A Broad View of Education and Teaching Based in Educational Neuroscience

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Abstract

Education and teaching facilitate the accumulation of human culture and its transmission across generations. Although many of the models of instructional design used in teaching in educational institutions are based in cultural experience and remain untested empirically, phenomenological investigations of learning and memory in cognitive psychology have led to the development of testable models. Recent scientific studies have proven useful in redesigning and developing models of instructional design and, therefore, in improving education and teaching. This study combines results from cognitive psychology and modern scientific disciplines, including information science, in order to erect a broad framework in which to examine learning and memory. Under the banner of educational neuroscience, this framework, which views learning and memory as resulting from plasticity in the connectivity of an organism, or a structure, with its environment, may have application in examining some of the recently-developed and testable models of instructional design.

1. Introduction

In a modern industrialised society each individual from the age of about five to sixteen may spend as many as twenty hours a week in an educational institution, with some individuals continuing such education for many more years. Such institutionalised education has become an important way for individuals to learn complex cultural information that would otherwise not be learned from parents, society or the natural environment [1,2]. This style of education has become also an important part more generally of the cultural (knowledge) accumulation process in human learning, largely because such education may enhance the transmission of culture, a process referred to here as cultural ratcheting [3]. Such accumulation includes any information that may be stored within or external to one human memory and then transmitted to another human memory through learning, thus ensuring that the information is passed from generation to generation.

2. Literature Review

Until recently, models of instructional design used for teaching in educational institutions have relied on an educational culture embedded in beliefs and assumptions. In institutionalised education many of the models of instructional design remaining in use were developed from within the social and behavioural sciences, or through historical practice, and there has been little attempt to verify empirically the efficacy of such models [1,4]. Teaching that uses these models of instructional design remains largely uninformed by studies of learning and memory in modern research disciplines, such as cognitive psychology or biology-related sciences, or by the degree of influence of non-empirical rationales and belief systems on those models of instructional design. Models of instructional design developed from studies in cognitive psychology have provided, in fact, evidence-based instructional principles that have lent themselves to empirical testing [5,6]. Evidence from such principles, many of which are based in cognitive load theory [6,7], supports the notion that some models of instructional design may not be efficient and it has been suggested that some common teaching practices should be abandoned in favour of more effective teaching strategies [8,9].

3. Research Rationale

The emergence of studies of the brain, in such disciplines as neuroscience and genetics, has affected our understanding of the function of learning and memory as described in studies of cognitive psychology [10,11]. Such studies in biology-related sciences, here referred to under the umbrella term integrative biology, provide a more detailed view of the internal workings of the brain, from the macroscopic to the molecular level, during cognitive

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processes. For example, some researchers have begun to detail the biology that may be involved in such important learning and memory processes as attention, working memory (short-term memory) and long-term memory [10,12,13,14]. Such research has detailed potential links between patterns of connections in the real world and their analogous record as memories in the brain as well as the patterns of connections that allow for efficient storage of large amounts of information in long-term memory [11,12]. There have been recent developments in studies of networks and systems that lend support, more generally, to an argument for common patterns in the structure and development of complex networks or information processing systems [15,16], and this includes human cognitive systems [17]. Such common patterns include those seen in the scale-free networks and small world networks described in models of information processing networks developed from biology and economics [15,16].

Despite these studies, there seems to be a divide between the phenomenologically-based studies in psychology, a discipline directed more towards philosophy and the social and behavioural sciences, and studies in integrative biology, which emphasise empirically-based studies of chemical structure and energetic relationships. Studies that combine integrative biology with studies in other disciplines have, however, begun to explore the matter and energy relationships that link the central nervous system with human responses to environment, for example in disciplines such as psychobiology and cognitive neuroscience. Such combination studies, therefore, may have the potential to influence the development of models of instructional design used in teaching in institutions, and researchers in the newly-named field of educational neuroscience are beginning to comment on the implications of such studies for the future of education [18,19,20,21]. It seems important, then, to examine how such studies may affect the development and use of models of instructional design and teaching strategies, such as those developed from cognitive psychology.

4. Contribution to Knowledge

It would appear that, even though some models of instructional design have incorporated some concepts from cognitive psychology, concepts from studies in integrative biology have not been fully absorbed in models of educational design. This includes even established concepts, such as Hebb's [22] relatively well-known ideas about information storage in hierarchies of neurons or Mountcastle's [23] view that different regions of the brain with similar basic structures may function in a similar way. One reason for this may be that the acceptance of the simplicity of memory storage mechanisms has been obfuscated by discussions of complexity of information [24,25], but there is also a lack of educational theorists who come from a background in the empirical sciences [1]. It may take some time, therefore, for models of educational design to accommodate any modern studies in integrative biology in a form that can in turn be evaluated by modern integrative scientists who are also experienced educators [18,26].

