unanticipated technological changes, will require a careful balance between variation and selection. Providers and their teachers will have to invest in professional development. Next generation LMSs will improve the selection process with data that can be mined for insights using new learning analytics. Centres of excellence could be useful in providing objective analysis of best practice and frontier thinking in digital pedagogy. Communities of practice may be necessary for peer assessment. Yet, the market for adult education is lucrative and looks likely to increase in the future. The extent to which digital pedagogy and the data that guides its selection become proprietary is uncertain but the risk to the further education learning system is arguably on the downside.

Information, Advice and Guidance

Technology is enabling new forms of diagnostic, formative and summative *e-assessment*. As learners engage further with MOOCs and social media, providers and teachers will be able to make important diagnostic assessments, adjust the pace of learning and content using automated formative assessment, and incorporate new opportunities for peer assessment. Modelling and simulation encourages learners to vary their strategies through self-assessment, and select those that are most successful. Technology is also improving the quality of the formative assessment that teachers provide by providing more analytics and data visualisation. Badges, ePortfolios and peer assessment are stretching the boundaries of summative assessment although it is important not to underestimate the institutional cultures and the social norms that will have to change for summative e-assessment to supersede current forms of accreditation. In addition, new forms of e-assessment raise interesting issues of identity for teachers and learners.

Learning analytics, which apply a social and pedagogical approach to educational data mining, have been one of the fastest growing research areas of learning technologies over the last decade or so. A significant development in in the nascent evolution of learning analytics has been the 2010 Purdue University 'Signals' project - it mines large educational datasets and applies algorithms to anticipate which students are in danger of failing courses and can be targeted with resources. Learning analytics are now beginning to be differentiated from more macro-based academic analytics, which are focused more on the relevance marketing and performance of providers. Academic analytics are no less important to the future sustainability of the VET sector. The emerging field of learning analytics faces several challenges for the future. Ethical and privacy issues have yet to be fully explored. There will need to be metadata standards for data to be portable between inter-operable systems but for some providers with closed systems it may not be in their interests to comply. The extent to which the data generated by 'Bring Your Own Device' initiatives can be integrated into the Learning Management Systems of providers is uncertain. Learning analytics are inextricably linked with online academic learning and for the VET sector off-the-shelf analytics are unlikely to be sufficient. It will take time and the resolution of many difficult issues to build up adequate longitudinal datasets but the tantalisingly end-game is improved selection of the teaching and learning strategies that lead to successful learning and labour market outcomes.

Next Generation Learning Management Systems are expected to integrate the management of technologies into a coherent system of systems that produces a seamless adaptive system for teaching and learning strategies. The roadmap to such systems is not merely technological although the hurdles of standards, inter-operability, privacy, and open data are considerable. It is also social, economic and political. For instance, the adult learning technology market is still maturing and its glut of new start-ups suggests that it will be increasingly lucrative. Providers face a difficult decision given that the right system may be wrong if path-dependency takes hold (VHS vs Betamax, Bluray vs HD-DVD, etc), or if either scale economies, emergent learner behaviour, and 'superstar economics' reduce the scope for choice.

Digital infrastructure

Much of the learning technology of the future is underpinned by *information and communication technology*. The semiconductor industry is projecting extraordinary innovation in both processing and data storage well into the next decade. Computation also depends on algorithms. In recent years algorithmic innovation has been outpacing that of data storage and processing. In many sectors of the economy algorithms and robotics are substituting capital for human labour. Innovation in algorithms could occur suddenly and quickly. The cost of communication technology tends to fall faster than that of processing but there are many other factors that determine the development of network infrastructure. On the take-up of super-fast broadband, the UK is currently a mid-table performer among its European comparators; Asia, an early adopter of infrastructure, has the highest take-up; whereas the US has a relatively low current take-up partly as a consequence of its fragmented television market. As learning technology becomes increasingly multi-sensory, improvements in ICT over the next 10 years, particularly through high resolution visual processing and the transmission of data, are likely to enable mobile learning. VET sector providers, teacher and learners, with access to cost-effective innovation will be at an advantage, all else being equal, to those without.

Cloud computing offers access to externally-hosted processing power and storage through telecommunications networks for popular devices such as computers, laptops, smartphone and tablets. Cloud computing is the most important ongoing innovation in ICT because it offers a highly ‘elastic’ supply of computing – including high performance capability – and at relatively low costs through its internal economies of scale. More than this, cloud computing is a reflection of a huge increase in human mobility and inter-connectivity. It is cloud-based services and telecommunications networks that have enabled trends in MOOCs, social media, BYOD and mobile learning. The scale economies of cloud-based services are likely to improve access to higher-quality modelling and simulation, and telepresence. For information, advice and guidance, the cloud can drive down the costs and increase the benefits of big data. For VET sector providers there are dilemmas in their adoption of cloud-based services that go beyond economic cost-benefit analyses. The design of cloud computing infrastructure is still developing and outages are not unusual. Providers and learners are much more exposed to the quality and reliability of their internet connectivity. For some low-income learners the digital divide could become a chasm. There is the risk that providers become locked into proprietary services particularly if the migration of data is difficult. Cost-effective services could also lock teachers and learners into less innovative pathways if services are generic, proprietary, and are, therefore, received passively. Data stored in different countries are subject to the different regulatory regimes but there are service-level agreements that can stipulate its geographical location. Service-level agreements will also have to address issues around the use, reuse and retention of data.

Disruptive innovation

Clayton Christensen analysed ‘creative destruction’ empirically over a number of years and found that many large resourceful organisations were caught out by disruptive technologies because they were designed to sustain their past innovations. Disruptors usually make expensive or complicated products or services cheaper and simpler, expand the market, and then migrate up the value chain. Christensen sees this playing out with MOOCs in HE. But incumbents in HE and FE are not entirely defenceless against disruption. FE colleges, for example, have advantageous access to the practice-based knowledge, skilled pedagogy, learning systems, and digital infrastructure that will be necessary to make MOOCs a cost-effective technology. And although MOOCs can produce considerable internal scale economies, technology is much less likely to enable the external or agglomeration scale economies that are crucial to learning outcomes and to innovation. FE college campuses have this advantage, in being able to provide blended multi-sensory learning and spaces for teachers and learners to interact. Social media knowledge markets and telepresence have important future roles in capturing external scale economies but they are unlikely to replace the richness of reality. The greatest disruption to the VET sector may well be structural reform. Structural reform would force FE colleges to develop the competitive advantage that differentiates them from other providers. These include high-quality pedagogy, networks of practice-based knowledge, and the external scale economies of campuses. The key to adapting to disruptive innovation, then, may be to “have the right people on the bus”.

Implications for policy

The rationale for public investment in education is based on market failures in funding and information, and on externalities. For governance, more generally, getting the balance right between variation and selection in order to improve adaptive capacity is the challenge for VET sector providers and policymakers. As the range and flexibility of accreditation develops and data on learning outcomes becomes more closely linked to actual labour market outcomes, micro-funding may improve the allocation of resources and replace some public investment with private investment. There are likely to be information failures in the selection of teaching and learning strategies as new technology is adopted. As such, there is arguably a role for some public investment in network-building and digital infrastructure for well-functioning knowledge markets. There could also be market, information and co-ordination failures among potential consortia for the technology that has internal scale economies like MOOCs and community clouds. Policy also has a role in supporting the development of sector standards that improve the portability of data between systems. Policy on accreditation, which in many ways hard-wires together the relationships in the technologically-enabled VET learning system, needs to adapt to signals from the labour market. Issues surrounding privacy are likely to require more care as longitudinal data accumulates. If learning and labour market outcomes can be improved in the future with big data and analytics then policymakers should support open data, suitably anonymised, as a positive externality. The implications for human identity in education of big data, algorithms and analytics require more critical consideration. Without due diligence to the development of socio-technical systems, we may race antagonistically against the machine rather than productively with it. If having “the right people on the bus” is more important than technology when adapting successfully to disruptive change, then labour market frictions in the VET sector merit attention.

1. Introduction

In recent years there has been a renewed public policy emphasis on vocational education and training (VET) mostly as a consequence of disequilibrium in the labour markets of advanced economies (Manyika, et al., 2012). The Department of Business Innovation and Skills (BIS) has set up a Further Education Learning Technology Action Group (FELTAG) to explore how the Further Education (FE) sector might respond to emerging technologies. FELTAG has commissioned a systematic horizon scan of technologies likely to be of value to the VET sector.

This horizon scanning synthesis report takes a broad definition of technology as applicable knowledge so that crucial advances in, for example, neuroscience or digital pedagogy are not overlooked. It also views learning technologies as part of a complex learning system. This means that as well as exploring teaching and learning technology, innovations in information, advice and guidance, and digital infrastructure are also included. The time horizon is 5-10 years.

There are limitations to this synthesis. Firstly it was carried out in brief period of time. Secondly it was produced by an individual whereas horizon scanning benefits greatly from participatory and pluralistic research methods. Thirdly, forward-looking assessments on the innovation value, innovation cost, and time to maturity of technologies can be contentious. Fortunately, FELTAG will use this report as part of a "process to assess the potential and identify drivers, barriers and policy implications using the FELTAG members". These caveats aside, the report concludes with views on disruptive innovation in the VET sector and on the implications for policy.

