Information, knowledge and technology

A.G.J. MacFarlane
Academic Advisory Board, University of the Highlands and Islands Project, UHI
Caledonia House, 63 Academy Street, Inverness, IV1 1BB, Scotland, U.K.

The role of technology

Technologies create possibilities whose evolution, when realized, is then driven by a combination of economic and social factors. The importance for education of information technology is that it enables the objectification of knowledge, thus making knowledge storable, transmittable over distance and interactively accessible. Two aspects of this technology, which will have a fundamental and continuing impact on higher education, are interactive computing and networking. In terms of the theory of knowledge (epistemology) the importance of interactive computing is that it creates the ability to construct knowledge-access systems and learning-support systems. These allow a learner highly interactive access to objective knowledge. A key factor in ensuring the success of such systems in education lies in the proper allocation of the respective roles played by a human teacher and the machine-based learning-support system. If an ever-available learning-support system combats the tyranny of time, then networking combats the tyranny of space. Networking enables remote and flexible access to learning support, and allows the formation of geographically distributed communities of learners and teachers.

A major social driver for the use of such technologies will be the growth of lifelong learning, both for the generation of skills to underpin economic growth, and for the removal of social inequalities by providing multiple entry points to a higher-education system. As lifelong learning becomes a reality, its economic impact on the higher-education system will be decisive. The standard 3–4 year span of higher education will be supplemented by a 30–40 year span of lifelong learning. It is in the area of lifelong learning that technology will have the greatest impact, and it is the emergence of this new sector of the education market that will radically alter the economic basis of higher education.

There is a fundamental problem facing all those involved in education that will not be resolved but which will be greatly exacerbated by technology. This is how to reconcile an individual's need to develop a self, which can live a fulfilling life as a responsible citizen among others, with the need to have an adaptable set of skills enabling action as an effective economic agent in a rapidly changing world. The tension between learning for life and learning for work poses a great challenge to everyone concerned with education and training. The distinction between them is not absolute, however. The ever-increasing impact of technology on work is

E-mail alistair_macfarlane/eo@fc.uhi.ac.uk

changing the nature of work and our involvement in it — the sort of coping, adaptive and reflective activities that have always been needed to get the best out of life are needed increasingly to deal with the uncertainties and complexities of work. We should use technology to emphasize what Wiener [1] called the human use of human beings. We must learn to use the machine's supremacy in information handling to allow us to organize our knowledge, and to deploy our wisdom, to improve the quality of our life by nurturing lifelong learning.

Information and knowledge

When we interact with our environment, there are two fundamentally different aspects to our experience of it. One aspect is the order that we experience in the world as sensed passively. This is of *patterns* in space and time formed by shapes, colours, smells, tactile sensations, tastes and sounds. The other aspect is the order that we experience when we engage actively with the world. This is of *mechanisms*, of relationships in a world described by cause and effect, of the order imposed by what David Hume called the "cement of the universe" [2]. Pattern and mechanism are dual aspects of the order that we experience in the world: mechanism generates pattern and pattern specifies mechanism.

Agents interact with the world and with each other. Since they inhabit the same physical world, they share a commonality of mechanisms that are grounded in the laws governing the behaviour of objects in the world. Interaction between an agent and an object involves an exchange of energy or matter, albeit possibly in only infinitesimal amounts. Hence it involves *correlated* changes in the state of both the agent and the object in the environment with which it is interacting. When the amount of energy exchanged is very small the change in the state of the object may be insignificant; it is the possibility of a correlated change in some state of the agent that is important. The feedback arrangement that is necessarily involved in any direct interaction, whereby action changes object, which changes perception, which leads to further action, and so on, sets up a tight correlation between some of an agent's states and those of the object with which it is interacting. Such a set of correlated states in some part of an agent can provide what we can call the agent's *representation* of an object. So, when an agent interacts with an object in its environment, a correlated pattern of states, instantiated as changes in matter or energy, can be generated within the agent. This in turn can be transformed into some form external to the agent, and thus communicated to other agents. Agents can communicate if and only if their interactions are coherent within their shared external environment: what one sends the other receives, what one encodes the other decodes. This *coherent* encoding and decoding requires a commonality of mechanisms grounded in the laws which govern the behaviour of objects in their shared world. If the communicating agents share appropriate features of their physical make-up and internal mechanisms, there will exist *shareable* representations of aspects of their common world. These shareable representations link internal states of both agents to objects in the external world. The agents interact with the world which they share, and with each other: their interactions with the world produce changes in their internal states, and their interactions with each other allow these internal changes of state to be co-ordinated mutually. These co-ordinated states correspond to representations of a shared perception of their common external environment.

