



The Technicity Thesis: a constructionist proposition

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Abstract

Constructionism entails learning by constructing objects open to inspection, which Papert claims is the most felicitous means of learning. This begs many questions. The cornerstone question is: How is the human capable of constructing objects? The keystone question is: How does this make learning most felicitous? An answer to both questions is offered by the proposition of a small, unique information processing adaptation in the human brain. The term ‘technicity,’ is adopted to denote this source of the human capacity for technology (and art). Information entropy at this source is far lower than that of environmental sensory input. The consequence is that technology is both simpler and more powerful than biological organisms. Mentally constructed, the concepts derived from the technicity adaptation are shown to be more congruent with properties of matter than are perceptually based concepts for which language is the evolved communication medium.

Keywords

Information, entropy, human evolution, technology, art, concept formation, primary school, Logo, body syntonicity, turtle geometry.

Introduction

This paper is the culmination of a decade of work on the technicity thesis. The trigger was certain behaviour by children with learning difficulties that raised the question: How do humans draw? This generalised to the more general question of technology and art, on which science was silent. Like the dark side of the moon, it appeared perceptually inaccessible. The first step in developing the notion of technicity, the linking of feature detector neurones (Hubel 1995) with drawing, was presented at Eurologo in Portugal. In Warsaw, the square/diamond effect offered supportive evidence that also called into question language primacy. Paris saw a more developed hypothesis based on the more recent understanding of the role of prefrontal cortex, a matter of interest in primary and special education (Ó Dúill 2010). Plausible though this proposal was in terms of the “how” of constructionism, it did not explain “why” it was felicitous. The cornerstones were in place but there was no keystone to hold the edifice together. For this the concept of ‘entropy and information’ (Stonier 1990) was required. This is used further to develop the technicity thesis.

Working from first principles, genetic, neurological and informational knowledge is assembled to offer a new perspective on human evolution. Key is recognition that information available to the genotype is of a different quality from that available to the phenotype. The former is of lower entropy, thus more powerful. The mechanism proposed in the earlier papers, reprised below, makes available this information to cognition. The thesis explains why technology is both simple and powerful. It precisely defines the difference between scientific and naïve concepts; and demonstrates this by the square/diamond effect. The secondary intellectual quality of language is also revealed, leading to reconsideration of Vigotsky’s (1962) ideas on thought and language.

Most work used in developing the thesis has reached the realms of non-specialist science. Key



sources include Lewin (1998), human evolution; Streidter (2004), brain evolution; Fuster (2008), prefrontal cortex; Dawkins (1989, 1999), genetics. The thesis is contrasted with the social brain and language theories (Dunbar 2004a, 2004b) and triangulated against current views on human evolution (Mellors 2007); child development, notably in drawing (Anning and Ring 2004); but mainly against the everyday experience of teachers and parents in the primary school years.

The Technicity Thesis

Technology is simple. Biology is complex. This is the conundrum. Simplicity is of low entropy: it requires little information to fully describe something simple. The 'second law insists that it is not possible to reduce entropy without doing work, without the expenditure of so-called free energy. Given that biological processes all increase complexity and thereby entropy, the appearance of low entropy entities, such as purified red ochre, associated with the earliest human, appears to be physically impossible. The Neanderthal, with a larger brain than modern humans and with very similar neurological architecture, signally failed to develop anything recognisably technological.

A critical distinction needs to be made between creating technology and making things, including tools. There is a discontinuity between animal artefacts and human technology. Animals construct their artefacts according to genetically determined templates. The result is that their constructions are species specific. The test for genetic templates is stasis over time. The tool assemblage of the Neanderthal remained unchanged for hundreds of thousands of years. Pigment production, whilst characteristic of the human and thereby a species identifier, has not remained static.