"A direct line to work"

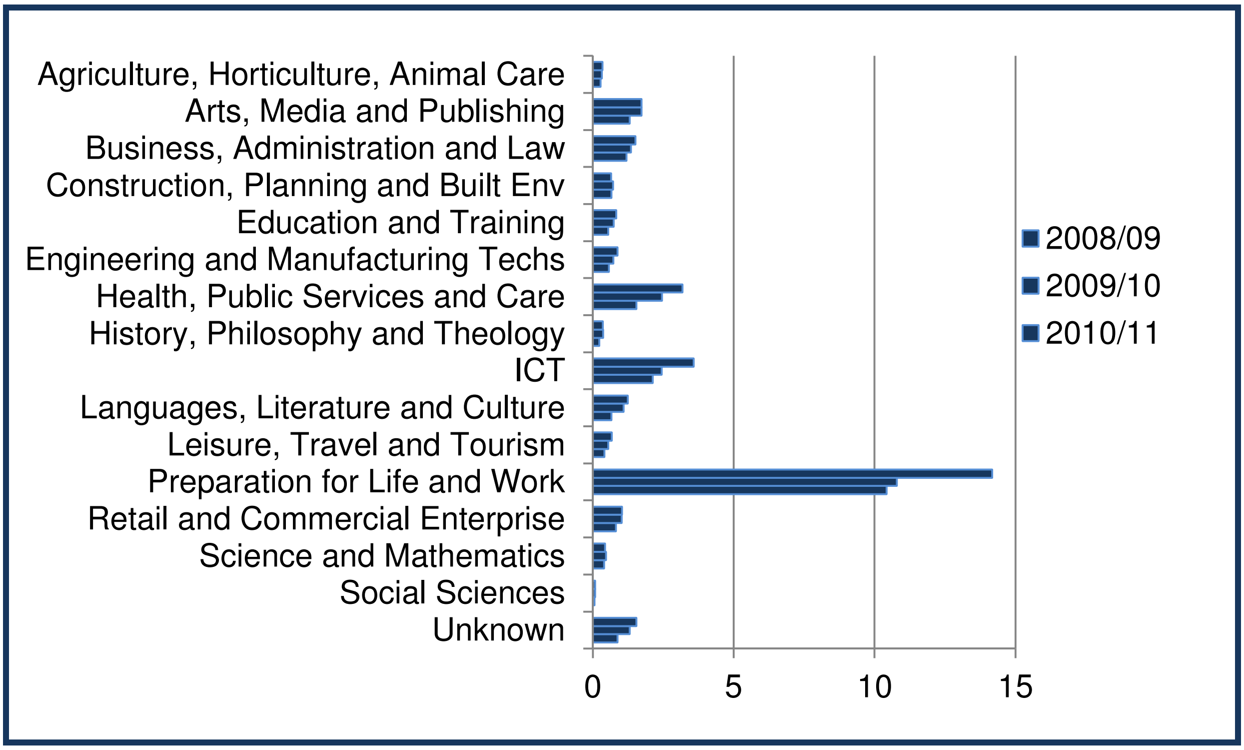

Figure 1.1, Adult (19+) Further Education College Learning Aims in England, 2008-2011 (000000s). Source: (The Data Service, 2013).

VET differs principally from compulsory and post-compulsory higher education because it is specifically practiced-based and is at its most effective a “direct line to work” (Commission on Adult Vocational Teaching and Learning, 2013). FE also aims to improve basic literacy and numeracy skills and provide an additional pathway for learners to higher education. There is a wide range of learning aims in English FE colleges (see Figure 1.1). The very high degree of interest in “Preparation for life and work” suggests that ‘learning to learn’ is an important objective.

The VET market

The market for adult education is already significant (see Table 1.1). The Inquiry into Lifelong Learning estimated the direct expenditure on post-compulsory adult learning in the UK in 2007/08 at around £55bn or 3.9% of GDP (Williams, et al., 2010). Although 'national performance’ spending on teaching provision for Higher Education (HE) and FE was roughly at a ratio of 2:1, the discrepancy on learner support was a striking 9:1 (Williams, et al., 2010).

Learning Purpose	**Expenditure (£bn)**
‘National performance’ public expenditure	12.9
Higher Education	(8.4)
Further Education	(4.5)
Other public programmes	1.2
Tax relief	3.7
Public sector employee development	7.7
Private sector employee development	16.2
Voluntary and community sector expenditure	3.8
Individual expenditure	9.4
Total expenditure	54.9

Table 1.1, UK expenditure on adult learning by learning purpose, 2007/08. Source: (Williams, et al., 2010).

Participation

Evidence suggests that around 40% of all adults in the UK participate in either informal or formal learning (Alkire, et al., 2009). Men and women participate at equal rates but women are more likely to depend on FE colleges (Jones, 2010). Participation declines markedly with age and is increasingly incongruent with the economic consequences of an ageing population (Aldridge & Tuckett, 2009). The minority ethnic population (apart from the Pakistani and Bangladeshi community) participates at a higher rate in adult learning than the general population although they participate less in formal adult education and are often disadvantaged by actual learning and subsequent labour market outcomes (Djan Tackey, et al., 2011). The starkest learning inequality may be that those with a disability participate in adult learning at half the rate of those who do not (Alkire, et al., 2009). There is clearly a role for technology to sustain and improve accessibility to adult vocational education and training. Yet, improving accessibility alone is unlikely to sufficient. Participation in adult learning is modulated by past educational attainment and current socioeconomic status (Jones, 2010). Thus, it may be also necessary to use technology to improve the efficacy of VET.

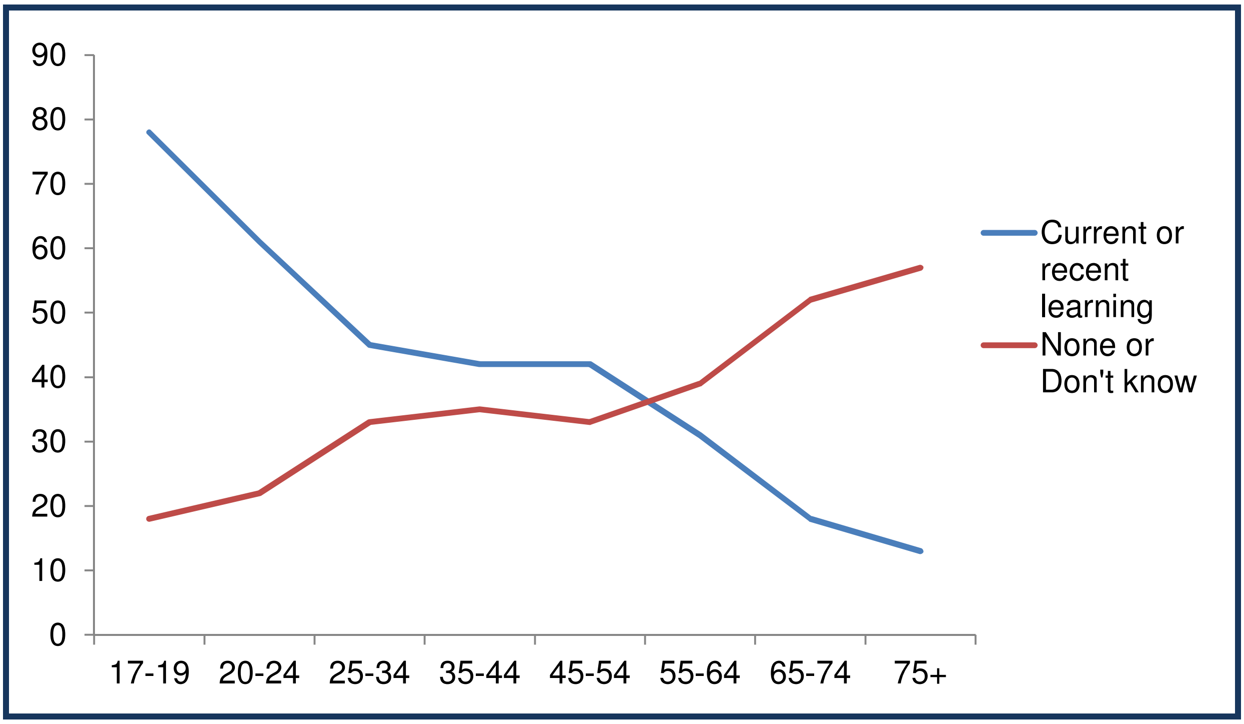

Figure 1.2, Participation in adult learning by age, 2009 (%). Source: (Aldridge & Tuckett, 2009).

Strategic choices

Successful strategy is a choice that multiplies the effectiveness of effort (Rumelt, 2011). For example, Walmart in the US broke through a retail industry hard ceiling - that “a full-line discount store needs a population base of at least 100,000”. Its strategic insight was that large stores in small towns were possible if all of its stores were managed as an integrated network. Choices usually fall into three categories – shaping the system, adapting to it, and cautiously reserving the right to play. A fresh diagnosis of uncertainty is necessary with which to adequately frame the strategic choice, and explore a portfolio of policies in this context - shaping bets, options, and no regrets moves. Walmart, for example, chose to make a big bet to shape the system.