Information, in an abstract sense, is what we use to characterize the order in the world in terms of shared perceptions of pattern and mechanism. Information, in a concrete sense, is a distribution of matter or energy that is meaningful for an agent in terms of description, prescription or communication, and which therefore can be used to represent some aspect of that order which is experienced in interacting with the world. When patterns are physically instantiated as spatial or temporal distributions of matter or energy, they can be exchanged between agents for the purposes of communication. Such physically instantiated distributions can also be used to describe and specify physical mechanisms. When information instantiates the representation of pattern without any further qualification, we will call it *data*, and when it specifically instantiates the representation of prescriptions for action we will call it *process* [3]. In summary:

> *Information: represents the world in terms of data and process. Data is a physical instantiation in matter or energy which represents a pattern in the world. Process is a physical instantiation in matter or energy which represents a mechanism in the world.*

Knowledge and information are different things: knowledge is a name we give to a capacity for action, and information is a name we give to abstract representations or concrete instantiations of pattern and mechanism. Knowledge — a capacity for action — arises from the execution of process on a processor (in the brain for a human agent). This executable process can be specified in terms of information. Hence knowledge can be shared by sharing information. This is acknowledged in everyday speech where the two words — information and knowledge — are often used as though they mean the same thing. We will, however, distinguish between them:

> *Knowledge: a capacity for action which an agent has by virtue of information instantiated as processes that can be carried out by a processor.*

Knowledge that is instantiated as information which can be accessed externally by, and shared between, agents we will call objective knowledge:

> *Objective knowledge: shareable, externally accessible information that can endow an agent with a capacity for effective action.*

Objective knowledge is information that is instantiated externally to an agent in a formal, explicit, stable, persisting and interactively accessible form which the agent can use as a basis for action. To provide objective knowledge, the information must be suitably encoded: one agent's objective knowledge is another agent's indecipherable information. Examples of symbolically encoded objective knowledge for a human agent are: books, videos, computer programs, diagrams, pictures, railway timetables, maps and other artefacts. Information and knowledge allow us to describe ways in which agents can collaborate and interact effectively. Information can be thought of as the *currency of agency*, since it is the medium of exchange for *societies of agency*, that is for groups of agents working together. Objective knowledge, instantiated in information-processing structures and in artefacts, can be thought of as the *capital of agency* for such societies, since it allows groups of agents to pool and share their capacities for action. The story of the evolution of civilization is a story of the formation of societies of agency, of the successive additions to human agency of material agency in the form of artefacts, and of machine agency in the form of instantiated processes. The result is an ever-increasing pool of objective knowledge. Among the most important artefacts in future knowledge economies will be machines on which processes defining objective knowledge can be run, and which will be used to create virtual worlds that agents can interact with and explore.

The agents sharing objective knowledge can be of different kinds, as in the case of human agent and computer. The fact that it can be stored, transmitted and shared across species-of-agent boundaries is what makes the generation of objective knowledge one of the most important aspects of modern technology and one of the main drivers of economic development. Objective knowledge can be thought of as giving us a lens through which we view the world, and the feedback mechanism by which agency grows can be thought of as continually generating, refining, correcting and polishing that lens. When we work in collaboration with other agents, including mechanical agents, this can be thought of as increasing the lens's power and versatility. In the same way as a microscope allows us to look at the arbitrarily small, and a telescope allows us to look at the arbitrarily large, the accumulated objective knowledge of a society of agents allows it to create systems with which it can grapple with the arbitrarily complex. There is a similar metaphor due to Joel de Rosnay [4], who called the capability endowed by systems theory and computing a *macroscope*. Modern technology puts within our grasp the possibility of effectively creating and using huge amounts of objective knowledge. Peering through the evolving macroscopes provided by such knowledge systems will open up new vistas of the arbitrarily complex, and enable us to create hitherto unimaginably high levels of agency.