Seeing red

Isolating a pure primary pigment like red is not trivial. The signal processing overhead required to extract red from the image at the retina would be very high if noise removal were used. This is not the evolutionary approach. Colour vision is an early adaptation. Fish, as children know from the classroom aquarium, have a very good colour sense. The underlying mechanism is the same in goldfish as in the human, though its location and scale differ. Hubel (1995) and colleagues first described this mechanism in primates, referring to the neurological structures as “blobs” from their histological appearance. These computational units are necessary because the receptors in the retina cannot fully resolve light into spectral colours, a consequence of the photochemicals used. Information on light colour is lost in the chemical reaction a photon energises in a receptor. The result of that reaction is a nerve impulse. A nerve impulse is not an analogue of sensation; it is a symbol. From a computational perspective, it is a symbol on a Turing tape with no intrinsic meaning. The meaning of the symbol emerges only when it is read by the machine and causes a change in its state. A symbol may only cause a change in machine state if a machine already has information about its meaning. This implies that information about the redness of red is built into the nervous system. That information about photons of 470 THz frequency, primary red, is built into the brain raises the question of its origin.

The source of the information is the genotype, not the environmental experience of its phenotype. This solves the entropy problem. Evolutionary processes work in geological time, not lifetimes. Genes have had aeons in which to incorporate information on properties of matter in their four-base code. A little reflection shows that they incorporate a very great amount of such information in order to build the body of the phenotype. The evolution of distance senses required the genome to have information about the medium used and to express that information in a suitable structure. Such structures are a function both of the property of matter to be discriminated, e.g. pressure in sound waves or photon frequency, and constraints of neurone function: the excitatory/inhibitory character of synapses in particular. In colour vision this leads to a system that generates a form of



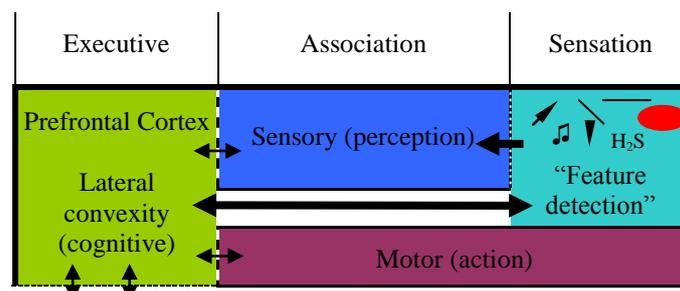
false colour rendering of spectral colours, which bends the spectral segment that is visible light back on itself to form a circle with non-spectral purple. The system defines a colour space by the opponent pairs: red/green, blue/yellow and black/white. In this way, photon frequency becomes a means of differentiation (red fruit contrasts with green leaves) and is incorporated into instinctual behaviour. This implies that all animals, including the human, with the same photon identification system ‘see’ a 470 THz photon as “red” in the same way. This does not imply that they all have a concept of red. For red to become a concept rather than a percept, it is necessary that information on pure unassociated colour be made directly available to cognition.

Neurone nature

Neurons are metabolically expensive informavores. Their representation increased in response to environmental complexity; in hominines at the expense of the gut. This implies that a capacity to model the world is adaptive. In mammals, neocortex evolved. This makes social behaviour and planning possible and inhibits instinct. Birds have a homologous structure. Prefrontal neocortex underwent the greatest relative expansion: from some 3% in the cat through 17% for chimpanzees to 27% for the human (and Neanderthal). In hominines, overall brain expansion was from some 450cc in chimpanzees to a Neanderthal maximum of over 1400cc. Expansion was accompanied by invasive connection of prefrontal neurons to most other parts of the brain. This is the means by which prefrontal cortex performs its executive function; modulating and moderating actions of the older brain; and manipulating memory from neocortex, motor and sensory, to create new possibilities from historical information: to plan for the future and to modify that plan in the light of experience. Over-production of neurons and connections is considerable. Both are pruned, leading to the loss of some 50% of neurons and connections by adulthood; neurons that receive no input die. Aggressive invasion by imperialistic prefrontal neurons turned out to be adaptive. There is no reason why this process should have ceased by the time that the Neanderthal, human and Denisovan shared a common ancestor, somewhere in the region of half a million years ago. The stage is now set to consider the adaptation that led to the human capacity for technology.