The UK Prime Minister has adopted a policy narrative that the nation must develop strategies to compete in “the global race for jobs and for wealth”. In recent years globalisation and technological change have been the major drivers in labour markets. In the US and UK, technology has been hollowing out routine cognitive and manual jobs from the economy and polarising the labour market between ‘lovely’ and ‘lousy’ jobs (Goos & Manning, 2007) (see also Figure 1.3). Skills-biased technological change is increasing the demand for and the returns to cognitive skills (Goldin & Katz, 2008). Recent sectoral analysis from BIS puts forward advanced manufacturing, knowledge-intensive traded services, and the energy and construction sectors as plausible strategic bets (Department for Business, Innovation and Skills, 2012). Rather than “race against the machine”, humans may begin to race with the machines using creativity, collaboration and human-centred design (Brynjolfsson & McAfee, 2011). Algorithms that transform big data into insight and drive robotics are becoming a general purpose technology delivering value across the economy but there are theoretical reasons to believe that they may struggle to replace human entrepreneurship (Nagel & Newman, 2004). Opportunities are increasing to personalise services, deliver high-quality care, and contribute to a growing health and wellbeing sector. Strategic choices, therefore, should be underpinned by an appreciation of the level of system uncertainty in which they will play out. For the VET sector, learning technologies may have to be robust to changes in practice over the next 10 years.

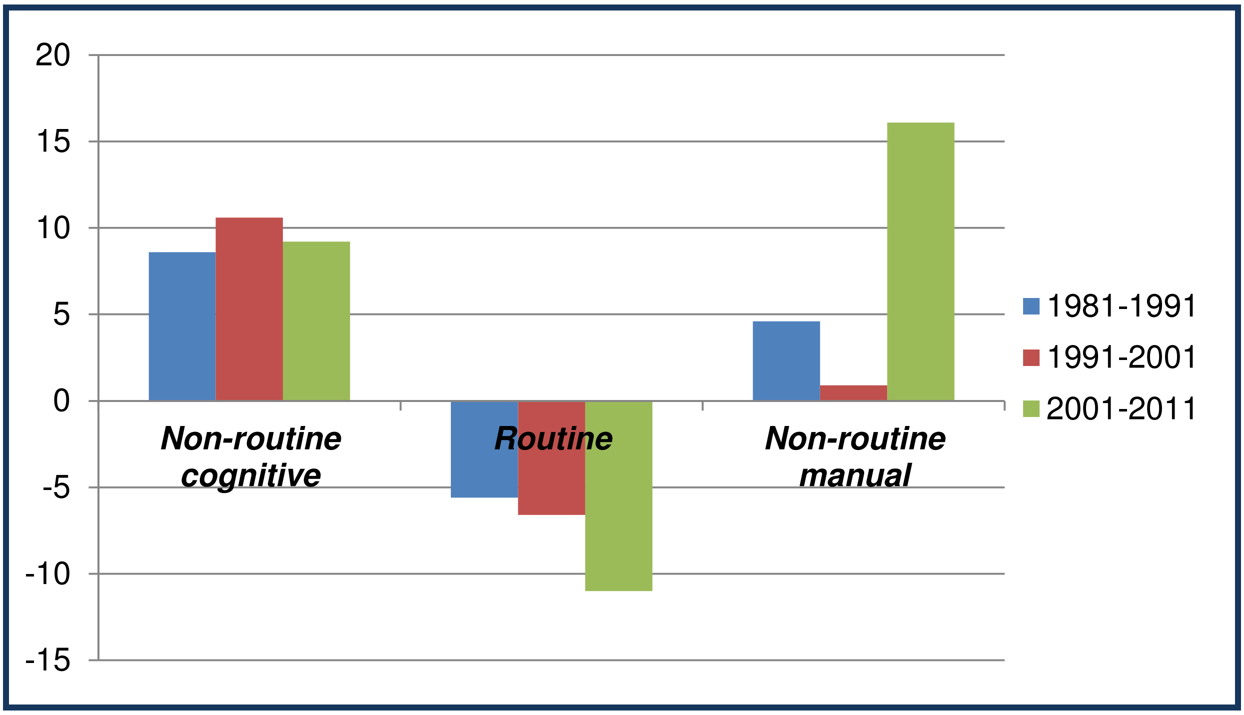

Figure 1.3, Percentage change in employment shares in the US, 1981-2011[1]. Source: (Jaimovich & and Siu, 2012).

[1] Non-routine cognitive occupations - management, business and financial operations, professional and related; Routine cognitive occupations - sales and related, office and administrative support; Routine manual occupations – production, transportation and material moving, natural resources, construction and maintenance, construction and extraction, installation, maintenance and repair; Non-routine manual - service

2. Prioritising technologies

Prioritising emerging technologies is challenging because policy instruments may falter against powerful social and organisational norms (Liebenau, 2007). Moreover, the diffusion of successful technologies can be highly unpredictable especially in an increasingly interconnected and networked world. Too often horizon scanning analysis distances technology from the values, behaviours, systems and culture that affect its adoption (Slaughter, 2012). For technologies with longer lead times, there is the additional complication of ensuring their robustness to future endogenous and exogenous change, and to events that with our existing knowledge we are unable to anticipate.

The specification for this horizon scan sought technologies likely to be of value to improve:

- (i) personal support for learning
- (ii) access to learning
- (iii) flexibility of provision
- (iv) efficiency and effectiveness of learning
- (v) ways of assessing learning, and
- (vi) data security and identity

In further communications with the experts leading on the workstream, preferences were expressed for technologies that could enable innovation, were learning-centred, could empower teachers, and that were propitious to the concept of a learning system. The additional and over-riding objective of this horizon scan is to stimulate thinking on “a process to assess the potential and identify drivers, barriers and policy implications using the FELTAG members”.

Innovation

For the purposes of this report innovation is defined very simply as a process that delivers more or similar value with lower costs. Improved processes can release scarce resources to be allocated elsewhere such as time for teacher professional development. But innovation is inherently risky and may, for example, have prohibitive costs of adoption. The preference for technologies that enable innovation means that the report explores the potential of several technologies for VET and assesses their ‘direction of travel’ to a horizon of 10 years.

A learning system

Understanding the VET sector as a learning system is useful because globalisation and technological change are driving turbulent change that requires increased variation or experimentation in the system. In addition, rigid top-down governance may no longer be sustainable given the pace of change in “global race”. Viewing the VET sector through the lens of complex adaptive systems thinking sees it as a system of learners, teachers, providers, researchers, and policymakers interacting with a degree of interdependence based on their own strategies (Axelrod & Cohen, 2000). Strategies will vary and if the system has effective feedback mechanisms those that prove innovative will be, increasingly, selected. The potential of the system to adapt to change rests on the balance between variation and selection. A systems-based approach means that this horizon scan cannot strictly be limited to technologies that directly influence teaching and learning strategies. It also explores the potential of technologies that may help to enable innovation in information, advice and guidance, as well as digital infrastructure.

Learner-centred principles

Technology is more likely to enable change than to drive it. NESTA has recently developed a set of learner-centred principles to prevent horizon scanning of learning technologies losing sight of learning outcomes (Luckin, et al., 2012). These principles (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) will be used when exploring the potential of learning technologies.

Scale economies

For technology to be a true 'game-changer' in the VET sector it may have to enable new economies of scale (Laurillard, 2013). It is beyond the scope of this report to analyse this in great detail but recent economic insights into scale economies may be valuable here. Scale economies, or cost efficiencies, are increased by the density of economic activity and decreased by the distance between economic agents; they also vary according to types of industry. Geography is an important consideration for the VET sector because of its historical relationship with practice and with place. There are possibly two questions to be explored for the VET sector. Firstly what types of scale economies might technology enable within the sector? Secondly, to what extent do the scale economies of the very industries that the sector services increase or decrease the potential of further education learning technologies?

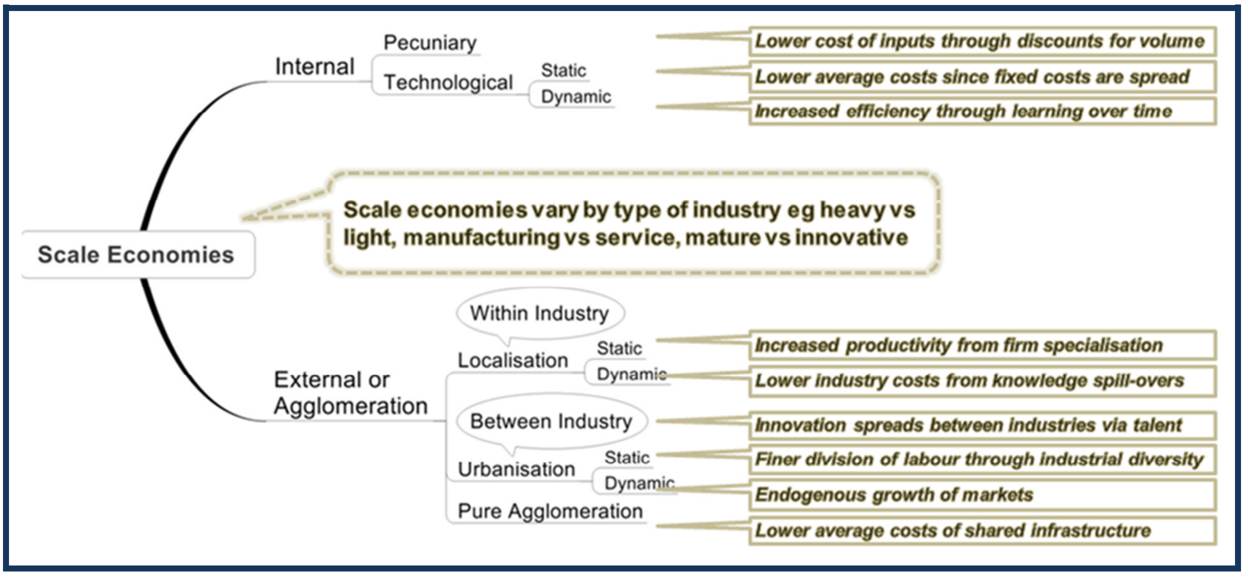

Figure 2.1, Examples of scale economies. Source: Ariel Research Analysis based on (World Bank, 2009).