Knowledge systems

Imagine that you are standing in any big library, before the stacks of technology-related journals. You are surrounded by information, but it is not in an immediately useful form. You are surrounded by *data* but what you need is *process*. The knowledge with which the library is filled is very difficult to access, and even more difficult to turn quickly into either illuminating insight or practical use. The difficulty of harnessing such forms of objective knowledge to useful effect poses a very real and formidable problem. A major challenge facing modern technology is how to use machine agency to produce knowledgeable machines that will help to: organize and make interactively accessible the large and growing amount of objective formal knowledge which is available; develop a coherent, communicable, synoptic overall view of any specific subject which can be used to illuminate and organize this objective knowledge; make the knowledge useable by practitioners — to provide them with a powerful toolkit; and relate the knowledge to reality, that is to experimental and practical investigations.

To use objective knowledge in this way, we must be able to create appropriate *knowledge systems*. In particular, we must devise arrangements by means of which human agents and knowledgeable machine agents can work together effectively. The emergence of such machines will have a profound effect on education and training, and they will enable lifelong learning to become a reality. Knowledgeable agents will become an embedded aspect of almost all manifestations of machine agency, giving help, advice and answering queries. They will become ubiquitous, encountered in almost every aspect of daily life in both embedded and autonomous manifestations. The limitations on the development of knowledgeable agents lie in the difficulty of extracting knowledge from human agents. Design activity will be carried out almost entirely by interactive knowledge-support systems [5,6] whose refinement and extension will become of determining importance for industrial competitiveness. Such knowledge systems will also become indispensable in the support of teaching, learning and training at all levels [7].

In such a knowledge system, the overall characterization of our knowledge of some specific object, say the Arc de Triomphe in Paris, will come from three complementary frameworks. The first, a data framework, comprises the raw information necessary to describe the object. We generate this information by seeing it, touching it, photographing it, measuring it, drawing it, and so forth, generating as much information as is needed for our purposes. A conceptual framework, comprises a set of generic concepts related to this type of object — for example, the generalized idea of arches, the many ways in which they may be built and used, and so forth. A schemata framework comprises a set of schemata which give a detailed prescription of how that particular type of arch, of which the concrete (pun intended) Arc de Triomphe is an instantiation, could be constructed, or, more usually, of how its construction could in principle be detailed. For most of us this prescription would be restricted to some general understanding of how such an object could be created, to complete the way in which we could coherently and intelligibly talk about it. Only in the knowledge system of a master builder would there be a complete and fully detailed specification of how to proceed in actually fabricating its components and constructing it.

For an example of how the parts of a knowledge system would fit together, and work in action, consider the legal problem of determining whether someone is guilty of a crime such as manslaughter or murder. This may be carried out in terms of a knowledge system with the following three frameworks: a data framework consisting of the evidence and testimony about the alleged crime, as collected and classified and available in documents and artefacts; a conceptual framework, consisting of the relevant concepts on which the law is based, as interpreted by a judge and jury; and a schemata framework, consisting of the relevant and formally codified law, which details the appropriate procedures to be followed, how the relevant penalties are to be determined, and so on. To resolve a question of guilt requires that the prescriptive application of the law be related both to the concepts for which the events which took place are specific individuations, and to the descriptions of the actual events and circumstances involved. It is important to note how the *open-ended* nature of the normal legal/judicial system allows all three frameworks to come into play. This is because the formal structure of codified law contains *exit points* by, for example, referring to the concept of 'reasonable force' which must be *interpreted* by the judge and jury against the generic framework of relevant concepts rather than the prescriptive framework of codified law. The extreme flexibility with which human agents use their knowledge systems seems to stem from the ease with which such a set of three meshed frameworks are used simultaneously, slipping effortlessly from one to the other as required.

