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NESTA Making Innovation Flourish

Innovation Technology

How new technologies are changing the way we innovate

By David Gann and Mark Dodgson

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How new technologies are changing the way we innovate

A new set of technologies is emerging that enables firms to innovate more rapidly, efficiently and accurately than ever before. This 'Innovation Technology' (IvT) includes eScience, virtual reality, simulation and modelling techniques, and rapid prototyping. Indeed, it is possible that it will have as profound an impact on economic growth and social well-being in today's knowledge economy as the development of machine tools had on the industrial economy of the mid-19th century.[1]

Over the next decade, understanding what IvT does, how to use it and where its limitations lie will prove critical for those running businesses, working in firms and providing public services. As a result, government policy-makers at all levels would do well to appreciate its implications.

Innovation entails the integration of scientific, engineering and market opportunities. The high rates of failure in innovation show this is a notoriously difficult thing to do successfully.[2] Failure is often caused by poor understanding of the risks of innovation, barriers and communications problems within and between organisations, and patchy information about markets and technologies.

IvT offers the potential to break down these barriers, making things that were previously costly and difficult to risk-assess more straightforward, and providing better and more comprehensible information from researchers, customers and other stakeholders. It enables organisations to develop new products and services more swiftly and efficiently than in the past, allowing people to create more adventurous innovations.

So, for example:

- 'eScience' is being used by Rolls-Royce to draw more effectively than ever before on the wide-ranging expertise in a number of university research centres to improve the performance and safety of its engines.

- Virtual reality is being used in the fashion and clothing industry to help improve our choices as consumers. Some stores are creating avatars with our body shapes to examine virtually what we would look like in particular clothes, so that we can quickly (and honestly) assess the results of our selections. Our clothes can then be manufactured using thousands of data points from our body shapes (rather than the traditional two or three) to ensure a perfect fit.

- Simulation and modelling allows rapid and accurate predictions on the effect of various congestion charge prices on traffic flow, extending the imagination of policy-makers and making it more likely that they will make better decisions based on better information.

- Rapid prototyping is allowing architects to engage clients, engineers and public authorities more deeply than in the past with their designs, by greater iteration around virtual and rapidly fabricated models, allowing them to produce innovative buildings that both deliver on their required function and delight with their form.

- Companies like *eon reality*,[3] based in Irvine, California, are at the forefront of developing 'mixed-reality' simulation studios that combine real and virtual objects to create virtual prototypes in 'immersive' studios with a high degree of detail. These enable firms and their customers to experience products and services before they are produced in reality. These studios combine the best technologies from the computer games world with advanced engineering and design tools, including the use of holographic imaging and touch-sensitive virtual models. Firms such as GE and Boeing are already making heavy use of these immersive studios to explore design options, allowing them to cut costs and time taken in traditional prototyping activities. Boeing recently used a fully immersive mixed-reality studio to design its 787 Dreamliner.

The emergence of IvT is not occurring against a static backdrop. It is happening in the context of (and is contributing to) fundamental changes in the innovation process itself; changes that mean that innovation can no longer be left to the 'skunk works' or a specialised R&D team.

Instead, for the world's best companies, innovation has become a core business process with ramifications for investment decisions, patterns of collaboration with customers, suppliers and other stakeholders, and choices about technology and markets, such that it is now a main Company Board strategy matter. Any firm, organisation or government keen on promoting innovation would do well to appreciate its significance.

Changes in business conditions are demanding constant innovation

After the longest period of uninterrupted economic prosperity in modern times, the drivers that gave rise to past growth may be changing, causing uncertainty and creating new pressures and opportunities to innovate.

The globalisation of production and opening-up of markets (seen most obviously in India and China), and the increase in out-sourcing and off-shoring from the West, means increased competition and the opportunity to 'globalise innovation'.

This change is not simply restricted to manufacturing; the UK's services industries are experiencing unprecedented growth as a proportion of the economy and in the extent to which, following government deregulation, they are tradeable internationally. The recent and intensifying focus on sustainability, climate change and its environmental consequences, and the carbon economy is simultaneously producing new opportunities and threats.