3. Teaching and Learning Technologies

MOOCs

Massively Open Online Courses (MOOCs) are already available for post-compulsory HE through providers such as Coursera and edX and for compulsory education through the Khan Academy. The extraordinary global popularity of MOOCs has received a great deal of attention but it is an immature market and business models are still developing. The production of Coursera and edX courses is currently cross-subsidised by the prestigious Higher Education providers who comprise its consortia or is boosted by speculative venture capital funding. The expectation is that learners will eventually pay at a minimum for formal accreditation (The Economist, 2013).

What is much less publicised is that the first provider of MOOCs was actually a VET sector provider (Bornstein, 2012). Advanced Learning Interactive Systems Online (ALISON) has been a successful for-profit social enterprise based in Ireland since 2007 (see Figure 3.1). Content is aggregated from a variety of sources based on mutually beneficial partnerships. Most other providers of online VET courses charge for courses or demand a subscription. Its business model is based on advertising and on fees for additional services such as Flash-based exams so that employers can test learning. ALISON has used MOOCs to develop internal scale economies. It offers several hundred vocational courses to a million registered users based mainly in the US, the UK, India, Malaysia, the Philippines, Nigeria and the Middle East. In 2011, around 50000 learners received certificates or diplomas.

Figure 3.1, ALISON, an innovative VET MOOC provider with internal scale economies.

In many ways MOOCs are a better fit for the FE sector because of their flexibility to adult learners who can learn at their own convenience and pace. VET MOOCs can also very meaningfully ‘flip the classroom’ so that more time can be spent hands-on learning industry practice. For the less-well funded FE sector, however, MOOCs are a challenge because there is much less opportunity to cross-subsidise the production of content. It is also a different proposition to craft content that blends well with practice-based learning and develop algorithms that accurately assess knowledge often more personalised than academic learning. Quality assurance of MOOC content is already an issue for providers such as the Khan Academy. Processes of variation and selection based on teacher and learner feedback may be dependent on the marketing know-how of providers of locked content.

This notwithstanding, MOOCs are an undoubted opportunity to improve accessibility to VET. Valuable data is generated by the learner that can be used with learning analytics to enhance learner management systems.

Innovation value: Medium	Innovation cost: High
Time to maturity: High	Learning system: Indirect, flips classroom
Learner-centred principles: Learning from experts, Learning from assessment	

Social media

There is a growing body of inter-disciplinary knowledge on social networks that builds upon the insights of researchers such as Mark Granovetter at Stanford University. Commercial social media platforms such as Facebook, Twitter, Youtube, Linkedin and Google+ are used extensively to develop social and professional networks and to diffuse information and user-generated content. Learning Management Systems (LMSs) have often attempted to harness the efficiency of networked communication through proprietary social media technologies but with seemingly mixed results (Comrie, 2013). The potential for increasing returns in networked knowledge economies means that the technology companies who succeed accumulate resources such as vast datasets which they can mine for innovation.

Learners will expect a culture of not only 'Bring your Own Device' but 'Bring Your Own Application' in the future. If providers manage to integrate the applications that learners prefer into their systems, they will be able to better analyse the social behaviour of learners and develop early diagnoses for those lacking social and collaborative skills. Learners are also expected to develop ePortfolios of user-generated content. There are however risks in encouraging learners to use popular social media platforms as part of their educational development not least because providers may struggle to protect the privacy of learners and the integrity of learning. And as social media becomes ubiquitous it creates a digital identity that can be assessed in ways that may prove inequitable.

The most powerful potential application of social media in the future could be in the distribution of a greater variety of VET teaching and learning strategies and in improving the efficiency of the selection process for success. As teachers develop their digital pedagogy, social media provides a platform for feedback and selection through peer assessment. The effects can be startling if systems appreciate the subtleties of powerful network dynamics. Peer assessment is growing popular especially in less hierarchical collaborative enterprises (Erickson, 2011). Among technology firms, for example, peer assessment of practioner strategies using social media is considered by many to be the most accurate assessment of performance (Kelly & Hess, 2013).

Peer assessment can also be encouraged among learners to vary and select their own strategies for learning and gain mutually beneficial feedback on user-generated content. Such formative assessment will also prepare learners for the new trends of peer assessment developing in the collaborative workplace. Plagiarism could reduce the variety of strategies in the absence of supervision or technology that promotes intellectual property rights.

As the Knowledge Management industry has found it to its cost, however, valuable intellectual property is more easily exchanged than shared. For social media to realise its potential in the VET sector, knowledge markets are likely to be necessary. Developing efficient knowledge markets requires careful design – defining 'knowledge objects', facilitating and incentivising exchange, respecting intellectual property rights, and encouraging competition (Bryan, 2004).

Innovation value: High	Innovation cost: Medium
Time to maturity:Low	Learning system: Selection
Learner-centred principles: Learning from assessment, Learning with others	

Telepresence

Telepresence, which enables teaches and learners to have a virtual presence in other locations, is widely used in social networks and in business. The technology is steadily progressing towards more realistic presences using higher resolution video and audio, and more reliable networking, with a direction of travel towards 3D and holograms. In the education sector frontier technology is being adopted predictably by business schools like the University of Pennsylvania's Wharton School. Wharton is using a sophisticated system with multiple cameras, displays and life-size projection to connect up its campuses in Philadelphia and San Francisco (McCracken, 2013). Telepresence is also being innovatively deployed in practice-based workplaces. The ADHD and Asperger's team of Northamptonshire Healthcare Foundation Trust, which offers highly specialised diagnostic assessments and interventions for adults, has increased the scale and flexibility of their consultations with Skype (Health Services Journal, 2012). There were technical challenges and confidentiality issues but these have been readily addressed.

Skype is already used in classroom settings to improve access to experts and other settings so much so that the company set up a website devoted to the exchange of innovative teaching and learning strategies. 'Skype in the Classroom' also enables classrooms to connect up with telepresence and has been used with much enthusiasm to exchange cultural practice. Its global community currently has around 43,000 teachers and 2,400 lessons[2].

Telepresence robots are now appearing in office environments, hospital wards and on the military battlefield principally to widen the reach of expert opinion (The Economist, 2013). For some the next development will be towards more lifelike robots with prosthetic limbs but another promising direction of travel is for the technology to get smaller. Smartphones are already being used in robotic cradles. Small multi-sensory telepresence devices could go even further in providing new perspective on frontier workplace practice and technology.

[2] https://education.skype.com/.

For many adult learners with busy lives getting access to the classroom is challenging enough. An innovative further education project in Denmark has successfully integrated telepresence with whiteboards to offer ‘parallel teaching’ to adult learners. With ‘Global Classroom VUC Storstrøm’ learners can now meaningfully participate in classrooms from the convenience of their homes[3]. There are internal and external scale economies because its technology produces more profitable classroom sizes and enables multiple classrooms to connect.

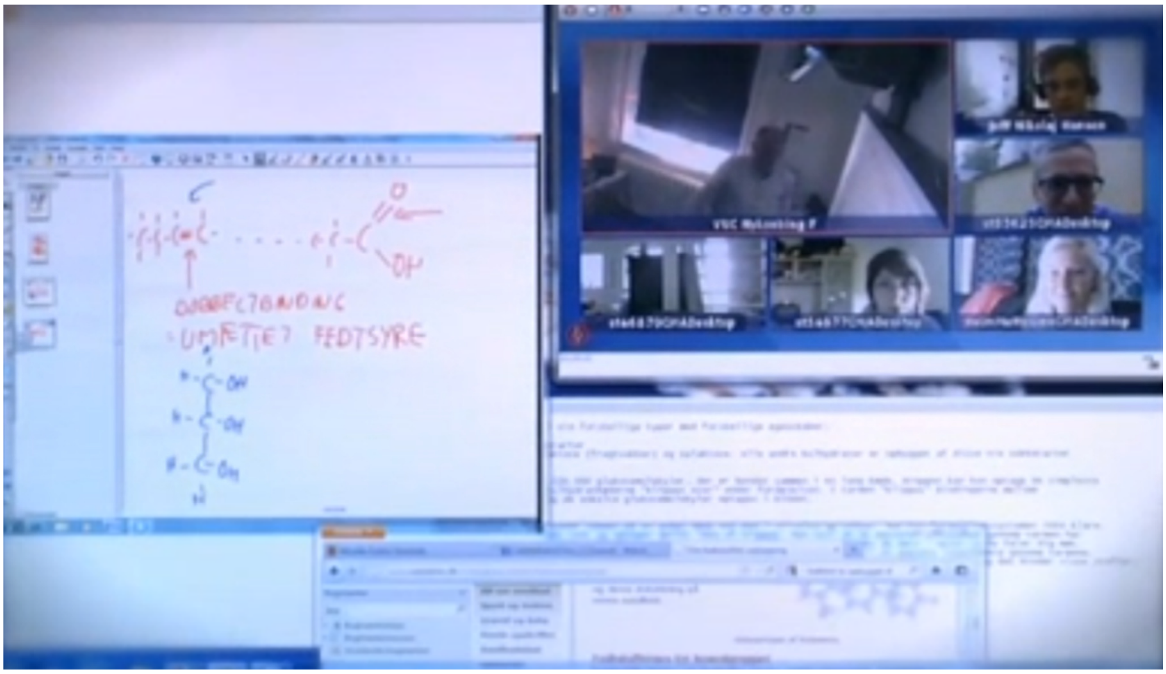

Figure 3.2, Global Classroom VU Storstrøm learner interface.

