TECHNOLOGY AND EDUCATION: A BROAD PERSPECTIVE

Geoff Woolcott
(Southern Cross University, Lismore)

Abstract

This paper examines technology and its place in modern education in the context of human cultural accumulation processes, where memories, formed as a result of the interaction of novel information with long-term memory, may be stored externally and also transmitted across generations. The learning of technology, considered in a broad sense as environmental manipulation, is tied to cultural accumulation processes and historical practice, but the application of technology across knowledge domains reflects its use prior to the development of subjects as taught in modern educational institutions. Although the use and effectiveness of technology in education is an important issue for the modern teacher, there is little in the way of effective scientific frameworks that allow the modern teacher to compare educational approaches and their effectiveness in teaching practice, and much less in the way of frameworks that can, in turn, be applied to assessing the use and effectiveness of technology. This paper explores the development of such a framework, based in a little-used view of information and suggests how this framework may be used to examine the role of technology in human learning and memory and to examine its intersection with education and teaching.

Introduction

Education and teaching are associated with learning and memory, with education and teaching serving the function of communicating memories as a body of culture from generation to generation through the process of learning. Education, such as that provided by interactions between children and parents, teachers and students, and individuals in the general community, is one of the primary methods of transmitting society's culture from one individual memory to another. Education that enables learning can transmit culture, here considered as inclusive of knowledge and skills, in a variety of ways, and one of the ways that the use of technology has benefited such education is through the provision of both teaching and learning tools, such as seen in the use of modern electronic media. Technology has provided also means for the storage and accumulation of culture, such as in books and computer systems, used for learning. Over the last four hundred years, institutionalised education, such as that provided in schools and universities in countries with the appropriate resources, has become one of the preferred methods of transmitting culture, and teachers and technology have played a critical function as institutionalised education has become widespread. Although the teaching role remains significant in modern learning institutions, technology appears to be playing an increasingly significant role in the learning conducted in some institutions.

In its broad sense, the term technology can be considered as involving human manipulation of the environment (Lane, 2009) and it is in this sense, which includes modern media technology, information storage and tool use more generally, that technology is considered in this paper. Unlike knowledge domains that have developed as separated subjects, technology in this broad sense has remained a component of all subjects taught in industrialised societies, even subjects, such as computer science, that are based heavily in electronic communication technology. It can be argued, in fact, that technology may have always played a role in education, including any education prior to the establishment of the institutions we are familiar with today. The accumulation of technology culture, and the transmission of this culture from generation to generation through education, therefore, forms part of the greater accumulation of culture obtained through learning and memory processes, including those processes involved in human environmental interactions such as negotiation of the physical world and social communication. In this paper, therefore, technology is examined from within a generalised view of learning and memory, a view based largely in combination studies of modern cognitive psychology and the integrative biology. This broad view of learning and memory offers a view of human cognition that may assist in examining the accumulation of culture, including the accumulation of technology culture and culture within subjects, across the broad vista of human education.

Cultural accumulation and technology

The accumulation of culture, including knowledge and skills, and its transfer from generation to generation appears to be a feature of human civilization, a feature that is served in the modern world by the teaching practices that arose out of industrialised society. This cultural accumulation, acting effectively as cultural ratcheting (Tomasello, 1999), utilises the transfer of information from the long-term memory of one individual to the long-term memory of another, sometimes via an external information store, such as a book or computer. Information stored in long-term memory is generated ultimately through the interaction of an individual with their environment, and uses processes that compare input information, or stimulus, with stored information. The processes that deal with input information identified as novel are here referred to as problem solving, and can lead to addition of new information to long-term memory or the restructuring of information stored already in long-term memory.