Creative connections

The technicity thesis proposes that, in the human, prefrontal neurons invasively connected to primary sensory cortex and its homologues thereby making available to cognition the information the genome expressed there and the manner of its structural expression. Such structures are active neurone circuits. They may be activated either by sensory input or by a probe from elsewhere. No teleology is involved; an ongoing neurogenetic process of expansion simply ran into a new class of information. When manipulated by the prefrontal cortex, the result was the creation of novel cognitive entities and these turned out to be adaptively advantageous. The proposed change in neural connectivity is shown schematically in figure 1.



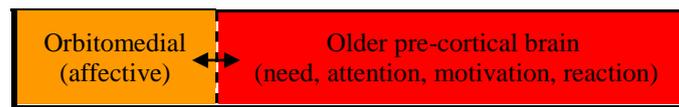


Figure 1. The architecture of the technicity adaptation. Extension of prefrontal neuron connection to the genomic information available in primary sensory cortex (arrow passing through the unshaded area) may be compared with the normal sensory-perceptual route (connections through the blue shaded areas). The type of information made available by the technicity adaptation from so-called feature detector neurons is illustrated symbolically. Note the reciprocal connectivity to the rest of the brain from prefrontal cortex and extensive connection between its cognitive and affective divisions.

That humans consider purple to be a colour, suggests that these neurone circuits are the source of colour concepts. The question now becomes: What other information might be available from this neural structure? The list includes: line length and angle and direction of motion in primary visual cortex, pitch in primary auditory cortex. The human ability to identify and blend notes to make perfumes and flavours in cuisine suggests olfactory bulb connections. There may well be others. For the present discussion, only line length and angle, the foundations of geometry, are needed.

Conflicting concepts

Linear cut-mark designs on bones are taken as an early sign of human behaviour. The Platonists identified geometric shape as an aspect of ideal form. Such activity is based on the composition of line length and angle information in prefrontal cortex. One ideal shape, the square, can affirm Papert's proposition about the felicity of construction. The shape may be physically constructed by folding; a straightedge and compass; or turtle commands, repeat 4 [fd (number) rt 90]; none of which are orientation sensitive. Now consider figure 2.

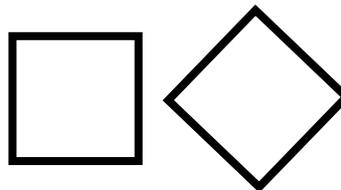


Figure 2. The square/diamond effect demonstrating the conflict between V-concepts and T-concepts. Both shapes are products of technicity and both are square, but the characteristics of the perceptual system lead to the perception, and naming, of two distinct objects.

Both shapes consist of pairs of equal length equidistant parallel lines intersecting at a right angle: a square. But the one-eighth rotation of the leftmost brings to mind a different, distinct form and name: diamond. At one level there is a single concept with a single verbal description; at another level two different linguistic concepts exist. Scientifically, they are the same cognitive construct, a product of technicity sourced from line orientation information in primary sensory cortex. Only when processed by the visual system does orientation becomes an issue; the result of perceptual artefact. Whilst this form is unique in generating the effect, it signals a general conceptual issue: the well documented divide between science and naïve perception. As the physical construction of a square and its rotation, and inspection of the effects of rotation, can overcome the perception of two objects in figure 2, so technicity-based constructs overcame the strong perception that the sun revolves around Earth.

Why is the technicity adaptation more powerful than perception and language? The answer lies in relative entropy, which the square/diamond effect helps clarify. The square is described only by



equality of side and angle, as the turtle geometric formulation demonstrates. The square/diamond effect includes orientation. Less information is needed to describe the technicity construct than to describe the perception-derived concept. It is, therefore, of lower entropy. Recalling that the brain is a physical system, Carnot principles show the technicity concept to be the more powerful.