For the VET sector, serving adult learners who require flexible learning and who seek access to practice that is used outside of classroom settings, getting telepresence right may not lead to the internal scale economies of MOOCs but it might capture some external or agglomeration scale economies and help fulfil some of the aims of FE.

Innovation value: Medium	Innovation cost: Medium
Time to maturity: Medium	Learning system: Variation
Learner-centred principles: Learning from experts, Learning with others, Learning from assessment, Learning in and across settings	

Modelling and simulation

The modelling of systems - either physically or abstractly - and their simulation are a powerful form of adaptive learning. In many ways they are the apogee of cognitive skills development. Innovation in computation together with big data – which has been called the “new raw material of the 21st century” – vastly increase the opportunities for the digital

[3] http://www.globalclassroom.eu/.

modelling and simulation of systems. Data visualisation tools also aid in the construction of models and in the interpretation of their simulated results. Digital modelling and simulation is increasingly being used in the VET sector to support practice-based adaptive learning (London Knowledge Lab, 2013). Yenka is licensed-based software that enables learners to develop their own digital models of STEM-based systems with which to test against reality[4]. Digital simulations using realistic models of practice are used in engineering, construction, health-care and business studies. Role-play simulations and scenario planning, indicative of an increasingly uncertain operating environment, are popular in finance, business and accounting studies, but may have further applications in areas such as engineering (London Knowledge Lab, 2013). Virtual labs are useful when developing concepts and practice that are either costly to teach (in resources and in time) or are constrained by health and safety issues. In the future, the internal scale economies of cloud-based services are likely to decrease the cost of digital modelling and simulation. Haptics, an internet of things, and robotics could drive a trend towards remote labs, which would give learners remote access to workplace equipment and machinery in controlled environments.

Figure 3.3, A robot creation enabled by a HummingBird kit.

In education the pedagogical theory of constructionism takes modelling and simulation one step further (Luckin, et al., 2012). It hypothesises that learners 'construct' knowledge as they make tangible objects rather than receiving it passively in a transfer from others. It is easy to forget in an age of supercomputing that early models were physical rather than abstract – for example orreries constructed to simulate the orbits of the planets. In US, Carnegie Mellon University's Robotics Institute has developed HummingBird Kits ($199) - mechatronic

[4] http://www.yenka.com/.

materials that can be combined with other craft materials project in order to make highly personalised robotic devices with unconventional applications[5]. The kits are aimed at improving the interest of female learners in programming (see Figure 3.3). Constructionism may also hold for the creation of digital objects. As innovation improves the accessibility of 3D printers (recent life cycle economic analysis suggests that even current 3D printers are economically attractive to households[6]) and robotics, modelling is likely to become a bona fide multi-sensory personalised learning experience.

Serious games and apps - increasingly put forward as new tools for adaptive learning - may also unburden teachers from some aspects of formative and summative assessment. Jane McGonigal, an expert in serious and alternate reality games, claims that well-designed multiplayer games inculcate the attributes that will be required for the jobs of the future such as collaboration and experimentation (McGonigal, 2008). Several of the most popular current gaming apps are serious. 'Plague Inc', which challenges learners to develop a pathogen that will infect and wipe out the global human population, provides a realistic simulation of disease epidemics[7]. 'Duolingo' invites learners to compete against their friends to learn a language[8]. The best serious and alternate reality games have been proven to be a powerful form of adaptive learning but they are costly to develop and their benefits are likely to be limited if the gaming model is received passively.

The use of digital modelling and simulation in education is not without its critics. Professor Sherry Turkle, a psychologist, observed the impact of computing at MIT in the 1980s and 2000s. She found that simulation freed students and researchers from the mundanity of repetitive processes, stimulating observation and experimentation, and supporting adaptive learning. The price to be paid for this immersion was diminishing scepticism. She documents evidence of deterioration in the scientific identity of young scientists who are "drunk with code" and indifferent to the inherent limitations of the computer as a scientific instrument (Turkle, 2009). She quotes one MIT physicist to illustrate the risks:

"My students know more and more about computer reality, but less and less about the real world. And they no longer even really know about computer reality because the simulations have become so complex that people don't build them any more. They just buy them and can't get beneath the surface. If the assumptions behind some simulation were flawed, my students wouldn't even know where or how to look for the problem." (Turkle, 2009)

Sensor technology based on an emerging 'internet of things' might be a way to embed constructionism in modelling and simulation. Sensors are becoming increasing small and networked and can be used to model and simulate physical environments. Intelligent sensor networks or so-called 'smart' systems use sensor technology to not only monitor but to actually shape system behaviour based on analytics. At the London Knowledge Lab, computer science students on a summer internship used sensor technology to capture data

[5] http://www.hummingbirdkit.com/.
[6] http://marginalrevolution.com/marginalrevolution/2013/07/the-household-economics-of-3-d-printers.html.
[7] http://www.ndemiccreations.com/en/.
[8] http://www.duolingo.com/.

on the temperature and light levels, and developed an app to visualise their analytics in real time[9].

Innovation value: High	Innovation cost: Medium
Time to maturity: Medium	Learning system: Variation, Selection
Learner-centred principles: Learning through making, Learning through inquiry, Learning through practising, Learning from assessment, Learning in and across settings	

Human-Computer Interaction

During the development phase for the first iPhone, Steve Jobs would routinely interrupt other unrelated meetings at Apple by producing a popular mobile phone and demonstrating to participants its baffling user interface (Isaacson, 2011). As information and communication technology becomes ubiquitous, demand for intuitive devices and applications will increase. Human-centred design is reshaping technology to be needs-driven by exploring applications together with technology users (Foresight, 2012). As populations age, for example, universal design ensures that technology is useful for and accessible to older people.

Haptic human-computer interfaces (HCIs) that incorporate tactility (touch) and kinesthetics (motion) are widely used in gaming and they have pedagogical potential for practice-based VET. Haptic interfaces have already been used to increase authenticity to classroom learning in medicine, dentistry, and animal welfare (London Knowledge Lab, 2013). Many people rely on tactility and kinesthetics to learn and they can be disadvantaged by formal education and traditional computing, which focus on visual and auditory learning.

The most significant developments in HCI are arguably in natural language and visual processing. Extraordinary advances are being made in natural language processing headlined by the application of IBM's Watson supercomputer in the finance and healthcare sectors; and by apps like Siri that are becoming de rigueur in mobile phones and cars. Visual processing is a weakness for computation although facial recognition algorithms are now widely available. Synthesising natural language and visual processing together with kinesthetics is leading irresistibly to augmented reality, which is likely to be the near future of HCI. The bricklaying team at South Staffordshire College has used augmented reality to markedly improve learning outcomes on their bricklaying course (Bloxham, 2013). The CARE (Creating Augmented Reality in Education) project at City University in London has used GPS and augmented reality to enable healthcare students to explore the health risks in local areas[10]. The advantage of this is the delivery of 'situated contextualised learning' (Bloxham, 2013). Consumer devices such as Google Glasses massively increase the opportunities to learn in and across settings but they may present challenges for pedagogy, educational inequality, and the integrity of learning.

More immediately, designing learning environments with effective HCI can stimulate collaborative skills. In Austria, the NiCE Discussion Room combines technology and space in order to develop a 'digital ecology' for learning with others (Luckin, et al., 2012). VET learning spaces should also provide "a direct line to work" by simulating the practice-based

[9] http://acssummerapp.webr.ly/blog/.
[10] http://blogs.city.ac.uk/care/.

environments of the workplace. Incorporating HCIs inappropriately into these spaces could distract from this experience.

Innovation value: Medium	Innovation cost: High
Time to maturity: Medium-High	Learning system: Variation
Learner-centred principles: Learning in and across settings, Learning through practising, Learning with others	

Neuroeducation

Neuroscience, the study of the brain and the nervous system, could be the most revolutionary and far-reaching area of scientific research of the 21st century (Taylor, 2012). The fundamental questions of how the brain perceives, thinks, acts and remembers have been invigorated by a remarkable integration of molecular and cell biology and psychology. Once at the periphery, neuroscience has become an inter-disciplinary field that is now central to both. Its scope ranges "from genes to cognition, from molecules to mind" (Kandel & Squire, 2000).

Although learning outcomes are also modulated by environmental factors, neuroscience research has provided new insights into the enduring plasticity of the brain and the transience of skill. One of the early breakthroughs in neuroeducation has been a deepening in the understanding of 'reinforcement learning' where an agent has to make choices through trial and error. In this decision-making framework, prediction errors update and guide the agent towards options that maximise reward. Following on from single-neuron recording experiments in monkeys, it has subsequently been discovered that "dopamine-mediated prediction error is used as a teaching signal to learn expected action values and to favour optimal choice in humans" (Dolan, 2008). Neuroeducation is likely to uncover further insights into adaptive learning that can be applied to learning through technology.