Technology in the broad sense (Lane, 2009) has, in fact, been part of human cultural accumulation longer than any culture taught within subject domains in educational institutions, in large part due to the use of technological devices to store information external to the human body. Written records, for example, were used to store information long before there was an industrialised society, as far back, in fact, as the earliest agrarian societies (Schmandt-Besserat, 1996). In recent times, there have been a number of developments that have made technology a prominent issue in educational institutions in industrialised societies, with electronic data storage and computing, as well as developments in other types of data storage, facilitating an increase in the amount of stored information as well as improved access to stored information. This has contributed to the development of interactive or static instructional devices that require only the learner and the device. It has contributed also to an increase in the number of students who use electronic devices for social communication along with a perceived need for educators to engage such students through the use of similar devices (Westwell, 2008). The origins of such technology culture, however, lie in human environmental interaction and problem solving, as is the case for subject-based culture.

In terms of integrative biology, technological knowledge refers broadly to knowledge of environmental manipulations involved in giving an organism a survival advantage over another organism. In terms of education, technology can be discussed in relation to the biological advantages involved in accumulating human culture. The storage of information externally to the long-term memory of individuals through the use of technology has been, arguably, a crucial factor in human survival in cooperative societies. The environmental interactions that constitute technology rely on the use of a well-developed human central nervous system and involve a large long-term memory and a well-developed problem-solving capacity. Such environmental interactions allow humans to respond more quickly than other organisms to short-term environmental change and, as a result, technological knowledge is central to the human advantage in such crucial activities as obtaining food, avoiding predators and reproducing in safety. It may have been, in fact, technology that allowed sufficient environmental information to be accumulated such that self-sufficient communities could share information through cooperative education. The bodies of knowledge that have developed into modern teaching subjects appear to be a development that occurred after the establishment of such self-sufficient communities. The following section looks at learning and memory, and environmental interaction, in a novel way in order to examine such environmental interaction and accumulation.

Learning and memory - a new look at information

Integrative biology, cognitive psychology and education

The dynamics of environmental interaction appear to change with growth and development of the individual, and some studies in integrative biology have suggested that education should involve enriched environments so that a minimum or critical number of neural associations are formed at sensitive periods in human development (Calvin, 1996, 2004). Some of these sensitive periods occur when neurons and synaptic junctions are being generated in increasing quantity, for example at ages up to three years, as these are periods when the sensory input from the environment influences the growth or delineation of neuronal pathways as base networks (Calvin, 1996, 2004; Edelman, 1987, 1989). Edelman (in Sylwester, 1995) has presented a view of an idealised learning environment that enables base and larger networks to be built up using the Darwinian principles of competition as the determining factor in retention of connections within what could be called memory elements or concepts. There appears to be little work done, however, in merging such views with the development of educational theories and practices

Some of the educational theories and practices that rest on a solid basis in cognitive psychology have lent themselves to empirical testing in educational settings (Sweller, van Merriënboer, & Paas, 1998) and detailed views of concepts from cognitive psychology provided from integrative biology (e.g., Calvin, 2004) suggest that the development of theories and practices from combination studies may be amenable additionally to the predictive testing of scientific empiricism. Ultimately, the aim of educational theories and practices is to provide environmental input for learning and to assess any behavioural feedback in order to assist in the modulation, formation and, sometimes, retention of new neuronal connections and patterns in memory. Models of instructional design derived from theories developed from modern cognitive psychology, such as cognitive load theory, have emphasized the importance of attention combined with the limitations in working memory in facilitating the formation of, and addition to schema in long-term memory. Studies in integrative biology appear to support such theories and offer insight into the optimal conditions under which neuronal patterns and connections are formed within the central nervous system, with the biological data from studies of learning and memory providing a wider context for testing the effectiveness of educational practices.

A flexible framework for learning and memory

Despite the application of integrative biology and cognitive psychology to studies in education, there is little in the way of consensus on how to accommodate information from differing studies of learning and memory, and studies of education and teaching. This paper, therefore, now outlines how studies in cognitive psychology and integrative biology may be combined with studies in education in order to erect a broader, more flexible framework within which to describe learning and memory processes in a very broad sense. This may lead to new strategies for the examination of cognition more generally, and subject teaching specifically (Woolcott, 2011, 2013). This flexible framework describes learning and memory processes in terms of information processing systems, and this is similar to the descriptions of human cognition and evolution in terms of natural information processing systems that have been used in some educational studies, such as those concerned with cognitive load theory (Sweller, 2004, 2010).

