Can there be a Science of Construction?

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Abstract

What is Constructionism? What is Instructionism? How are they related? Is either idea well enough defined to be tested scientifically? Or are both philosophical postures adopted by people who have differing views of children and education? If both are more philosophical than testable, they have little relevance for classroom teachers. The craft of the teacher has a deep history. It has employed “talk and chalk” for over five millennia. The only novel element is the computer.

The art of science is simplification – and surprise. The current formulations: Constructionism as making physical objects; Instructionism as verbal transmission, are inadequate. However, two aspects of Logo, Turtle Graphics & Talk, suggest a route forward. Were these to represent two distinct human capabilities, we might reduce capacity to Construct to the human ability to draw. Instruction may then be reduced to the human capacity to talk. We contrast drawing with talking.

A review of behavioural science reveals a massive hole in psychology. We do not know how human beings have the capacity to draw – in contrast to quite detailed knowledge about speech. It follows that proponents of verbally-based instruction have a scientific basis Constructionists cannot match, The advent of a constructive medium, the computer, highlights this deficit.

The task in this paper is to assemble evidence that might offer Constructionism some scientific support. Our species is considered in its evolutionary setting. This includes mapping the sequence of hominine evolution and considering genetic foundations for society and technology. Two important concepts are: reciprocal altruism; and the extended phenotype. Aspects of the large brain that characterises our species are considered, particularly the executive function of prefrontal cortex, and its connectivity and maturation in relation to primary education.

A hypothesis about how humans are able to draw is presented. The theory is that the human brain is more extensively interconnected than that of our precursors. Uniquely, prefrontal cortex accesses information about how the brain processes primary information. Support for this hypothesis is provided from primary school years, the archaeological record of our species, and a small psychological experiment. Herein are found the elements of our technological capability. The word ‘technicity’ is borrowed from philosophy to denote this evolutionary adaptation.

The idea is applied to the media used in primary education, specifically in literacy and numeracy. t raise the question of whether a constructive medium would help children to learn more easily. There is also an implication that primary education in practice has an overall technicity focus.

Given the evolutionary importance of verbal communication, research is needed to clarify the role of “talk and chalk” in the classroom relative to construction. We are unconscious users of language and view literacy from a utilitarian perspective: a skill for learning and life. Is it perhaps time to ask the question: In what manner has technicity enhanced and refined language?

In summary, the claim is made that available science may not only support the constructionist position but also its stance on instructionist method. Technology, the hallmark of humanity, is at the heart of education. The new computer technology is arguably our most powerful constructive medium. The analysis in this paper suggests that increased use of the full potential of the new medium for active processing in teaching method with bring major cognitive benefits.

Keywords

Computers, learning, talking, drawing, constructivism, evolution, teaching method, technicity

Introduction

I am a teacher. I have taught children for many years, at both primary and secondary level. However, most of the children I taught had learning difficulties. Throughout my teaching career I have been beset by theorists and so-called educational innovators. I have been asked to be modern and then to be traditional. When, in the 1980s the computer arrived. I thought, "Here is a new educational medium with huge potential." (Doyle 1986). I was excited by the consequences for literacy of a machine that could read and write; excited by a machine that could do sums; and I was excited by a machine that children could teach to do things. That was three decades ago.

I have enjoyed being involved with Logo, although opportunities to use it with my children were, and remain, limited. But the Logo community and the biennial EuroLogo Conferences provided an opportunity for me to think outside the classroom box. I met people who had a view of the computer not dissimilar from mine. I didn't really mind that these conferences tended to be mathematically oriented. There was a delightful mix of practical innovation with innovative practice. I was made uncomfortable, however, by the small amount of such innovation that transferred to school. Comenius Logo, when it arrived in the 1990s with graphics as primary data, seemed better suited to the everyday classroom. I am pleased that Logo-based microworlds introduce children to computers in at least one country (Ilieva and Ivailov 2003).

I was not too concerned when the Eurologo name was dropped for "Constructionism," and an extra year skipped to avoid clashing with WCCE2009. However, when I was asked by a very talented primary school teacher, what "constructionism" was I found myself in some difficulty. I (just) survived the behaviourism of the '60s and '70s and avoided the traditionalism of the '80s and '90s. Am I to be seduced by another "ism" In the twenty-first century?

No! A classroom teacher with boisterous children, I need effective techniques at my fingertips. But, with the computer this was, and still is, not possible. The computer is a new medium. I want teaching methods that fully realise its potential. However, the formulation of Constructionism has forced me to take a step back from the computer and to consider what it is to construct.

Towards science

Constructionism is defined through philosophical discussion and illustrative parable (Harel and Papert 1991, Papert 1994, LCSI 1999). That is, verbally. A science of construction is seen as premature. Reduction to a simple catch-phrase is resisted. Not unreasonable, but science works by simplification. So that, in the words of an English idiom, the wood can be seen for the trees.