Neuroeducation will also have an important future role in understanding the neural basis of the mental representations important for literacy and numeracy (Goswami, 2008). Along with cognitive psychology, neuroscience is improving understanding of executive function, which is the brain's mechanism for self-regulation. The equivalent concept in educational research is 'non-cognitive' skills but its definitions are less precise and there is a paucity of evidence on how to specifically improve adult non-cognitive skills. Neuroscience research, on the other hand, is investigating to what extent cognitive training programmes can strengthen executive function (Royal Society, 2011).

The application of neuroscience to education has been constrained so far by a lack of inter-disciplinary connectivity between educators, psychologists and neuroscientists (Royal Society, 2011). One of the unfortunate consequences of this lack of connectivity has been the rise of 'neuro-myths'. For example, contrary to their own experience, teachers have been advised learning styles can be visual, auditory or kinesthetic (VAK). Neuroeducation is likely to guide teachers in the development of a multi-sensory education enabled by new learning technology (Goswami, 2008). In 2012, the cognitive training market surpassed $1bn despite being based on flimsy scientific evidence (The Economist, 2013). New providers such as Lumosity are trying to learn from the controversy that surrounded Brain Gym by recruiting neuroscientists and evaluating their products with peer-reviewed research. The demand for cognitive training by adult learners is evident. Lumosity and DuoLingo, which targets cognitive training at language skills, have hugely popular apps that and the market is expected to grow to $6.2 bn in 2020 (The Economist, 2013).

Pharmacological cognitive enhancers such as Ritalin or Modafinil, which can influence neurotransmitters in certain cognitive processes, are already being used to improve motivation and concentration (Royal Society, 2011). The increasing returns to high quality education are likely to drive an increase in their unregulated use; but the long-term effects of cognitive enhancing drugs are under-researched and, furthermore, ethical issues of access and fairness surround their consumption.

Innovation value: High	Innovation cost: High
Time to maturity: Medium-High	Learning system: Variation
Learner-centred principles: Learning through practising, Learning by assessment	

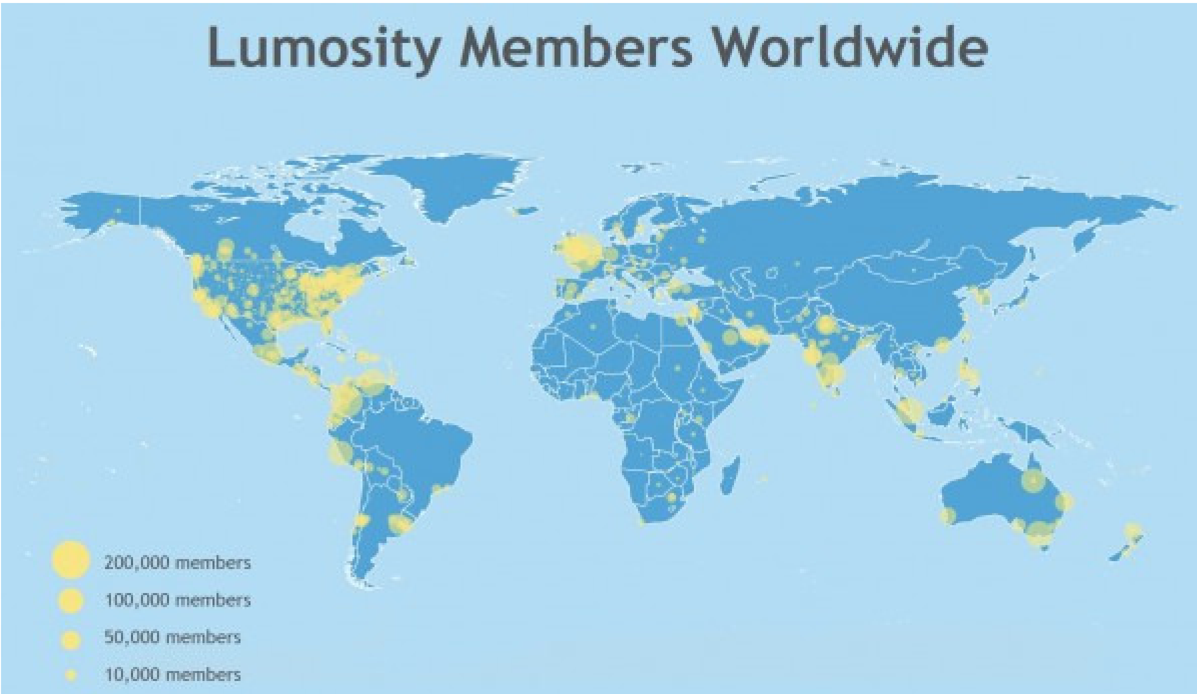

Figure 3.4, Geographical distribution of the 45m registered users of the Lumosity website[11].

'Edugenetics'

The ongoing development of neuro- and bio-markers for educational risk in early years and cognitive decline in older age suggests a growing role for genomics in education. The cost of sequencing personal genomes is falling rapidly and there are already affordable consumer services offering more limited forms of analysis. There has been remarkable research into the relationship between genes and the environments that activate them but there is much that is as yet poorly understood particularly in education. For experts, a highly personalised education based on genetics is not expected in the next decade (Howard-Jones, 2008). However, as the 'Brain Gym' controversy has demonstrated, educational fashions need not

[11] http://www.lumosity.com/.

be evidence-based. Even if major innovations in 'edugenetics' are expected in the future, but not within a decade, the profound ethical and identity issues surrounding their use may emerge prematurely.

Innovation value: High	Innovation cost: High
Time to maturity: Not within 10 years	Learning system: Variation, Selection
Learner-centred principles: Indirect, enabling	

Digital pedagogy

The promise of enabling technology will dissipate quickly without a new digital pedagogy that explores a variety of teaching strategies and selects for success using enhanced forms of e-assessment. There is the possibility of positive non-linear effects where professional development leads to efficacious learning which in turn frees teachers to further enhance their digital pedagogy (Laurillard, 2013). On the other hand if technology is imposed without strategies that appreciate their innovation costs and benefits, and their overall position in a complex learning system, a vicious cycle could ensue with diminishing development and fragility in provision.

Realising the innovation potential of the flipped classroom, new HCIs, multi-sensory learning, neuroeducation, modelling and simulation, social media, telepresence, and other as yet unanticipated technological changes, will require a careful balance between variation and selection. Providers and their teachers will have to invest in professional development. Next generation LMSs will improve the selection process with data that can be mined for insights using new learning analytics. Centres of excellence could be useful in providing objective analysis of best practice and frontier thinking in digital pedagogy (Laurillard, 2013). Communities of practice may be necessary for peer assessment. Yet, the market for adult education is lucrative and looks likely to increase in the future. The extent to which digital pedagogy and the data that guides its selection become proprietary is uncertain but, given the 'superstar economics' of networked knowledge economies, the risk to the further education learning system is arguably on the downside.

Innovation value: High	Innovation cost: Medium
Time to maturity: Medium	Learning system: Variation, Selection
Learner-centred principles: Indirect, enabling	

4. Information, Advice and Guidance

E-assessment

Technology is enabling new forms of diagnostic, formative and summative assessment. As learners engage further with MOOCs and social media, providers and teachers will be able to use social network analysis to make important diagnostic assessments. MOOC systems can adjust the pace of learning and their content using automated formative assessment. Both technologies also offer new opportunities to use peer assessment. Modelling and simulation encourages learners to vary their strategies through self-assessment, and select those that are most successful. Technology is also improving the quality of the formative assessment that teachers provide by providing more analytics and data visualisation. The Khan Academy already provides learners and teachers with a dashboard of relatively 'coarse-grained' formative e-assessment that could be significantly enhanced by LMS data (see Figure 4.1). Teachers are using these learning dashboards to better target their scarce resources for 1:1 formative assessment (Thompson, 2011). In some instances formative e-assessment has improved the relationship between teachers and learners in circumstances where learners felt unable to approach teachers with their own self-diagnostic concerns (Thompson, 2011).

		6.04d Plot Diagram	6.05c Imagery	6.04a Theme development	6.04c word choice and mood	6.01e Word Analogies
Name	Mastery	73% overall	74% overall	78% overall	82% overall	84% overall
Elmo Almen 2/5	80% B	100%	67%	67%	100%	67%
Shannon Anderson 1/5	70% C	100%	50%	67%	67%	67%
Ashley Arrington 5/5	97% A	100%	84%	100%	100%	100%
Bryon Azad 4/5	93% A	100%	100%	100%	67%	100%
Tim Boldenow 1/5	57% F	67%	84%	33%	67%	33%
Darren Bottomley 0/4	59% F	67%	67%	33%	-	67%
Penelope Butner 1/5	67% D	67%	33%	100%	67%	67%
Georgeann Courtnage 2/5	70% C	67%	84%	100%	33%	67%

Figure 4.1, Formative e-assessment through the Khan Academy Teaching Dashboard[12].