In this flexible framework, however, the concepts of learning and memory have been generalised across both organismal and non-organismal structures, and all discrete matter and energy units within the universe are described as information processing systems, with changes in information within such units described as processing (Woolcott, 2011). The information within a structure (as matter and energy), including any internal structural or positional relationships, actual or potential, is the memory of that structure, regardless of the learning mechanism. The communication of such information both into and out of any structure can be described in terms of learning if there is a resultant change in memory. Learning and memory, therefore, are described in terms of the overarching range of possibilities or potentialities of any change of matter and energy within such information processing systems. The novel conceptualisation of information and information processing systems described here is not related closely to the probabilistic and mathematical conceptualisations based in information theory or computing (e.g., Chaitin, 2011; Shannon & Weaver, 1963), some of which led to the development of concepts of information processing used in cognitive psychology and education (Lachman et al., 1979; Miller, 2003), but rather to conceptualisations based in the more observable world of matter and energy assumed in many scientific studies (Pigliucci, 2011; Wolfram, 2002), where information may be considered as either matter or energy (see, e.g., discussion of information as 'thing' in Bates, 2005).

Human learning and memory within the framework

This framework was developed from a consideration that learning and memory of an organism or structure involve three temporally connected, but separable, stages in information flow; environmental information input to or output from a structure, processing of resultant information changes within the structure, and changes in the observed state of the structure resulting from any information processing. Within this framework, a human can be considered as a discrete matter and energy unit and human connectivity can be considered in terms of interactions with environment of the human information processing system and, as well, any designated structure within the human system can be considered also as a similarly discrete entity. On this basis human learning and memory can be described as a function of human connectivity with environment, as well as a function of connectivity of the central nervous system, as a component system, with its environment and, in particular, of the nested component system of neuronal connectivity that is the brain.

Within the broad sense of this flexible framework, interaction with environment is integral to learning and memory in all information processing systems. In organisms with a centralised nervous system, learning and memory interactions in the component that is the nervous system, inclusive of the nested component of the brain, allow for faster responses to environmental input than those responses seen in organisms without such a centralised system. In organisms, such as humans, that have a well-developed and complex nervous system organised around a brain, there can be a degree of environmental manipulation due to the interaction of novel information with information pathways that may provide a number of scenarios based on past experiences and additional associations created through thinking. There is, however, always a link of the organism to the environment, either through sensory input or through motor output and such feedback systems as positional sensors in muscles (Calvin, 2004; Grillner, 2003).

This framework supports the consideration separately, in a formal scientific sense, of the differing aspects of the human cognitive system, as component systems, which is, in practice, a common method in dealing with learning and memory in cognitive psychology and integrative biology (Woolcott, 2011, 2013). In considering a human individual as a type of universal information processing system, there may be differing component systems that may process information in different ways and over different time frames, but which may contribute to an assessable human performance, even if these systems sometimes overlap or are nested within other systems. Consideration of such components systems suggests that it may be more useful to consider aspects of an individual's performance that may result from interacting components of that individual as an information processing system. A follow on from this would be to consider performance of overlapping aspects of a subject-domain, rather than considering a student's performance over an entire subject domain. In this way the degree of expertise that an individual may have obtained in a culturally-valued knowledge domain may be assessed, so long as it is recognised also that various components of the student's cognitive and related systems may contribute differently to that expressed expertise.