The effect also demonstrates the weakness of language noted by Papert. Rotating produces the effect and resolves it: two perceptual, verbally-denoted concepts resolved into one. In so doing it produces a conflict with language. This is to be expected. Language, which serves perceptual processes, was fully evolved before the human technicity adaptation arose. Technicity, though the more powerful cognitive capacity, is verbally inarticulate and consequently must convey thought through constructed physical forms: Papert’s objects open to inspection. Here lies both the power of the technicity adaptation and the difficulty of its verbal communication.

In technicity contexts, language lacks the means of expression and new terms must be coined. In this case the word “concept” has ceased to be adequately expressive. It is proposed to resolve this by prefixing. Concepts originating from the technicity adaptation will be T-concepts. Those that arise by normal perceptual processes become V-concepts. The T denotes technicity as the source of the concept and honours Alan Turing (Ince 1992) whose thinking helped their identification. V denotes the perceptual/social/verbal nexus that is the foundation of these concepts and honours Lev Vigotsky (1962) who first described their formation. The crucial difference between the two is that a V-concept may be accepted because of its internal linguistic consistency but a T-concept is consistent with the behaviour of the physical world; to which technicity uniquely provides the human with cognitive access. Some differences between these two qualities of concept are shown in table 1.

T-concept	V-concept
Technicity based (genomic)	Perception based (experiential)
Non-linguistic (constructed product)	Verbal (internal and spoken utterance)
Low entropy (simple and powerful)	Environmental entropy (complex)
Species level (universal)	Culture level (specific)
Tested against properties of matter	Tested for cultural consistency

Table 1. Some differences in quality between T-concepts and V-concepts.

As an aside, it may be noted that, although only indirectly derived from language, mathematical formulations must also be proved against the real world.

Art and aesthetics

Prefrontal cortex has two divisions, affective and cognitive. The relationship between the two is described by Damasio (2006) and Fuster (2008). The effect is to give art and technology the same foundation, the difference being largely in affect: the constructions of the technologist have less affect when perceived than do those of the artist. However, at the creative construction stage they both entail control over the properties the materials employed. In order to play a violin concerto it is necessary to compose the music, using pitch information from primary sensory cortex, and build a violin using craft knowledge of wood and fibres. Science can describe the relationship between string length and pitch but evocative sounds rely on the craft exercise of technicity.

Triangulating technicity

The technicity thesis is a proposition designed to be tested for congruence with reality; merely to



be plausible is insufficient.

Child development and activity in kindergarten and primary school are by far the best sources of evidence, though little regarded by constructionists. By the age of eight, as figure 3 shows, the basic information that the technicity adaptation provides has begun to be combined into complex representations, though the purity of that information still shines through in simple geometric constructions and primary colouring. The drawing shows the use of mental processes that are also present in the structure in language. If these forms do not originate from the technicity adaptation, how does an immature mind extract them from sensory input, from environmental information?



Figure 3. A drawing by an eight year-old girl, illustrating the composition of primary-sensory-sourced information to create an aesthetically pleasing and expressive communication.

The earliest signs used to identify the presence of the human include pigment processing and the presence of points and other geometric microliths used to make component-built tools. There is no evidence that the larger-brained Neanderthal ever progressed beyond the standard Mousterian tool assemblage even when coexisting with the human. Neither is there evidence of artistic ability nor of any ability to organize living space (Findlayson 2010).

The mechanism proposed for the technicity adaptation is consistent with current knowledge in the fields of genetics, brain evolution and the role of prefrontal cortex. That the technicity adaptation comes on stream during the years of elementary education, from infancy to puberty, is consistent with the finding that prefrontal maturation takes place during this phase and is highly influenced by experience: hence the universal importance given to primary schooling.