Badges, ePortfolios and peer assessment are stretching the boundaries of summative assessment. It is important not to underestimate the institutional cultures and the social norms that will have to change for summative e-assessment to supersede current forms of accreditation. But for adult learning in the VET sector, where learners are often unable to commit to full-time classroom learning, and moreover where practice-based learning can sometimes fit uncomfortably with academic assessment, these innovations are promising. For example, it may improve 'learning to learn' for learners who have been disadvantaged or frankly disenchanted by traditional assessment.

[12] https://www.khanacademy.org/.

New forms of e-assessment raise interesting issues of identity for teachers and learners. Some researchers are sceptical of the potential of computation to replace the expert knowledge accumulated by complex human brains (Kahneman & Klein, 2009). Teachers may not have the time or the agency to override e-assessment in the future. Learners may feel constrained or disenfranchised by a system of assessment that is contingent on the limitations of algorithms.

Case study: Badges

Badges have been widely used to certify informal learning. They have also been used for lower-value workplace vocational education and training. Badges are used most successfully in gaming where they incentivise sequential learning with short-term objectives. The Khan Academy offers proprietary badges for compulsory education and markets its own e-assessment as "badges worth bragging about". This is revealing of the challenges that badges face in adult learning. They are mostly proprietary and lack common standards for portability. Mozilla's 'Open Badge Initiative' is trying to counter this trend. Badges are also associated with youth and currently lack the credibility of formal summative assessment in the educational sector and workplace. But there are signals of change. The Financial Times recently posed the question on Stanford's 'Introduction to AI' MOOC: "If you were a Silicon Valley chief executive hiring AI engineers, would you prefer the top student in the privileged minority who took CS221 in the 'old' days? Or the best of the 160,000 self-motivators in the online class?" Institutions are notoriously slow to change. However, the adoption of badges in the VET sector also depends on business culture and norms, which may be quicker to change than those of institutions. If badges start to be recognised as a genuine "direct line to work" resistance will lessen.

Innovation value: Medium	Innovation cost: Medium
Time to maturity: Medium	Learning system: Selection
Learner-centred principles: Learning from assessment	

Learning analytics

Analytics are used with some sophistication in business for relevance marketing; and driven by ICT and big data their application is widening. Learning analytics or "the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimising learning and the environments in which it occurs" has been one of the fastest growing research areas of learning technologies over the last decade or so (Ferguson, 2012). Learning analytics apply a social and pedagogical approach to educational data mining. They build upon previous developments in social network analysis, latent semantic analysis and dispositions analysis. They also use data visualisation extensively to analyse and interpret results (Ferguson, 2012).

A significant development in in the nascent evolution of learning analytics has been the 2010 Purdue University 'Signals' project[13]. It mines large educational datasets and applies algorithms to anticipate which students are in danger of failing courses and can be targeted

[13] http://www.itap.purdue.edu/studio//signals/.

with resources. Evaluation of the project so far suggests that it is improving learning outcomes (Ferguson, 2012). Learning analytics are now beginning to be differentiated from more macro-based academic analytics, which are focused more on the relevance marketing and performance of providers. Academic analytics are no less important to the future sustainability of the VET sector.

Figure 4.2, Purdue University's 'Signals' learning analytics system.

The emerging field of learning analytics faces several challenges for the future. Ethical and privacy issues have yet to be fully explored. How transparent are the algorithms that transform the data into analytics? Will the process become overly deterministic? Will adult learners expect unmediated access to internal analysis of their performance and what affect will this have on learning outcomes? Will funders such as employers track progress? Could comparable learning analytics visualised for ready consumption become part of job applications? What happens to learner data once their relationship with the provider has ended? There will need to be metadata standards for data to be portable between inter-operable systems but for some providers with closed systems it may not be in their interests to comply. The extent to which the data generated by 'Bring Your Own Device' initiatives can be integrated into the Learning Management Systems of providers is uncertain. Learning analytics are inextricably linked with online academic learning and for the VET sector off-the-shelf analytics are unlikely to be sufficient. For the learning technologies such as modelling and simulation that have particular applicability to practice-based learning outcomes, special analytics may be necessary. It will take time and the resolution of many difficult issues to build up adequate longitudinal datasets but the tantalisingly end-game is improved selection of the teaching and learning strategies that lead to successful learning and labour market outcomes.

Innovation value: High	Innovation cost: Medium
Time to maturity: High	Learning system: Selection
Learner-centred principles: Learning from assessment	

Next Generation Learning Management Systems

Teachers and learners are beginning to experience multiple de facto Learning Management Systems. As well as the LMSs of further education providers (or alternatively their Virtual Learning Environments), they also have to navigate the systems of existing teaching and learning technologies such as smartphones, tablets, MOOCs, licensed software, cloud-based services, apps, and social media.

Next Generation LMSs are expected to integrate the management of technologies into a coherent system of systems that produces a seamless adaptive system for teaching and learning strategies. The roadmap to such systems is not merely technological although the hurdles of standards, inter-operability, privacy, and open data are considerable. It is also social, economic and political. It may even be complex. For instance, the adult learning technology market is still maturing and its glut of new start-ups suggests that it will be increasingly lucrative. Blackboard, a major provider of software-based LMSs, recently surprised many by buying Moodlerooms, a cloud-based LMS that was developed by its main competitor. Providers face a difficult decision given that the right system may be wrong if path-dependency takes hold (VHS vs Betamax, Bluray vs HD-DVD, etc), or if either scale economies, emergent learner behaviour, and ‘superstar economics’ reduce the scope for choice.

Innovation value: High	Innovation cost: High
Time to maturity: Medium	Learning system: Selection
Learner-centred principles: Learning from assessment	

Case study: Which LMS?

Education providers who have to implement an LMS already face a difficult decision. Do they implement a cloud-based service or host it on their own network? Cloud-based services reduce the need for internal expertise but leave teachers and learners dependent on support from external providers. They increasingly have the advantage of scale economies to reduce costs, however. Do they implement a proprietary or an open-source LMS? An open-source LMS like Moodle with no licensing fees can be hosted on internal servers for relatively very little cost. But this might be risky if internal expertise is stretched. On the other hand, open-source LMSs can enable more innovation because they usually energise an ecosystem of developers pushing the possibilities of the system. Proprietary LMSs may be closed to external innovators. A further consideration is access to the data generated by the system and the ability to apply customised analytics to drive adaption. The decision is ultimately contingent on the size and resources of the education provider, its desire for customisation, and the internal expertise it can rely on to implement, support and develop the system. With sufficient internal expertise, and with teachers and practice-based learners willing to engage, small-scale VET sector providers can be cost-effective LMS innovators. Nevertheless, navigating the roadmap to the Next Generation will be challenging.

Source: (Curran, 2011).

5. Digital infrastructure

Information and communication technology

Much of the learning technology of the future is underpinned by information and communication technology. The semiconductor industry is projecting extraordinary innovation in both processing (MPU) and data storage (DRAM) well into the next decade (see Table 5.1)

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
DRAM	0.12	0.08	0.06	0.04	0.030	0.021	0.015	0.011	0.007	0.005	0.004
MPU	1.66	1.18	0.83	0.59	0.416	0.294	0.208	0.147	0.104	0.074	0.052

Table 5.1, Projected computing costs at production (DRAM cost/bit at packaged microcents, Cost-performance MPU microcents/transistor). Source: (International Technology Roadmap for Semiconductors, 2012).

Rivalling the massive parallelism in the human brain has been the long game of computing but it is still some way from the sophistication of its energy-efficient complex neuron network architecture. Biological and quantum computing have the theoretical capability to vastly improve processing power but the technologies are far from maturity. In any case, cloud-computing services now increasingly provide cost-effective access to frontier super-computing capability.

Storage and processing gains notwithstanding, computation also depends on algorithms. An algorithm is a 'well-defined' sequence of instructions that autonomously solves a problem. Many important problems though are computationally intractable, which means that human creativity is more important than increased processing power in finding a solution. Algorithms are also a sequential technology in the sense that they are inter-linked and solving one can help towards the solution of another. This means that innovation in algorithms could occur suddenly and quickly. In recent years algorithmic innovation has been outpacing that of data storage and processing (Hromkovič, 2009). In many sectors of the economy algorithms and robotics are substituting capital for human labour.

The cost of communication technology tends to fall faster than that of processing but there are many other factors that determine the development of network infrastructure (Stewart, 2008). Almost 100% of premises in UK now have access to current generation fixed-line broadband and the take-up is around 71% (Ofcom, 2012). For the next generation of super-fast broadband the coverage is around 65% and take-up is around 7%. On the take-up of super-fast broadband, the UK is currently a mid-table performer among its European comparators; Asia (Japan, South Korea, Hong Kong), an early adopter of infrastructure, has the highest take-up; whereas the US has a relatively low current take-up partly as a consequence of its fragmented television market (Broadband Stakeholder Group, 2012). The UK's average fixed-line broadband speeds have risen partly as a result of super-fast broadband take-up to 12.7Mbit/s, an increase of 69% since 2011 (Ofcom, 2012). Some UK commentators are agitating for the funds being allocated to the HS2 rail network to be diverted to improving super-fast broadband coverage (Arthur, 2013). In August 2013 the UK Government auctioned off the 4G mobile broadband spectra to EE, O2, Vodafone and 3, and, Niche Spectrum Ventures, a subsidiary of BT. The time to maturity of the next generation of mobile networks has been estimated at another decade.