A viewpoint based in learning and memory as due to interacting component systems, may be useful in examining the influence of such aspects as motivation and emotion, aspects which have are beginning to be examined in an educational context (Geake, 2009; Grandin, 2006; Panksepp, 1998). This componentised view of learning and memory, obtained from consideration of the flexible framework, may accommodate also the consideration of knowledge acquisition in specialised domains in individuals that may otherwise have differences in cognitive connectivity, such as may occur in higher functioning in individuals within the autism spectrum (Grandin, 2009: Mottron et al., 2009). There may be many different reasons for the development of expertise through neuronal connectivity and some of these may be related to the same neuronal hyper-connectivity and hyper-plasticity that may result in lack of expertise and differential connectivity (Markram et al., 2007). The framework for learning and memory here, as applied to the human organism, allows some comparison also of such differing expertise through consideration of parallels that may be present between studies based in integrative biology and those based in the social and behavioural sciences (Woolcott, 2011, 2013).

Implications of the framework for technology

In the context of human education, technology can be discussed with respect to environmental interactions that rely on use of a well-developed human central nervous system that has an efficient problem-solving ability and a large long-term memory. Humans, like all organisms with a central nervous system, can respond to environmental change quickly and this offers advantages in such survival-oriented activities as obtaining food, avoiding predators and reproducing. For such organisms, technology might be broadly described as any activity that can manipulate an aspect of environment through problem solving, that is, interaction with novel information, such that there is a reproductive or survival advantage over other organisms. In humans, therefore, technology can be linked to to addition of created information to long-term memory (Sweller, 2004; Sweller et al., 1998) and creativity (Geake, 2009; Sweller & Mann, 2009), if there is some kind of muscular output involved. Such a broad description, however, leaves many issues unresolved, for example, whether a given environmental interaction is a manipulation, whether such a manipulation actually offers an advantage, or whether an organism has intended any advantage.

Within the broad framework outlined above, the entire human organism can be treated as an information processing system, with some of its interactions with environment considered as learning, where such interactions change the memory of that system. The human information processing system, however, can only change according to the laws of matter and energy interactions that relate to the information within the system. Although many such changes may not be observable, over a given time period, observable changes vary from the microscopic, for example, those changes to blood flow observed in magnetic resonance images, to the macroscopic changes seen as the muscular contractions observed as behaviour. Some of these changes manifest as production of tools, with tools sometimes seen exclusively as technology, from simple levers to more complex devices such as computers and printing presses. Such tool-making, and tool use, reflects changes to the human information processing system as a whole, and not just changes to the nervous or muscular systems, changes that result in information output from the system. This does not mean, however, that many of the changes that result in learning and memory of the human as a system are not related to changes in the component nervous system. Environmental interactions involved in problem solving (in the sense of Sweller et al., 1998, not in the sense of solving a problem), for example, are considered to be the main function of the nervous system and its function in short-term and long-term memory (e.g., Tonegawa et al., 2003), as well as any resulting muscular contraction. There will also be input to the system as feedback during that motion. This may be related in turn to tool production or use and, in this sense, technology is related to a gain in memory of the system as a result of information input from the environment, as well as a loss of information from the system as motion.

It must be recognised that, even though components of the human system have a learning and memory function, the entire human system has learning and has memory due to the interacting components of the system, which are linked as a single holistic system (e.g., Squire & Kandel, 2008). From the perspective of this information processing framework, therefore, learning interactions could be considered as being involved with technology only if those interactions can be separated from other environmental interactions, and if it can be shown that such interactions are advantageous to the system. It remains problematic, however, to discuss, within an educational context, technology and its use within subjects. Even though advantageous environmental manipulations, such a writing, could be described as technology, so could less tangible environmental manipulations such as fanning a spark to start a fire, or cooling objects in water, or even persuading someone to complete a task (e.g., see discussion in Lane, 2009), and it is difficult to apply any of these uniquely to any particular subject. The subjects taught in schools were developed relatively recently, compared to some technologies, and can be considered artificial constructs that use the same information processing as technology, through the same human system and its interaction with environment. It is suggested here, therefore, that school subjects have been separated largely through historical practice from aspects of technology, but that both are inextricably linked.