There has long been the issue of the gulf between the “two cultures” of the sciences and arts (or humanities). This was categorised in terms of cocktail party conversation by Snow (1963) using Shakespeare and the Second Law as exemplars. In selecting Shakespeare, Snow placed the focus on the socio-linguistic domain, which has great evolutionary depth. This contrasts with the fruits of technicity, which are recent and have only secondary linguistic representation.

Finally, there is the issue of entropy. Technology is of far lower entropy, defined in both physical



and information terms, than biological phenotypes but is commensurate with that of genes. This means that technological forms created from this information have greater power than those that originate from perception: simple T-concepts are more powerful than complex V-concepts.

Summary

The economy of the technicity thesis is greater than its alternatives: language and the social brain. Some elements from which technology and art are constructed, and against which the verbal (and mathematical) hypotheses of science are tested, are listed in table 2.

Colour	Line	Motion	Pitch	Chemical
Pigment	Shapes	Projectiles	Tone	Flavour
Art	Architecture	Choreography	Music	Cuisine
Spectrum	Writing	Machines	Time	Molecules
Photons	Geometry	Entropy	Relativity	Particles

Table 2. Some sources of genomic information expressed in neurone circuits and behavioural correlates.

A cognitive consequence of the neurological architecture of technicity is an additional quality of concept. Directly sourced from low entropy information, T-concepts provide the entrée to science through technology and moderate social V-concepts derived from verbal-perceptual experience.

Technicity and linguistic thinking: T-concepts vs. V-concepts

Thought, from a technicity perspective is not language. T-conceptual thinking, by definition, is non-linguistic thought. In the case of music, dance, games, visual arts, architecture, mechanical and electronic design and production, and mathematics, the involvement of language is minimal: reducing to injunctions such as, “Do it like that.” Scientific enquiry is different. Academic means of communication are largely verbal. Conceptual frameworks shared between peers are expressed in language. Testing of scientific concepts is carried out, however, not against rigorous linguistic formulations, as is the case with philosophy and mathematics, but in terms of congruence with physical reality. Thus, the foundation of science is the technology devised to verify new ideas. Old ideas expressed in language and based on established perceptual processes are resistant to change because they fit the current view of reality. Advances in science appear to be outlandish when first proposed, even to eminent scholars: vide Einstein and quantum theory. Acceptance of scientific ideas, however unreasonable they might appear to V-conceptual thought, comes about because they work out in practice. This cognitive conflict explains the time needed for scientific ideas to take hold and the difficulty that many people have in accepting them. The V/T concept division may also lead to misconceptions, particularly where a large intellectual investment has been made. In the constructionist community there is a nice example of this process at work.

LOGO and Turtle Graphics

At the time the microcomputer entered the primary school classroom there was much discussion about its role: tool, tutor or tutee. For the present, the first is dominant. Papert, with a computerist background, was as much concerned with the programmability of the medium and its potential, as he saw it, to catalyse the early development of Piagetian formal operational thinking. LOGO, as a formal programming language might offer a means to this end. Work with the button box and the floor turtle suggested an entry point for young children of kindergarten and primary school age.



The simple ‘forward, back and turn’ commands to this small robot spawned turtle graphics and its academic big brother turtle geometry. Turtle graphics was simply the name for turtle drawing. Its academic variant offered educational kudos: a flexible relative geometry to complement the rigid frame of Cartesian coordinates. Turtle geometry (Abelson & diSessa 1980) was new math. Papert saw it as a means of inculcating mathematical thinking at primary school level. At another time in another place, it might have become a carefully researched PhD project. At the time, however, it was a poorly researched vehicle for getting computer science ideas into primary education. When primary school teachers expressed concerns about the subject matter in relation to the shape and space curriculum they taught, they were condemned as conservative and obstructive. A culture of questioning the professionalism of primary school teachers made this appear not unreasonable.