This structure allows us to consider how human and machine capabilities can complement each other best in using knowledge. In this context, the remark above about open-endedness is crucially important. Any accurate description of a knowledge system involving both humans and machines must show how explicit and tacit knowledge mesh together. A machine can supply in principle any amount of information, and so it obviously can provide immensely powerful support for the data framework. It can also provide very powerful support for a user's (or learner's) conceptual and schemata frameworks. This can be done with appropriate data and process in the form of structured (e.g. hyperlinked) texts, film, animation, simulation, narrative, interactively accessible databases, automated reasoning processes and expert systems. A machine could clearly offer powerful help as an assistant to human agents in using knowledge. The degree to which it could function on its own is set by the difficulty of making the tacit knowledge of human agents explicit [8,9]. The success of arrangements in which humans and machines work together will depend critically on a complete and coherent meshing of the human and machine knowledge systems, joined together at the relevant entry and exit points. In an ideal combination of human and machine agency, the machine will underpin all the formal, explicit and rational activities of the human, imposing coherency and supplying logical, computational and organizational power. The human will supply intuition, experience, inventiveness, ingenuity and flair. Such systems offer an immense potential for the development of learning-support systems.

The future of universities

The future of universities will be determined by the outcome of struggles to reconcile the conflicting demands of providing learning for life and learning for work. In an industrial economy labour is divided and tasks are mechanized. In a knowledge economy knowledge is divided and tasks are professionalized; the instantiation of knowledge in information is then used to mechanize and support the basic tasks underpinning professional skills — jobs are first professionalized, then industrialized. As the use of highly specialized professionals, supported by a mechanization of information-processing tasks, spreads throughout industry and commerce it is inevitable that this trend will impinge severely on higher education. Universities will face severe competition from new forms of provision — they will have to adapt to both professionalization and industrialization. Their current provision of an incoherent mixture of learning for life supplied through diverse social arrangements, and learning for work supplied through inefficient procedures separated from the realities of the workplace, will face brutal competition from cost-effective, professionally delivered learning-support providers delivering learning for work directly into the home or workplace at a time, in a location and in a style to suit the individual learner. The demand for graduate and postgraduate levels of education and training in the lifelong-learning sector of the knowledge economy will also grow inexorably, and so open up the whole sector for competition.

The pressures to improve nursery, primary, secondary and further education and to increase the participation rate in all forms of post-compulsory education will combine to continue a relentless squeeze on higher-education costs. At the same time a large and important new sector — lifelong learning — will emerge to provide important new opportunities for higher education. All those involved in higher education must face the possibility of radical change, including the emergence as envisaged by Hague [10] of radically new types of provider. Universities will face an ever-growing challenge to their professional training activities. There will be a relentless development of a very wide range of professional services in the knowledge economy, which will parallel the relentless development of automation in an industrial economy. Highly skilled technology-assisted professional services will supply the demands of the major part of the lifelong-learning sector. In the learning economy a spectrum of supply will be forced to match the spectrum of demand. Some of the more extreme results (from the point of view of a traditional academic) are already emerging. These include the distance-learning-based mega-university [11] and the development of what an article in the *New Yorker* [12] has sardonically dubbed the “drive-thru university”.

If one thinks of the various sectors of the learning economy, from nursery to lifelong, as laid out in a spectrum along a horizontal axis from left to right, then the state’s support for an individual’s learning will be concentrated on the compulsory-education sectors on the left, and this support will diminish sharply as one moves to the right through the post-compulsory sectors. New funding support arrangements, such as Learning Accounts in the U.K., will be created to enable a mixture of state, employer and individual contributions to finance lifelong-learning studies. The transition from state support to individual support of learning will take place most sharply in the higher-education sector. The development of universities will be determined by how they react to the pressures and opportunities arising from the professionalization and industrialization of learning support. All the traditional activities of a university, research, scholarship, teaching and professional training, will be challenged by the emergence of highly professional competing providers.