Conclusion

Since shared culture is a feature of human society, any addition to an individual long-term memory through problem solving, or creativity, may become part of a society's body of culture through teaching and learning processes. This can be seen as advantageous for human survival and reproduction since the build-up of a shared culture is a major factor in human survival, for example the shared knowledge and skills required for agrarian practices and animal husbandry that has facilitated human settlement. Within societies, therefore, technology can be considered not only as development of a tool, but also a development of a farming practice, or a business practice, or other activity that involves an environmental interaction that acts to advantage an individual's survival or reproduction. Since education and teaching function in communication of memories, they are an important mode of transmission of the part of the body of culture that is technological knowledge.

The neuronal processes involved in accumulating culture, and this includes both technological and subject-based cultural accumulation, include the association of information, spatially and temporally, from a variety of differing sensory inputs, as well as processes that are involved in reinforcing or inhibiting patterns of neuronal connectivity. Memory formation, however, does not exclusively involve neuronal cell connectivity, but relies also on the complex interaction of neurons with other elements of the nervous system, and complex interactions of the nervous system with other component systems of the human organism. In terms of neuronal connectivity, however, there may be little distinction between culture labeled as science or history and culture labeled as technology. Although this has caused some dispute among theorists (Dehaene, 2004), any differences may lie in the access to long-term memory activated by input environmental information and to the contextualization and re-organisation of information in long-term memory.

When considered within the broad information processing framework described here, technology can be seen as new knowledge and skills, or culture, added to the human system and referred to in terms of problem solving and long-term memory. Thus, technology culture is included in the larger body of culture accumulated through the transmission of memories involved in education and teaching. Although technology is sometimes considered as separate from other aspects of human knowledge and skills, it needs to be viewed in the context of human culture as part of the collective memory of human society. Modern education appears to differentiate technology teaching from subject teaching, and studies in integrative biology indicate that this may be due to an overarching influence of technology as the knowledge and skills involved in environmental manipulation that can be applied across all subjects. Technology may have, in fact, contributed to the success of human settlement as well as the education and accumulation of culture that developed as a result of such settlement. This is not to say that technology knowledge is more valuable than knowledge developed in subject domains, but rather that any knowledge needs to be considered in a context of value to the society in which it is being accumulated. It is important in modern education, therefore, to maintain the connectedness of environmental information that is reflected in a fully-integrated or contextualized connectivity that is not totally subject dependent. Studies of cognitive psychology and integrative biology indicate that information contained in the separate subjects taught at schools and other educational institutions may best be learned, not as separate elements as suggested in some educational literature, but as elements that are totally integrated with as many strong links across the total knowledge and skill base of an individual. In this way culture such as technology and mathematics may become more fully integrated as components of a human cultural accumulation that is based in the negotiation of the environment necessary for, at the very least, human survival.

References

Bates, M.J. (2005). Information and knowledge: An evolutionary framework for information science. *Information Research*, *10*(4) paper 239. Retrieved from http://InformationR.net/ir/10-4/paper239.html.

Calvin, W.H. (1996). *The cerebral code: Thinking a thought in the mosaics of the mind*. Cambridge: MIT Press.

Calvin, W.H. (2004). *A brief history of the mind: From apes to intellect and beyond.* London: Oxford University Press.

Chaitin, G.J. (2011). Complexity, randomness and remarks on physics. In G.J. Chaitin, F.A. Doria, & N.C.A. da Costa (Eds.), *Goedel's way: Exploits into an undecidable world* (pp. 31-53). Boca Raton, London & New York: CRC Press.

Dehaene, S. (2004). Evolution of human cortical circuits for reading and arithmetic: The “neuronal recycling” hypothesis. In S. Dehaene, J.-R. Duhamel, M.D. Hauser, & G. Rizzolatti (Eds.), *From Monkey Brain to Human Brain* (pp. 133-158). Cambridge, USA: MIT Press.

Edelman, G.M. (1987). *Neural darwinism: The theory of neuronal group selection*. New York: Basic Books.