Changes in management and ownership of financial capital are creating additional uncertainties. Entrepreneurial capital, in the form of venture funds and private equity, appears, in many areas, to be usurping stock market capital, intensifying the requirements of return on assets.

And in many sectors, firms are offering integrated systems of bundled products and services to meet customer needs, adding significantly to their complexity. It is now normal, for example, for mobile phones to incorporate telephony, internet access, musical devices, camera and video, global positioning systems, and payment systems.

In this environment, the ability to develop and use an advanced innovation process has become a major source of sustainable competitive advantage.

The innovation process is changing

Innovation is the successful commercial exploitation or public implementation of new ideas. The innovation process in the private sector involves organising the resources a firm possesses – its people, capital, technology, and connections to other assets – to merge science, engineering and market opportunities.

The success of innovation outcomes and processes depends critically on the guidance of effective innovation strategies, especially around how value is to be created and reaped. Invention and creativity are important elements of innovation, but are only ingredients in a larger set of activities that need to be strategically co-ordinated if it is to be successful. The full innovation process involves co-ordinating activities such as design, research, engineering and development, operations management, commercialisation, marketing and customer relationships, and the management of intellectual property.

Over the last 50 years, our understanding of innovation processes has evolved from two simple linear models to more complex, systemic and iterative approaches (see box below).[4]

Five generations of innovation process

During the 1950s and 1960s, the *research-push* or first generation model was prevalent. This approach assumes that innovation is a linear process, beginning with scientific discovery, passing through invention, engineering, and manufacturing activities, and ending with the marketing of a new product or process. The management challenge was simply to increase effectively investments in R&D.

From the early- to mid-1960s a second linear model of innovation was adopted by public policy-makers and industrial managers: the *demand-pull* or second generation approach. In this model, innovations derive from a perceived demand, which influences the direction and rate of technology development. The management challenge was simply to invest effectively in marketing and plan efficiently around identified customer demand.

Both linear models of innovation were oversimplified representations of what actually happens in innovation processes. Rothwell, for example, showed that at an industry-wide level the importance of *research-push* and *demand-pull* may vary during different phases in the innovation process, and across industry and market sectors.[5] So, for example, the development of the computer industry relied initially on basic knowledge of particle physics for its semiconductors and subsequently on mass manufacturing and distribution expertise.By the 1970s, the *coupling* or third generation model became evident. This involved integrating both *research-push* and *demand-pull* approaches and was centred on an interactive process with its emphasis on the feedback effects between the market and research phases of the earlier linear models. The management challenge of this process involves significant investments in cross-organisational communications and integration.

The high level of integration between various elements of the firm in innovation is further elaborated in the fourth generation, *collaborative*, approach which highlights the complex iterations, feedback loops, and inter-relationships between marketing, R&D, operations, distribution, and which also brings to the fore the externally orientated aspects of the innovation process. This model emerged in the 1980s and reflected growing understanding about the way innovation involved more than just a broad-based input from research and the market, and included close relationships with key customers, suppliers and partners. There was increased appreciation of the internal organisational practices that encouraged innovation, especially the move away from sequential departmental involvement towards a more fluid, inclusive and process-based approach. The importance of technology in assisting the innovation process, by having common Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) platforms for example, was identified. Based on experiences with government policies and programmes encouraging collaborative R&D, such as Sematech in the USA, ESPRIT in Europe and the Alvey Programme in the UK, the process recognises the role that can be played by alliances with other firms and competitors. The management challenges become significantly more widespread beyond R&D and marketing and become more strategic in nature, because the process involves many internal functions and decisions about external relationships and sources of knowledge.