A good starting point is the wording on the Constructionism2010 website:

> Constructionism shares constructivism's connotation of learning as "building knowledge structures" irrespective of the circumstances of learning.
>
> It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity.

The first paragraph provides a part of our foundation. It restates the Piagetian position, which is now well accepted scientifically (Bransford et al 2000). The second paragraph is our starting point. What does "constructing a public entity" mean? Also, what is the "instructionism," which Papert contrasts with constructionism?

It is easy to find a simplification for Instructionism. Papert prefixes it with "verbal." Let us reduce instruction to "**speech**" (the "talk" of school parlance).

Constructionism has been stereotyped as “making things,” but this does not capture its essence. I propose to reduce construction to “**drawing**” (the “chalk” of school parlance). Is it not said that “A picture is worth a thousand words.”?

Reduction to “speech” and “drawing” brings immediate clarity:

A. Speech is an evolved biological adaptation unique to extant humans (Pinker 1995). It is a genetically determined part of the phenotype. Specific anatomical, physiological and neurological structures have evolved for speech. A normal child born into any culture will become a competent user of its language by the age of four. The languages of all humans, though different in sound and structure, are equally expressive.

B. Drawing is technology. Anatomical, physiological or neural adaptations for technology are not apparent. Children draw from the age of about four, but children’s drawings are unreal assemblages of geometric-like forms. Technology is unique to modern humans. It extends our phenotype in myriad increasingly complex ways. Sophistication, function, power, construction, and materials of technology vary across cultures (Diamond 1998).

It is seems that we may have isolated two separate human capabilities. Burling (2005) captures their mutual isolation in the following anecdote:

> The only technical instruction I could ever elicit would come when a man would reach for my tool and materials, demonstrate the manner in which the job should be done, and then hand them back along with the injunction: “Do it like that.”

Our technological capability needs a name as concise as “**language**.” I will use “**technicity**”, a word derived from Heidegger’s (1977) philosophical enquiry into the essence of technology

A hole in knowledge

For a summary of scientific evidence, it is useful to turn to student texts. “Atkinson and Hilgard”, (Nolen-Hoeksema et al 2009), the introduction to psychology of my student days, has now reached its 15th edition. There is a chapter entitled “Language and Thought.” There is no chapter on construction or technology and less reference to drawing than in the original. There is no consideration of how the beautiful illustrations of visual illusions in Gregory’s (1966) “Eye and Brain” come about. Books on children’s drawing development can be counted on one hand. Kellogg (1969), Gardner (1980), Cox (1992), and Anning and Ring (2004), treat drawing as art. Only Goodenough (1926) considers drawing from a cognitive perspective. Otherwise: nothing.

Verbal instructionists can call upon a huge literature to back their claims. One text influential in education is “Thought and Language” (Vigotsky 1962) which also emphasises social interaction, equally well researched. The school curriculum puts language first; in the UK it is as “English.”

Constructionism has a problem.

Evolutionary context

The following section contains the essential points that are relevant but includes sources which can provide additional background or clarification if required.

Human evolution

Darwin’s (1859 1968) theory of evolution has proved scientifically more fruitful than those based on mythology (Kramer 1972). The modern synthesis with genetics (Dawkins 1989, Jones 1994) provides a powerful tool for studying human origins (Lewin 1998, Stringer and Andrews 2005, Mellars et al 2007). It seems that human evolution was a three stage process:

1. Evolutionary split from the apes to form the hominine lineage about 2.5 million years ago;

2. Rapid expansion of brain size about 1.8 million years ago. This was accompanied by reduction in sexual dimorphism; extended childhood; range expansion outside Africa into Europe and Asia; a complex tool assemblage including a characteristic bi-facial hand-axe; and increased behavioural complexity. The species identified are Homo ergaster followed by Homo erectus. Evidence suggests that speech originated in these species.
3. A second burst of brain expansion happened 0.5 a million years ago. It is associated with archaic Homo sapiens. Two well documented species are the Neanderthals and modern Humans (us). Cold-adapted Neanderthals were confined to Europe. Genetic evidence suggests our direct ancestors emerged in Africa by 200,000 years ago. There is evidence for 'modern' behaviour (technology) from 300,000 years ago (McBrearty and Brooks 2000). Some 70,000 years ago we spread out from Africa, reaching Australia (by boat) 50,000 years ago. We were living in Europe 10,000 years later, where we influenced and out-competed the Neanderthals. Both we and the Neanderthals had a fully developed suite of speech adaptations. So, although we differed in our technological capability, both species (and our common ancestor) may have had genetically modern language.