There are, however, parallels that have been drawn between modern integrative biology and cognitive psychology in order to accommodate the continually changing landscape of modern research as it relates to learning and memory, and its links with education and teaching [20]. Such parallels have arisen partly from an increase in research and discussion that merges ideas about learning and memory processes and pathways in organismal and non-organismal structures and systems [20,21], and from the combination of results from studies in evolutionary biology and cognitive function with those from studies in education and the information sciences [27,28]. Such merging of concepts, for example, has been used to examine information flow in the natural information processing systems of evolution and human cognition and this has been applied to the delineation and further development of educational principles derived from models of educational design based in cognitive load theory [28]. The results of such comparisons have been utilised in refining evidence-based and testable instructional methods for education and teaching [5], and including those that apply to learning in electronic media platforms [6]. Some researchers are investigating how functional information-processing structures, some of which may be involved in learning and memory, can emerge in complex dynamical systems that are not organismal [29,30].

Recent studies that show the commonality in patterning of network structures and their generalised effects, as well as the independence of the nature, or components, of those structures, has reinforced the view that there may be common underlying principles to systems and networks previously thought to be unrelated. Such underlying principles are relevant to studies of cognitive function and point to a valuable expansion of instructional principles that are tied more closely to biological models of cognitive processes that take place within the human central nervous system. Development of such principles in a biological context may offer valuable insights into learning and into models of instructional design.

On the basis of combination studies on a wide range of organisms and non-organismal structures, and the parallels that have arisen from such studies, learning and memory can be said to 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 (information processing), and changes in the observed state of the structure resulting from any such information processing. This broad sense of learning and memory has parallels in educational practice, for example in considering teaching as having a cycle of three parts: one, where the teacher assesses the information state of the learner in order to best determine the information to be presented for learning; two, where the teacher presents to-be-learned information in a pattern that is accessible to the learner, in an environment that encourages information input and; three, where the teacher assesses, through information output, whether any presented information has been remembered (through processing). The teacher then begins the cycle again by using this last assessment as a basis for further presentation of information.

5. Analysis of Findings

Learning and memory can be thought of, in an even broader sense, as associated with the interaction of an organismal or non-organismal structure with its environment through information pathways or systems of connectivity. The information communicated into or out of the structure is either matter or energy and the pattern of connectivity or pathway between environment and the structure is spatiotemporal, since the information is first in one place and then later in another. Some of the information communicated in any such interaction may result in changes to the structure, including changes in information content or connectivity of information within the structure. For any structure, however, the communication of information both into and out of a structure can be described as learning if there is a resultant change in the information (knowledge or memory) within that structure. This change in information can be referred to as information processing [21]. Given such input or output of information, the state, or activity, of a structure relies on observation of change of the structure due to the information within it.

This flexible framework, which describes learning and memory processes in terms of universal information processing systems, embraces the concepts framed in cognitive load theory and used to describe human cognition and evolution in terms of natural information processing systems [28]. This more universal framework, however, describes all discrete matter and energy units within the universe as information processing systems, with changes in information within such units described as processing [21]. Within this framework, therefore, a human is a discrete matter and energy unit, with human connectivity described in terms of interactions of the human information processing system with its environment, within a definable matter and energy universe. As a result, this framework incorporates a view of human learning and memory as a function of connectivity within the central nervous system, in particular of neuronal connectivity in the brain, and as a function of human connectivity with environment, a connectivity proposed in some scientific studies of learning and memory [31,32]. Within this framework any structure within the human system can be viewed as a discrete entity and this is consistent with studies that view the function of cognitive structures effectively as isolated entities, as is the case with many modern studies in cognitive psychology and integrative biology [10,13,14,32].

This framework, although described ultimately in a terms of matter and energy interactions, supports recent models of instructional design that have been developed from cognitive psychology, and this includes those developed from cognitive load theory. This is largely because the framework supports parallels drawn between apparently common processes that have been described from different conceptual viewpoints [20,21]. By supporting such parallels and by finding common conceptual ground, this flexible framework may be useful in comparing and combining approaches to human cognition and models of instructional design that may appear, initially at least, to be different conceptually.