The fifth generation innovation process, which appeared in the 1990s, more fully encompasses the high levels of *strategic and technological integration* found between different functions and organisations inside and outside the firm. It captures the way these are being enhanced by the 'digitalisation' of the innovation process through the use of IvT and new organisational techniques, such as concurrent rather than sequential development. The fifth generation moves away from the 'silos' of functional divisions – such as R&D, marketing and operations – towards organisation according with business processes. Research, development, design and engineering take place in concurrent iterations, supported by IvT in a highly fluid model. The value-creating activities of the firm are intimately linked with its suppliers and customers and the networks and communities to which the firm belongs. Lead-users and first tier suppliers are brought into the centre of the process. All the technological activities in the firm are directed by increasingly coherent and effective innovation strategies.

The current, fifth generation, innovation process is a response to the continuing high levels of risk and uncertainty in innovation. Within the firm there is increasing focus on using the best organisational forms and practices, skill balances and technologies to enable maximum flexibility and responsiveness to deal with unpredictable and turbulent markets.

Over the last few years, it has become evident that the speed of change and development of the IvTs supporting innovation are themselves increasing. This further enables innovation to become a core business process and part of the service offer between firms and their customers in many industries.

These improved IvTs may indeed herald a new *sixth generation* innovation process; one driven by enhanced opportunities to utilise creativity and ideas distributed amongst many diverse actors inside and outside of the firm, and to optimise through simulation and modelling not only the creation and diffusion of new products and services, and the processes by which they are produced and delivered, but also the most effective strategies for delivering value.

What exactly is Innovation Technology?

The concept of a suite of technologies supporting the information and knowledge flows needed to manage, co-ordinate and deliver innovation was first described in the early 1990s.[6]

Research into the development of automation systems in the manufacturing industry during the 1980s revealed how Information Technology (IT) was being harnessed to link design with production. Systems such as Computer-Aided Design (CAD) enabled digital information about a particular product to be used to produce a schedule of parts and processes which could be transferred to systems that control processes of production – Computer-Aided Manufacturing (CAM).

As these approaches became more widespread, and problems in using them were ironed out, new technologies for Computer-Integrated Manufacturing (CIM) emerged. The benefit of these systems lay in capturing information about product design and production processes that could feed forward into next generation product and process development. This use of IT to inform new digital blueprints was recognised as having profound consequences for how innovation takes place.

Our research into these practices since the late 1990s led us to conclude that a new suite of digital tools were being combined together to provide a powerful infrastructure enabling firms to develop products and services more quickly, reliably and cheaply – *intensifying* the innovation process. We concluded that these technologies had a more profound effect on the innovation process than traditional business IT systems and we called these technologies and infrastructure 'Innovation Technology'.[7]

IvT comprises three main types of technology platform:

- *eScience*, or Grid technologies, which have their basis in high-volume data transmission, scientific computing and the internet. These include software that allows shared diagnosis and analysis of data by teams working in different locations and in different parts of the research and development process. They involve 'middleware' that allows visualisation of merged data sets to improve the shared understanding and operation of virtual research organisations.

- *Modelling, simulation and visualisation technologies,* which evolved from CAD systems and benefited significantly from developments in the computer games industry. Simulation enables design and development teams to explore options and test combinations of ideas in a virtual environment. This reduces the cost and time involved in combining different components and elements in comparison to traditional design and development processes. It also enables more stakeholders, including customers and regulators, to engage in earlier stages of product and service innovation.

- *Virtual and rapid prototyping systems,* some of which have emerged from CAM, enabling firms to explore options about how to produce products and services quickly and cost-effectively, assessing their commercial viability.

We observed that firms using these systems were able to integrate innovation activities in new ways, working concurrently to reduce lead-times in getting new products to market and engaging more deeply with potential users to ensure that they create products and services that meet market expectations.