Both Papert (1981) and the authors of Turtle Geometry reported so-called bugs in the children’s thinking. Three classic bugs are shown in table 3 along with their associated explanations. These explanations seem reasonable and have an authentic mathematical and computer science feel. The suggested general solution was to “play turtle” to get the idea of heading. Teachers tried this with children moving paper arrowheads in different orientations. Papert went further and proposed that if children “Walked Turtle” a cognitive phenomenon that he called “body syntonicity” would lead to the internalising of the concept of heading and the ability to describe shapes in “Turtle Talk”. However, experience in the primary school classroom with turtle graphics suggested that there was a problem of greater cognitive depth and the idea of body syntonicity was questionable.

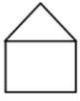
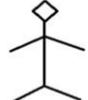
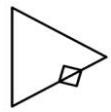
	Triangle	House	Man
Target			
Outcome			
Explanation	Thinking about the internal angle of the shape rather than the “heading” of the Turtle	Failure to realise that an “interface” procedure is needed to place the Turtle in the right state to draw.	Solved by breaking the drawing into procedures for the parts and then combining them, but see the house bug.

Table 3. The turtle geometric bugs reported in Mindstorms and Turtle Geometry.

Body syntonicity

Papert expressed the idea of body syntonicity, derived from Freud’s ego syntonicity, as follows:

“The Turtle circle incident illustrates syntonic learning. This term is borrowed from clinical psychology and can be contrasted to the dissociated learning already discussed. Sometimes the term is used with qualifiers that refer to different kinds of syntonicity. For example the Turtle circle is body syntonic in that the circle is firmly related to the children’s sense and knowledge about their own bodies. Or it is ego syntonic in that it is coherent with children’s sense of themselves a people with intentions, goals, desires, likes, and dislikes. A child who draws a Turtle circle wants to draw the circle; doing it produces pride and achievement.”



Turtle geometry is learnable because it is syntonic.” (Mindstorms p.63)

This argument is a linguistic one based on observation and analogy. The notion is V-conceptual. When referred to physical reality it is seen to conflict with the childhood development of drawing which is instrumental. The constructive processes of technicity make shapes, like the ones played with in infant posting boxes and in kindergarten. The child has a concept of circle already in mind, the earliest scribbles are circular. It follows that stepping around a circle and describing the action is but to create a mnemonic to link to the programming language. Papert’s linking with the aesthetic is, however, entirely consistent with technicity and is highly educationally important.

Rotating squares

Unqualified hindsight is of little value, but when informed by a new perspective can help to guide thinking. On the preceding page of *Mindstorms* is the illustration in table 4 column two. Rotating figures was a pastime that mathematics educators liked because it emphasises the invariance of the form, illustrates symmetry and is aesthetically pleasing. The rotation here is 120°, the angle of turn for the turtle triangle. Papert suggests other angles be tried, illustrating the shape produced by 36°. A turn of 45° (table 4, column 3) is not mentioned. The shape is disturbing, dissonant. Conceptual conflict arises from V-conceptual perceptuo-linguistic effects. It is perceived as two different figures and not as the same one rotated. It feels anti-mathetic. When repeated eight times the figure in column 4 is generated. Here diamond and square vie for dominance.

to square repeat 4 [fd 50 rt 90]	repeat 3 [square rt 120]	repeat 2 [square rt 135]	repeat 8 [square rt 135]

Table 4. Rotations reported in *Mindstorms* and the square/diamond rotation.

Do we see the mathematician’s search for pattern and symmetry subconsciously overlooking the dissonance? Did educational philosophy and mathematical evangelism misdirect critical thought? Whatever, the need for new ideas to be rigorously tested against reality is shown in stark relief.

Education

It should be obvious that the technicity adaptation imposes the requirement for education on the human. T-conceptual products of technicity do not derive from a genetically specified capability as do animal artefacts and communication, including human language. They cannot be activated and refined by immersion in the social milieu. Epistemological processes are required to transmit and increment knowledge generationally. These matters are discussed in a companion paper.