Describing learning and memory in a broad sense, however, indicates that it may be useful to consider a more universal, overarching view of such environmental interaction in order that teachers and researchers evaluate effectively models of instructional design and teaching methods. For example, when considered in the context of education, the concept of learning and memory as human information processing is sometimes geared toward information input and many models of instructional design are based inherently on an assumption that information presentation is the most significant environmental interaction in learning. Information, however, flows not only from the environment to an individual, but also from an individual to the environment. The consideration of both inward and outward information flow is a common strategy, however, in some areas of science, for example, in ecology, where organisms are considered in terms of environmental inputs and outputs, and neuroscience, where information transfer into and out of neuronal synapses is integral to studies of information flow. Studies based in integrative biology lend support to a contention that there is a significant effect on learning due to input and output information flow of even simple, but often overlooked,

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environmental factors, such as water, oxygen and glucose [33,34]. It follows, therefore, that learning principles derived from a broader sense of information flow may apply to teaching and instructional design in relation to organisation of environmental input and outputs.

The broad sense of information flow described in this framework considers also that it may be useful to consider learning and memory over differing time periods. This can most easily be seen in studies of changes in synapses and neuronal connections in the brain, which may alter in the short term, through chemical or energetic interactions not related to DNA, or in the long term through DNA-related interactions, and there may even be longer-term interactions that influence information flow that supports storage of information in memory [32,35]. Despite this indication of the importance of information flow over varying time periods, in many educational environments instruction assumes that there is temporal continuity of information input from the senses and some models of instructional design appear to assume that information as sensory input to the brain is continuous, regardless of the modality of sensory input. These models, therefore, do not take into account the degree to which changes in rate and amount of flow of discrete inputs may affect some learners.

There are, however, models, based partly in educational neuroscience, that do assume that information flow is discrete, and some recently-developed intervention programs, such as those that are designed to improve specific cognitive functions used in reading [36], operate through slowing down of the flow of sensory information in order that discrete groups of information can be learned more readily. There is time needed also for some non-use periods, over varying time frames, in order to allow for restructuring or building of new neural pathways after a specific amount of sensory input at a given flow rate. Additionally, the central nervous system must be consistently and adequately supplied with nutrients and is subject, therefore, to the physico-chemical limitations on information flow.

Models of instructional design adapted from theories, such as cognitive load theory, based in limitations of working memory (WM) and attentional processes, appear to be adaptable to limitations on information flow, including physico-chemical limitations. These aspects of WM and attentional limitation, however, need to be made empirically-assessable components of models of educational design and there appears to be little work done on integration of such physiological limitations into such models. Specifically, existing studies of the limitations placed on WM and attention by physico-chemical input to the central nervous system need to be examined so that their effect on learning processes can be quantified for use in models of instructional design. A more complete model of instructional design may need to examine, therefore, the physiological baseline of WM and attention with regard to such factors as health, toxicity and age, and relate this baseline more generally to learning, over varying time frames in organisms with a central nervous system.

6. Conclusion

There are numerous educational theories that purport to provide methods of enabling successful teaching and many teaching strategies based solely in historical practice, but there is little support for any claim to empirical verification of their efficacy [1]. In contrast, some of the theories developed through examination of cognitive psychology, such as cognitive load theory, have provided testable principles with proven efficacy [7]. Studies in integrative biology indicate that there may be biological parallels to the phenomenology that underpins modern models of instructional design, such as those in cognitive load theory [20,21]. The combination of results from a wide range of studies indicates that there may be some benefit in describing learning and memory processes in terms of information connectivity and information processing, and such description has been applied to studies in education [20,21,28]. The broad sense of learning and memory described briefly in the educational neuroscience framework above is based in studies that combine a number of successful modern research disciplines, and supports the view that all human environmental interactions may need to be considered in order that teachers and researchers evaluate effectively any teaching methods or models of instructional design.

Examination of learning and memory within this framework supports the notion, already suggested in studies in both cognitive psychology and educational neuroscience, that problem solving, the interaction of novel environmental information with stored information, is the main function of learning and memory in the human interaction with environment [7,10,28], where the term problem solving is used in a context related to function of the nervous system rather than in a more exclusive sense, say, of solving a written problem [5,7]. This notion is central to any educational strategy and the main aim in education, therefore, should be development of such problem-solving ability through promotion of appropriate environmental interaction, and this includes interaction within the internal environment, in order that each individual maximise the potential for such interaction and in order that assessment of such problem solving ability is evaluated in a broader scientific context. It may be useful, therefore, to re-evaluate education and teaching from within frameworks based in information processing systems in order to more fully incorporate knowledge of brain processing and environmental interaction.

7. References

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