Although the full integration of these various technologies has not yet been achieved, they are already creating a new era of faster, better and cheaper innovation processes. They are creating important new business streams for companies that use it well, like Arup and Ricardo Engineering in the UK, by allowing them to work more closely and effectively with customers and researchers. They are increasing the speed of innovation; the 'automation' of drug discovery at GlaxoSmithKline (GSK) is estimated to reduce the time it takes to get a new drug to market by up to two years, and its use in car design is argued to reduce the time it takes from four to three years.[8]

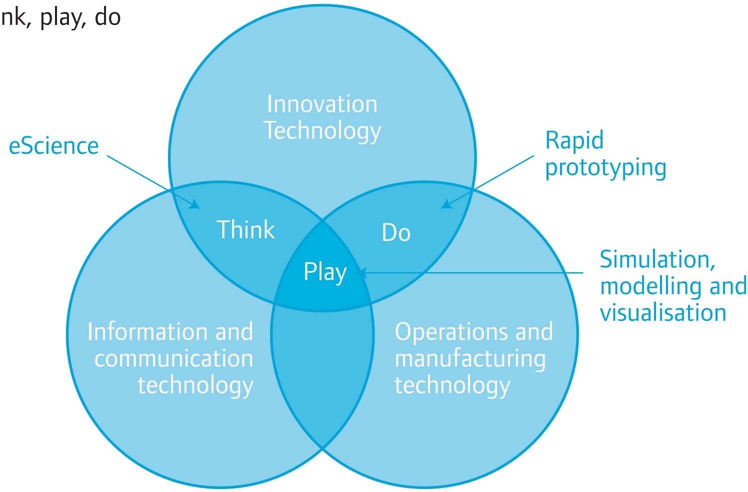
This new innovation process looks very different from one associated with more traditional research and development, design and engineering activities. It involves a greater degree of experimentation, searching for and generating a wider range of new ideas that might contribute to creating market opportunities.[9]

But firms that generate lots of ideas also run the risk of creating uncertainty about which idea to invest in and the consequences for deploying their particular resources and capabilities. They need a mechanism to identify the ideas with highest potential without killing off the stream of new ideas that could be of value in the future.

Making choices about which options to progress involves playing with and shaping ideas in virtual environments – what Schrage calls 'serious play'.[10] And once an idea has been selected and honed it can be refined for implementation using virtual and rapid prototyping systems. We called this new IvT-enabled process 'Think, Play, Do'.

Figure 1 shows the main IvT components and processes in relation to more traditional operations and manufacturing technologies (OMT) and information and communications technologies (ICT) which support everyday business processes.

Figure 1: Think, play, do



Source: Dodgson, Gann and Salter (2005).[11]

A good example of the way eScience supports the search and experimentation process can be seen in the pharmaceutical sector where firms like GSK deploy powerful computing systems to analyse patterns in cell chemistry in the search for new 'leads' which are then taken to the next stage of testing and development. In the aerospace sector, firms like Rolls-Royce use Grid technologies to connect research teams in different locations, including in their University Technology Centres. For example, a project called DAME (Distributed Aircraft Maintenance Environment) uses high-bandwidth computer networks to connect engineers developing real-time monitoring of jet engines. Research conducted at Rolls-Royce's collaborative University Technology Centres is accessed in this way, enabling wider and deeper perspectives and knowledge to be drawn upon. Another project – the AtlanTICC Alliance – uses spare capacity on transatlantic fibre optic cables to connect scientists conducting experiments at Imperial College London with those in Georgia Tech and Oakridge National Laboratories.

An important feature of IvT is the way it enables more open, distributed approaches to innovation.[12] Open innovation recognises the significant business opportunities of learning from and engaging with external sources of ideas, and the internet has provided opportunities for firms to search more widely and in places they had not envisaged before. This is being facilitated by web-portals designed to link 'solution-seekers' with 'problem-solvers' in what have become on-line innovation dating agencies, brokering services and trading sites, like an 'eBay' for technology: examples include www.yet2.com and www.innocentive.com. Procter & Gamble was among the first firms to organise their innovation processes to exploit this form of IvT.[13]

Simulation tools are commonly used in a wide range of industries from automobiles to aerospace. One feature of most approaches to simulation is the ability to visualise results in a graphical way, enabling expert users to recognise patterns quickly and accurately. This form of IvT for the first time also enables non-expert user groups to understand the results of what are often highly complex mathematical equations. Visualisation provides new ways of communicating options and choices across diverse communities and is usually far better than text-based reporting for engaging with decision-makers. As Irving Wladawsky-Berger, IBM's former head of technology strategy, says: "visualisation is the broadband into the brain".