Edelman, G.M. (1989). *The remembered present*. New York: Basic Books.

Geake, J. G. (2009). *The Brain at school: Educational neuroscience in the classroom*. Australia: McGraw Hill - Open University Press.

Grandin, T. (2006). *Thinking in pictures and other reports from my life with autism*. New York: Vintage, Random House.

Grandin, T. (2009). How does visual thinking work in the mind of a person with autism. *Philosophical Transactions of the Royal Society, B*, *364*, 1437-1442.

Grillner, S. (2003). The motor infrastructure: From ion channels to neuronal networks. *Nature Reviews Neuroscience*, *4*, 573-586.

Lachman, R., Lachman, J.L., & Butterfield, E.C. (1979). *Cognitive psychology and information processing: An introduction.* Hillsdale: Lawrence Erlbaum.

Lane, A. (2009). World Around Us - What is technology? [Television broadcast]. UK: BBC. Accessed at http://www.open2.net/sciencetechnologynature/worldaroundus/whatistechnology.html.

Markram, H., Rinaldi, T., & Markram, K. (2007). The intense world syndrome – an alternative hypothesis for autism. *Frontiers in Neuroscience*, *1*, 77-96.

Miller, G.A. (2003). The cognitive revolution: A historical perspective. *Trends in Cognitive Sciences*, *7*(3), 141-144.

Mottron, L., Dawson, M., & Soulières, I. (2009). What aspects of autism predispose to talent. *Philosophical Transactions of the Royal Society, B*, *364*, 1351-1357.

Panksepp, J. (1998). *Affective neuroscience: The foundations of human and animal emotions*. New York: Oxford University Press.

Pigliucci, M. (2011). What about information? *EMBO reports*, *12*(92). doi:10.1038/embor.2010.213

Schmandt-Besserat, D. (1996). *How Writing Came About*. Austin: University of Texas Press.

Shannon, C.E., & Weaver, W. (1963). *The mathematical theory of communication*. Urbana: University of Illinois Press.

Squire, L.R., & Kandel, E.R. (2008). *Memory: From mind to molecules*. Second edition. Greenwood Village: Roberts & Company.

Sweller, J. (2004). Instructional design consequences of an analogy between evolution by natural selection and human cognitive architecture. *Instructional Science*, *32*, 9-31.

Sweller, J. (2010). Cognitive load theory: Recent theoretical advances. In J. Plass, R. Moreno, & R. Breunken (Eds.), *Cognitive load theory* (pp. 29-47). New York: Cambridge University Press.

Sweller, J., & Mann, L. (2011). The psychology of creativity and its educational consequences. In L. Mann & J. Chan (Eds.), *Creativity and innovation in business and beyond: Social science perspectives and policy implications* (pp. 223-238). New York: Routledge.

Sweller, J., van Merriënboer, J., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*, 251-296.

Sylwester, R. (1995). *A celebration of neurons: An educator’s guide to the human brain*. Vermont: Association for Supervision and Curriculum Development.

Tomasello, M. (1999). *The cultural origins of human cognition*. Cambridge: Harvard University Press.

Tonegawa, S., Nakazawa, K., & Wilson, M.A. (2003). Genetic neuroscience of mammalian learning and memory. *Philosophical Transactions of the Royal society of London, B*, *358*, 787-795.

Westwell, M. (2008). Mind over matter: The science of learning when teaching matters. Seminar at the University of New South Wales, August 2008, organised by Education.au, Australia. Podcast acccessed at http://educationau.edu.au/jahia/Jahia/home/mind_over_matter.

Wolfram, S. (2002). *A new kind of science*. Champaign: Wolfram Media.

Woolcott, G. (2011). A broad view of education and teaching based in educational neuroscience. *International Journal for Cross-Disciplinary Subjects in Education*, *Special Issue*, *1*(1), 601-606.

Woolcott, G. (2013). Giftedness as cultural accumulation: An information processing perspective. *High Ability Studies* (in press).