Conclusion

A thesis is useful only if it illuminates cognitively dark corners, suggests further research, and (preferably) has immediate application. Technicity fulfils all these requirements and more. The



instruction/construction distinction hinted at by Papert is given a sound biological foundation, and, fittingly for the conference location, the Platonist's question concerning the redness of red is given an answer; and geometry, as written over the Academy door, takes on new meaning. Most importantly, however, the cognitive complexity, so frequently passed over, of the primary phase of education is thrown into sharp relief – to the possible embarrassment of academe.

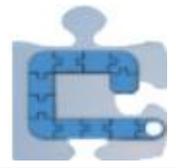
Nobody expects the second law of thermodynamics to appear at a conference as mathematically oriented as Eurologo; but it has now. Entropy underpins technicity, the evolutionary adaptation unique to the human and the source of the species' technological capability and artistic ability. It is the power behind constructionist educational methods. It offers both prospects and discomfort.

Acknowledgements

Richad Noss, for redirecting a primary school teacher to *Mindstorms*.

References

- Abelson, H. and diSessa, A. (1981). *Turtle Geometry: The Computer as a Medium for Exploring Mathematics*. Boston, Mass: The MIT Press.
- Anning, A. and Ring, K. (2004). *Making Sense of Children's Drawings*. Maidenhead Berks: Open University Press.
- Bransford, J. D., Brown, A. L., Cocking, R. R. (eds.) (2000). *How People Learn, Expanded Edition*. Washington DC: National Academy Press.
- Damasio, A. (2006). *Descartes' Error: Emotion, reason and the human brain*. London: Vintage.
- Dawkins, R. (1989). *The Selfish Gene*. Oxford: Oxford University Press.
- Dawkins, R. (1999). *The Extended Phenotype*. Oxford: Oxford University Press.
- Dunbar, R. (2004a). *Grooming, Gossip and the Evolution of Language*. London: Faber & Faber.
- Dunbar, R. (2004b). *The Human Story*. London: Faber & Faber.
- Finlayson, C. (2010). *Humans Who Went Extinct: Why Neanderthals died out and we survived*. Oxford: Oxford University Press.
- Fuster, J.M. (2008). *The Prefrontal Cortex. Fourth Edition*. London: Academic Press.
- Harel, I., & Papert, S. (1991). *Constructionism*. Norwood, NJ: Ablex Publishing Corporation.
- Hubel, D.H. (1995) *Eye, Brain, and Vision*. <http://hubel.med.harvard.edu/index.html> [20.07.2011]
- Ince, D. C. (1992). *Collected Works of Alan Turing: Mechanical Intelligence*. London, New Holland
- Lewin, R. (1998), *Principles of Human Evolution*. Malden MA: Blackwell Scientific.
- Mellors, P. Boyle, K. Bar-Yosef, O. and Stringer, C. (eds). (2007). *Rethinking the Human Revolution*, Cambridge: McDonald Institute Monograph.
- Ó Dúill, M. (2010). *Can there be a Science of Construction?* In: Clayson, E.J., Kalaš, I, Eds. *Proceedings of Constructionism 2010 – 12th European Logo Conference*. Faculty of Mathematics, Physics and Informatics Comenius University, Bratislava.
- Papert, S. (1980). *Mindstorms*. Brighton: Harvester Press.
- Snow, C. P. (1963): *The Two Cultures and a Second Look*. New English Library, London.



Constructionism 2012, Athens, Greece

Stonier, T. (1990): *Information and the Internal Structure of the Universe*. London: Springer-Verlag.

Striedter, G.F. (2005): *Principles of Brain Evolution*. Sunderland MA: Sinauer Associates.

Vigotsky, L. (1962): *Thought and Language*. The MIT Press, Cambridge MA.