An example of the use of simulation tools to support a new level of innovation can be seen in the way in which the engineering company, Arup, has developed a novel approach to designing buildings that are safe in the event of fire.

Arup Fire, the division responsible for fire engineering, grew rapidly in size following the events of 9/11 when demand increased for engineers to verify that new building designs and existing buildings would be safe in the event of a serious fire or disaster. This work is supported by a suite of simulation tools, including advances in well-established techniques such as Finite Element Analysis (FEA) to check the integrity of a building's structure in the event of fire, and Computational Fluid Dynamics (CFD) to model the flow of smoke within a building and how to control it; along with new simulation and visualisation techniques to analyse the evacuation of people from buildings.

These techniques enable engineers to work with architects, clients, regulators, fire authorities, and representatives from insurance companies, to assess whether a building is likely to perform safely. Simulations using virtual reality models are carried out at the design stage and in some cases have resulted in innovations that have improved safety and reduced costs by changing the ways in which a building's structure and layout are designed. One such innovation is the design of buildings that enable safe evacuation using lifts rather than traditional stairs as fire escapes, leading in future to the advice that 'in case of fire, please use the elevator'.[14] In this way, the use of IvT has enabled previously unimagined innovations to be not only successfully designed but successfully introduced.

Simulations are being used extensively in sport, where reliable and fast judgements about competitor behaviour are extremely valuable. McLaren Racing analyses the performance of its cars and its competitors during actual races, feeding information back to the race team to enhance performance. The Australian cricket team is developing real-time simulation of competitors' bowling actions during Test Matches, enabling immediate practice of batting adjustments to be made in the pavilion.

The UK inventor Paul Hawkins' Hawk-Eye ball tracking system has been developed with IBM to support refereeing decisions at Wimbledon 2007, and to provide a mixed reality experience for ardent tennis fans who can play against their favourite 'pro' in a simulated environment using actual ball vectors. This mix of real data with virtual design is stimulating the growth of powerful simulation tools such as those developed by *eon reality* (described on p.5). It is highly likely that IvT used to conduct such detailed and real-time analysis of competitors will find applications in the business world.

The third area of IvT includes prototyping, which in manufacturing industries has traditionally involved building physical models and mock-ups. Virtual prototyping systems linked to rapid prototyping devices are having a major impact on the speed and accuracy with which new products and services can be tested for production and commercial viability. The development of low-cost rapid prototyping systems enables data from computer-generated virtual systems to be used to create physical models swiftly.

Procter & Gamble (P&G), for example, uses virtual and rapid prototyping to test whether new packaging containers can be opened by disabled or elderly people, and how appealing they are likely to be in the particular market sector they address prior to scaling up to mass manufacture. In the case of its development of a new package for a men's fragrance, it tested the appeal of various bottle shapes with groups of women (the major purchasers of men's fragrances), who had accurate representations of the options available to them without P&G having to go to the expense of producing glass prototypes. In some engineering industries there are attempts to use rapid prototyping machines to produce 3D prints of parts from materials that can be used in the final artefact, which might lead to a new form of bespoke 'manufacture'. There are many rapid developments in these technologies, some of which hold the prospect of allowing manufacturing to occur in the home (see www.fabathome.org).

The use of IvT is not limited to large engineering and science-based firms. Evidence shows that it is rapidly becoming ubiquitous. It is found, for example, in small architectural practices, such as Frank Gehry, who designed and constructed the Bilbao Guggenheim supported by the CATIA software system. Architects regularly use 'walk through' representations of buildings with clients, prior to their construction, allowing their customers to get a feel of the layout and ambience of their homes or offices before a brick is laid. Firms in financial services, entertainment and computer games are also using IvT widely. For example, HBOS uses data-mining techniques to analyse large volumes of customer data, identifying market segmentation for novel, highly targeted service offerings. Egg has deployed sophisticated simulation tools to model customer life-cycle profitability for novel pricing and loyalty approaches. Deutsche Bank makes extensive use of risk modelling to identify major risks and likely impact of alternative risk reduction strategies.