As learning technology becomes increasingly multi-sensory, improvements in ICT over the next 10 years, particularly through high resolution visual processing and the transmission of data, are likely to enable mobile learning. VET sector providers, teacher and learners, with access to cost-effective innovation will be at an advantage, all else being equal, to those without.

There is currently a stimulating debate among economists on the future impact of ICT. Brian Arthur, an economist who works in Silicon Valley sees computation as the foundation of a new automated economy. He argues that this 'second economy' by wiring muscular physical capital with a neural layer of algorithms and networked communication could plausibly overtake the physical economy in two to three decades (Arthur, 2010). Other economists including Robert Gordon and Tyler Cowen believe that the major innovations of computation may have already occurred (The Economist, 2013). The Turing model of computing developed in the 1930s still endures even if quantum computing and massive parallelism could significantly enhance it. In 1931 the immensely talented logician Kurt Gödel proved that it is not possible to fully formalise human mathematical intuition with algorithms suggesting theoretical if not practical limitations to their innovation (Nagel & Newman, 2004). This difficulty in modelling the complex neuron networks of the human brain may be partly why the vision of semantic web where information can be retrieved intelligently and serendipitously has yet to be realised and has been superseded by more modest goals towards linked data.

Future innovation in ICT is very important to the VET sector because it will not only enable much of the learning technology and analytics-based management systems expected on a 10-year horizon. It is also likely to significantly shape future labour markets.

Innovation value: High	Innovation cost: Low
Time to maturity: Low	Learning system: Indirect, enabling
Learner-centred principles: Indirect, enabling	

Cloud computing

Cloud computing offers access to externally-hosted processing power and storage through telecommunications networks for popular devices such as computers, laptops, smartphone and tablets. Cloud-based services currently come in three flavours – Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). For example, an externally-hosted proprietary LMS would be SaaS, and the iTunes University, which is an app store for multi-media educational content, is PaaS. If a provider decided to develop an externally-hosted LMS based on open-source code or chose to create their own fully customisable app store that would be IaaS. Cloud computing is the most important ongoing innovation in ICT because it offers a highly 'elastic' supply of computing – including high performance capability – and at relatively low costs through its internal economies of scale. More than this, cloud computing is a reflection of a huge increase in human mobility and inter-connectivity. It is cloud-based services and telecommunications networks that have enabled trends in MOOCs, social media, BYOD and mobile learning.

The scale economies of cloud-based services are likely to improve access to higher-quality modelling and simulation, and telepresence. For information, advice and guidance, the cloud can drive down the costs and increase the benefits of big data.

For VET sector providers there are also dilemmas in their adoption of cloud-based services that go beyond economic cost-benefit analyses. The design of cloud computing infrastructure is still developing and outages are not unusual. Providers and learners are much more exposed to the quality and reliability of their internet connectivity. For some low-income learners the digital divide could become a chasm. There is the risk that providers become locked into proprietary services particularly if the migration of data is difficult. Several cloud-based service providers have signed up to the principles of the 'Open Cloud Manifesto' but as in banking enabling switching may not be in their interests[14]. SaaS and PaaS reduce costs but they could also lock teachers and learners into less innovative pathways if services are generic, proprietary, and are, therefore, received passively. Community clouds are an interesting way to ameliorate this risk. G-Cloud, the UK Government community cloud for the public sector, provides IaaS[15]. Data stored in different countries are subject to the different regulatory regimes but there are service-level agreements that can stipulate its geographical location. Service-level agreements will also have to address issues around the use, reuse and retention of data.

Innovation value: High	Innovation cost: Medium
Time to maturity: Low	Learning system: Indirect, enabling
Learner-centred principles: Indirect, enabling	

[14] http://www.opencloudmanifesto.org/.
[15] http://gcloud.civilservice.gov.uk/.

6. Disruptive innovation

Clayton Christensen, a professor of business administration at Harvard Business School, wrote a book in 1997 called 'The Innovator's Dilemma' that shook up the world of strategic thinking. Christensen analysed 'creative destruction' empirically over a number of years and found that many large resourceful organisations were caught out by disruptive technologies because they were designed to sustain their past innovations:

"As long as the organization continues to face the same sorts of problems that its processes and values were designed to address, managing the organization can be straightforward. But because those factors also define what an organization cannot do, they constitute disabilities when the problems facing the company change fundamentally." (Christensen & Overdorf, 2000)

Disruptors usually make expensive or complicated products or services cheaper and simpler, expand the market, and then migrate up the value chain. Christensen sees this playing out with MOOCs in HE. But incumbents in HE and FE are not entirely defenceless against disruption (Christensen & Eyring, 2011). FE colleges have advantageous access to the practice-based knowledge, skilled pedagogy, learning systems, and digital infrastructure that will be necessary to make MOOCs a cost-effective technology. And although MOOCs can produce considerable internal scale economies, technology is much less likely to enable the external or agglomeration scale economies that are crucial to learning outcomes and to innovation. FE college campuses have this advantage, in being able to provide blended multi-sensory learning and spaces for teachers and learners to interact. Social media knowledge markets and telepresence have important future roles in capturing external scale economies but they are unlikely to replace the richness of reality.

The greatest disruption to the VET sector may well be structural. Andrew Kelly and Frederick Hess, two experts in education policy and enterprise, see beyond the rise of MOOCs to more profound disruption in adult learning. They call for a reform agenda based on four principles (Kelly & Hess, 2013):

1. Focus on learning outcomes rather than the act of delivery
2. Openness to new providers
3. Unbundling of products and services
4. Portability

FE is arguably accomodating the first two principles at present. But further structural reform would force FE colleges to develop the competitive advantage that differentiates them from other providers. These include high-quality pedagogy, networks of practice-based knowledge, and the external scale economies of campuses. Clinging to the caché of accreditation may no longer be sustainable. Sector-based and employer academies may be precursors to employers with attractive branding and valuable intellectual property entering a restructured VET market with "a direct line to work".

Yet, the key to adapting to disruptive innovation may be relatively simple in theory, if admittedly complicated in practice. For Christensen, with decades of experience, the answer is not technology. It is to put people ahead of strategy:

"That may sound un-business like, but… the most successful businesses make sure that they have the right people on the 'bus' before they decide where the company is going. These must be people who are both capable and committed to 'A-plus effort'" (Christensen & Eyring, 2011)

7. Implications for policy

The rationale for public investment in education is based on market failures in funding and information, and on externalities. Adult learners may not be able to gain access to funding even if their investment is an efficient allocation of resources. It remains challenging to assess which VET courses will lead to improved labour market outcomes (Wolf, 2011). Employers may be reluctant to train their employees because they may not recoup their full investment. VET also offers positive externalities to society that may not be adequately valued by markets.

Micro-funding such as peer-to-peer lending is beginning to disrupt the banking industry (The Economist, 2012). As the range and flexibility of accreditation develops and data on learning outcomes becomes more closely linked to actual labour market outcomes, micro-funding may improve the allocation of resources and replace some public investment with private investment. If the adult learning market restructures along the lines of the principles outlined in §7, there may be an increase in for-profit and social enterprises.

There are likely to be information failures in the selection of teaching and learning strategies as new technology is adopted. There is arguably a role for some public investment in network-building and digital infrastructure for well-functioning knowledge markets. There could also be market, information and co-ordination failures among potential consortia for the technology that has internal scale economies like MOOCs and community clouds. Policy also has a role in supporting the development of sector standards that improve the portability of data between systems.

For governance, more generally, it is obvious that learning technologies are not discrete modules in a simple system. They are inter-connected entities with in some cases non-linear relationships that need to be expertly aligned to learning and labour market outcomes. Learning technology strategies should not be distinct from overall VET provider strategies. Technology could just as easily diminish learner outcomes and teacher's professional development if chosen off-the-shelf or implemented ineptly. Policy on accreditation, which in many ways hard-wires together the relationships in the technologically-enabled VET learning system, needs to adapt to signals from the labour market.

There is a trend in VET policy away from micro-management (Wolf, 2011). Getting the balance right between variation and selection, or experimentation and exploitation, in order to improve adaptive capacity is the challenge for VET sector providers and policymakers. Will there be sufficient development of digital pedagogy? Will cost-effective investments in proprietary technology lock teachers and learners into less innovative pathways?

Issues surrounding privacy are likely to require more care as longitudinal data accumulates - service-level agreements with cloud-based services ought to address this but more innovative VET providers using IaaS will need to invest in expertise. On the other hand, if learning and labour market outcomes can be improved in the future with big data and analytics then policymakers should support open data, suitably anonymised, as a positive externality.

The implications for human identity in education of big data, algorithms and analytics require more critical consideration. Some researchers who examine decision-making have grave doubts about the capability of computation to match the mix of intuition and analysis used by experts in the field (Klein, 1999). The brain represents an exemplar of "the messiness of the real". Despite the achievements of neuroscience, we are far from simulating its complexity with massively-parallel super-computing; and most neuroscience experts do not expect a significant paradigm shift in the next 10 years. Teachers, learners, and possibly the labour market, may neither appreciate nor even equate learning outcomes with opaque algorithms and learning analytics. Without due diligence to the development of socio-technical systems, we may race antagonistically against the machine rather than productively with it.

Lastly, if having the right people on the bus is more important than technology when adapting successfully to disruptive change, what are the frictions in the labour markets that select who travels in the future on the VET sector bus? Without change the "the global race for wealth and jobs" may be run before it has even departed.

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