In the sphere of research a combination of the professionalization of research, the increasing sophistication of equipment, the growth of big-team research and its increasing internationalization will concentrate activity into larger and fewer units. Only a few universities will be able to continue research at the highest international level. Even scholarship, which one might think of as the inviolable preserve of universities, will come under threat. The cost of reference-library provision, like the cost of laboratory equipment in scientific research, will result in larger but fewer research collections. Although these trends in the availability of resources for scholarship will be balanced by the emergence of electronic libraries whose contents can be accessed over the Internet, this remote access will enable scholarly activity to be pursued away from universities. Hague [10] has made the interesting observation that, in future, certain kinds of scholarly activity might be carried out best away from a university environment. These trends will of course be exacerbated by the demands on their time made by the increasing need for university staff to be providers of teaching for a range of customers — undergraduates, postgraduates and lifelong learners.

In the sphere of teaching, communications technology and computing technology will combine to break the tyrannies of space and time, so enabling an individual's learning to be supported as, when and where they may choose. While this potentially offers universities great freedom and flexibility in arranging their teaching provision, it also opens the way for new types of provider to compete in the learning-support market. Professional training, which has long been the nearly exclusive preserve of the universities, will become an essential component of lifelong learning. Professional institutions will become involved increasingly in its provision, as will major industrial organizations. Specialized areas such as aerospace engineering, semiconductor manufacturing and so on will be provided for best by the relevant industrial organizations. This is illustrated by the emergence of Motorola University in the U.S.A. and a British Aerospace University in the U.K. With the flexible and efficient support of learning that technology can provide, such specialized skills are best acquired where the work is actually done.

To summarize the impact of technology on higher education one can argue as follows. A knowledge economy is one whose main resource is knowledge, in the form of both know-how and know-that. In addition to ever more sophisticated artefacts like computers, cars and aircraft, its outputs will comprise a wide range of in-person services, general production services and knowledge-based services. These will include things like computer software, consultancy of all types, design, education and training, financial advice and management — everything involving knowledge-based skills. Most of the knowledge on which the knowledge economy depends will be instantiated in information, and so the knowledge economy will depend crucially on, and will foster the development of, information technology. The widespread use and the sophisticated development of this information technology will transform the ways in which learning can be supported. Most of the workers in the knowledge economy will be highly specialized professionals, with flexible working arrangements, and they will be dedicated to keeping their skills up to date. They will supplement their specialized in-work training with self-organized learning throughout their working life. When one takes into account that a working life is in the order of 40 years compared with the normal undergraduate course of 3–4 years then it is certain that, in time, the lifelong-learning sector will be the largest in the learning economy. We can thus conclude that the major driver of change in higher education will be the emergence of lifelong learning as a key component of a fully developed knowledge economy.

Perhaps the best way to look at the longer-term future of universities is to reflect on the reconciliation of learning for life with learning for work. In the knowledge economy a spectrum of learning-support activity will emerge emphasizing learning for life at one end and providing learning for work at the other. Individual universities will have to decide where to place themselves on the spectrum between ‘for life’ and ‘for work’. New forms of provider will emerge to dominate the for-work area. New entities like the University for Industry in the U.K. will act as brokering, co-ordinating and initiating agencies to shape the for-work provision. In addition to positioning themselves on the learning-support spectrum, universities will have to compete with new forms of provider in their other spheres of research, scholarship and professional training. Although the name university will persist as an increasingly meaningless label, from what we now call universities will emerge a diverse range of providers adjusted to match the demand spectrum for learning required by the knowledge economy. Learning for life is generic, broad and concerned with understanding; at its best it imparts wisdom. Learning for work is specific, narrow and concerned with applicability; at its best it imparts splendid technique and high skills. The division of knowledge which is fundamental to the working of a knowledge economy ensures that knowledge of an applicable sort will be divided, formalized, systematized and that the associated forms of learning support will become mechanized and industrialized. Learning for work will take place mostly in the lifelong-learning sector and will be provided ultimately by wholly new forms of institution. Universities choosing to concentrate on this sector will become industrialized. They will evolve into highly professional providers of knowledge-based services competitive within, and integrated into, the knowledge economy. Learning for work throughout life will be provided by virtual universities using the full power of interactive computing, networking and automated knowledge systems. But something more will be needed for learning for life.

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