Innovation Technology itself is changing rapidly

The growth in commercial use of the internet has created a massive new set of opportunities for new technologies to support innovators.

In their early days, Web 1.0 technologies provided some useful capabilities in the search for data, but did not enable the social and business interactions which are all-important in the innovation process. New Web 2.0 technologies such as Second Life and social networking sites are being introduced which have provided a new set of opportunities for on-line communities of innovators.[15]

The use of a range of web-based systems – including blogging, wikis, on-line encyclopedias and podcasting – is creating an environment in which people develop their ideas in a more horizontal, collaborative way than before. Some of these tools are being developed following success in the market for multi-player games involving huge numbers of players. Other Web 2.0 technologies such as 'mash-up' software are being developed to enable innovators to capture, combine and analyse data from different sources on-line. They may provide new ways for firms to better relate to markets and understand highly engaged and active customers expecting to be involved in the development of the products and services they want.

In future, the possibilities envisaged for Web 3.0 technologies, including immersive systems that enable firms to share 'mixed-reality' (concurrent real and virtual) experiences of possible products and services, will improve the way choices can be honed through interaction with different user reference groups. These simulated and immersive systems will involve suppliers and partners modelling value maximisation amongst various options and the equitable distribution of their results.

The technologies underpinning IvT are evolving so rapidly that we might expect a new generation of innovation tools to be appearing within the next five years.

Consequences, limits and implications

The development of systems such as Web 2.0 and 3.0, and their merger into (or use as) IvT, are providing new opportunities for communities of innovators to evolve, creating flatter structures, subverting the role of 'experts' through discussions in on-line communities using wikis, MySpace, Facebook and other collaborative spaces.[16] We can anticipate that this will maintain the momentum of changes that are breaking down barriers between organisations, disciplines, professionals and the public/private realm, thereby creating an entirely new environment for innovation.

The types of models and prototypes we have observed are, in some cases, enabling a new form of collective experimentation and enquiry about different ideas, visions and stories. Customers and end-users can actively engage in the design of new products and services, shaping outcomes. Propellerhead, a Swedish music software company, for example, has thousands of users and customers contributing to the development of its products.[17] More people can potentially be involved in informing decision-making processes, in what Eric von Hippel describes as a more 'democratic' innovation process.[18]

Although IvT provides the potential for delivering more and better innovation, producing returns that can be reinvested in even more innovation – a virtuous cycle enabled by technology – there are very significant challenges to its effective use.

An appreciation of the importance of analytical skills and judgement based on craft knowledge and experience remains critical. Existing knowledge and skills amongst IvT users are essential to success. The ill-informed use of IvT can produce inaccurate results and lead to catastrophic failure in new projects.[19] The value of modelling, for example, depends upon the user understanding the reliability of data put in, the assumptions and simplifications involved in the model, and the results coming out.

Important challenges remain. Simulations rely on data in which small errors or misjudgements can be magnified, leading to both lay people and experts making big mistakes. Professor John Burland, the soil mechanics expert who used modelling techniques to prevent the collapse of the Leaning Tower of Pisa, has expressed his concern in this regard. He says: "Validation is extremely important. It's all very well to have your all-singing-all-dancing model. But how reliable is it? Do you have to calibrate it? A huge amount of my work involves being sceptical about the particular programmes we are using. We test the model against known cases. We test it against physics." The engine design company, Ricardo Engineering, takes great care to ensure its modelling tools are used by properly educated engineers because of examples where inappropriately educated users had produced results inaccurate to orders of magnitude.[20] Experts, on the other hand, might be encouraged by overconfidence in the technology to take risky short-cuts.

There may be problems with the interpretation and validation of results – slick use of virtual reality visualisations can present results in a convincing manner, masking problems in the ways in which models are built and potential errors in data underpinning them, resulting in misunderstanding and misinterpretation. The value of use of these tools depends upon the quality of questions being addressed, and clear understanding of the assumptions and simplifications built into the models and results which they portray.

Furthermore, more concurrency of people working on multiple projects and increased speed of delivery of information and feedback lead to less time for reflection and thinking about problems before they arise.

All these continuing challenges highlight how innovation remains risky. Recognition of the limitations of the use of IvT by its users is essential for its successful application. It has to be recognised that technology is but a tool whose development and use is a result of human choices, reflecting personal differences, organisational preferences, and political realities. The value of these technologies, we believe, will lie in their use by organisations keen to realise and supplement the skills and creativity of their employees, enabling better communications across organisational and technological boundaries, and enhancing their commitment to and engagement with their work.

These technologies should not be used to de-skill, but to enable the expansion and integration of different skills so necessary for creating solutions to complex and complicated problems. As with previous vintages of technological change, the greatest benefit of IvT will lie with its effective integration with existing technologies in ICT and operations and manufacturing technologies (OMT) to gain most benefit. Engineers and designers using IvT will need to become less self-reliant within their own technological spheres, and better skilled at working across disciplines and with multiple parties.

Consequences for business strategy and leadership

The use of IvT and its associated work practices is still being enacted, and the new strategies used to take advantage of its possibilities are still being developed. We speculate, however, that several consequences might be seen.

Rather than innovation being an important component of business strategy, innovation will become the strategy itself. Strategy will be conducted in the context of open business models, with high levels of user-involvement. As individual firms become more dependent on external parties for the realisation of their innovation strategies, assisted by the use of IvT, the quality of their networks and choices they make about their collaborators and partners will become ever more important. Increasing numbers of designated Innovation Directors will be appointed at Board level to contribute to the development and implementation of innovation strategy.[21] They will have the job of ensuring the organisation's IvT infrastructure provides the basis for the firm's external exchanges around innovation. Design will become a key component of the strategy of the firm, not in the traditional sense, but in the way in which craft and judgement is allied to data in creating options and making choices about uncertain and complex technologies and markets. IvT will become a critical support tool for these design decisions. Managing intellectual property in such circumstances will be particularly challenging as its creation will be shared across organisations, but its ownership will convey substantial advantages as any protection it offers improves the confidence of its owners to collaborate.

The only source of sustainable competitive advantage will be innovation leadership: doing it better than others. Essentially, IvT will improve the efficiency of all innovators, so that the major difference between competitors will lie in the effectiveness of the innovation. That is, it will not be a matter of 'how good are we at producing new products and services?' but 'how good are we at choosing the right products and services that build our competitiveness and enhance our performance?' Leaders themselves will need to be creative, understand risk, tolerate experimentation and failure, and show good judgement to enable them to manage within systems in which there are no right answers. They will need to be fully aware of the advantages and shortcomings of IvT. They will need to be expert at new pattern recognition and picking up weak signals from the periphery of their experience that have the potential to be disruptive to their businesses.

Senior managers will need to construct and manage teams in new and collaborative ways. All innovative activities will be collaborative, interactive and deeply and widely connected through using IvT. The old 'not-invented-here' ethos will be totally jettisoned and the search for external ideas – on-line, and occasionally from self-organising communities – will be a priority. The physical location of members of teams will become less important, although initial face-to-face, 'getting to know you', trust building, exercises will remain essential. Members of teams will be expected to self-organise in ways that pose challenges for conventional hierarchical authority structures. The networking and brokerage skills of members will be at a premium, with particular emphasis on the quality and validity of externally sourced knowledge – from research scientists to front office staff, from government regulators to local community interest groups, from large multinationals to small entrepreneurial start-ups. IvT may produce enormous amounts of data, but it still requires good judgements about its relevance and reliability.

What should public institutions and governments do?

Governments and public institutions need to be ahead of the game in understanding changes in the innovation process and to be fully aware of IvT and its potential.

Most directly, IvT can enhance the efficiency and productivity of public services and extend the range of those services and the way governments and public institutions engage with the public.

Well-implemented IvT systems can improve policy decision-making through their capacity to simulate options and present them visually in a way that is understood by lay people. The decision to introduce the London Congestion Charge, for example, was made after some very complicated mathematical calculations were represented to decision-makers using a simple heat map. Similar visual representation of infrastructural investments and their environmental consequences during and after their construction could help improve the engagement of all interested parties.

To benefit, governments and institutions, like the NHS and utilities, need to develop the technical infrastructure to support innovation – investing in the backbone of IvT such as eScience. Regional Development Agencies and Research and Technology Organisations will have an important role to play in providing demonstration sites to reveal the possibilities that the technologies present.

Government can also help to create the organisational infrastructure and collaboration skills, such as brokerages and brokering, which will be needed to enable next generation innovation processes to succeed. It can fund new centres of excellence that bridge traditional disciplinary divides – such as Design-London, which combines design from the Royal College of Art with engineering and business management from Imperial College – and that therefore accelerate both the development and dissemination of these technologies.

Across the UK, the role of universities will have to change. They will need to become more entrepreneurial, in the classical sense of seeking more and deeper combinations of disparate knowledge and resources, some of which will be well outside their normal activities. Some of these new combinations will entail vastly improved connections between the public and private sectors, others will involve combinations of different directions of scientific enquiry unconnected to the needs of industry. European universities currently lag far behind the leading edge of innovative practice. Many will need to restructure their educational offerings considerably to provide the talent and skills necessary for new generation innovation. They will need to plan how to use the potential of IvT to enhance the educational and training experiences of a wide range of students, from medicine and engineering to design and arts.

Innovation technology offers the prospect of generating more ideas, selecting more efficiently from them and then developing them faster. Moreover, it increasingly offers the prospect of doing this not just for the UK's biggest businesses but for its smaller ones and for its public services – improving quality of life and maintaining our economic edge in an increasingly competitive world.

The measures outlined above to increase the speed and effectiveness of IvT adoption are not simple, nor do they offer quick wins. Indeed, it may not be obvious when they are succeeding. But the speed of the development of international competition based on innovation means that we have to quickly and cleverly use every tool available to its fullest advantage to improve innovation in the UK.

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David Gann

Professor David Gann is head of the Innovation and Entrepreneurship Group, Tanaka Business School, Imperial College London. He holds the Chair in Technology and Innovation Management – a joint appointment between the Tanaka Business School and the Department of Civil and Environmental Engineering. This post enables new research and teaching opportunities to be developed and exploited, linking issues in social sciences and business management with those in engineering, science, technology and medicine. David's personal research includes work recently published in *Think, Play, Do: Technology, Innovation, and Organization*, co-authored with Mark Dodgson and Ammon Salter, on the intensification of innovation, focusing on 'Innovation Technology' (IvT). A Chartered Civil Engineer, David consults with a number of leading companies, and is Group Innovation Executive at Laing O'Rourke and Chairman of the Think Play Do Group.

Mark Dodgson

Professor Mark Dodgson is Director of the Technology and Innovation Management Centre at the University of Queensland Business School, Visiting Professor at the Tanaka Business School, Imperial College London, and an International Fellow at the Advanced Institute of Management Research in the UK. He was previously Executive Director of the National Graduate School of Management at the Australian National University. Mark has lectured and researched widely throughout Europe, North America, Asia and Latin America, and has been an invited participant at international conferences in over 35 countries. He has been an advisor and consultant to many European Commission programmes and to numerous UK, US, European, Asian, and Australian government departments and agencies. He has produced ten books and over 90 academic articles and reports on innovation.

NESTA

1 Plough Place
London EC4A 1DE
research@nesta.org.uk

www.nesta.org.uk

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