The balance of the evidence supports the proposition that spoken language evolved before our species did. Conversely, there is no evidence that technicity evolved in any species prior to us.

Genes and society

The survival of the fittest has come a long way since Darwin. Hamilton (1964) showed that nepotism facilitates family gene-pool survival, which may explain, for example, the menopause. More powerfully, Trivers (2000) demonstrated that cooperation between strangers can enhance the individual survival of both. This life-style is called "reciprocal altruism" (RA). It is the way we live. The prerequisites include the ability to recognise other individuals (we recognise faces) and good memory for events. These favour species with a large neo-cortex. The problem with RA is cheating: attractive in the short term but disastrous – mathematically modelled as the "Prisoners Dilemma" (Axelrod 2006, Cosmides and Tooby 1992). The loophole for cheats is the need to cooperate on first meeting. Hence, a stranger is more likely to be a cheat than a neighbour. Nettle (1999) demonstrated that certain characteristics of language, including accent and language diversity, are powerful determinants of successful reciprocal altruism in terms both of stranger detection and group identity. Dunbar (2004a 2004b) suggests that gossip and theory of mind (ToM) both assist this life-style. The levels of intentionality (ToM) at which people operate when gossiping is commensurate with levels of recursion (embedded clauses) used in language.

We are the only species to live in huge city communities with specialised services and roles, which we trade with strangers. The relationship between reciprocal altruism, large group living, and language suggests that this biological adaptation is prerequisite for our life-style.

A large brain

A big neo-cortex processes more information, so aids survival in complex environments (Ashby 1971). The first cortical expansion (above) was adaptive in complex natural environments. Byrne and Whiten (1988), Whiten and Byrne (1997) suggest that the later expansion was an adaptation to a complex social environment (see Barrett et al 2002). A larger cortex entails a greater range of capabilities (Deacon 1997). New brain areas are created and there is increased connectivity (Streidter 2005). In the human, the greatest expansion occurred in prefrontal cortex. Prefrontal cortex is massively reciprocally connected to all parts of the brain. It has an executive function, providing working memory, selective attention, and planning functions (Fuster 2008). The orbito-medial part is mainly connected to the limbic system and is concerned with motivation and long-term planning (Damasio 2006). Lateral prefrontal cortex is connected to pre-motor and sensory association areas. It is largely involved with cognition. No area of this cortex can be isolated as a language-module. Language processing, like other working memory tasks, appears widely distributed. The role of prefrontal cortex is to "invent futures from the past;" that is, to access and reassemble memory to offer the choice of a range of alternative action-scenarios in a given circumstance. In other words, it is the source of creativity for humans and other mammals.

In the human, prefrontal cortex matures rapidly between the ages of 6 and10, reaching the adult stage by about 12. Lateral (cognitive) prefrontal cortex continues to mature into the third decade of life. Phases of education in industrial societies appear to run in concert with this maturation.

Genes and tools

Biological (phenotypic) adaptations are built by genes. Dawkins (1999) powerful idea of the “extended phenotype” brings construction into the genetic realm. A bird is more likely to survive if nest ‘design’ is built into its brain as a genetically determined behaviour – a template. This is because generational transmission is unreliable, even in chimpanzees (Matsuzawa et al 2001). Learned behaviour is viable only if not critical for survival. An indicator of genetic determination is stability over time. The tool assemblages of all hominine species, other than modern humans, were stable for very long periods: Homo erectus, 1.5 million years; Neanderthals, 300,000 years.

We are the only species to let the genetic tool-template atrophy. For us, the risk inherent in generational learning is mitigated by the RA lifestyle and speech. But there is no benefit unless tools become technology. I.e. there is a mechanism for generational learning to improve design.

Whence technology?

I offer pointers to a process by which one hominine developed a lifestyle of such complexity that it can support the plot of a Shakespeare play with all the levels of interpersonal intentionality therein (Dunbar 2004b). It is not surprising that Deacon (1997), a neuro-scientist, argues that our symbolic capabilities emerged from a co-evolution of language and brain. Default to Language is attractive but it cannot be sufficient; and neither can the socio-sexual driver that Power (1999) perceives in the evolution of art. Other species spoke and had complex social relations, but they didn’t build a computer, even after 200,000 years. The literature does not illuminate the mental ‘how’ of human technology. Brain research offers little enlightenment. I hope education will.

Technicity: a hypothesis

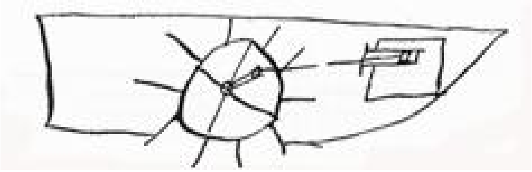
Hubel (1995) described feature detecting neurones in primary visual cortex. There are neurones that react to lines of specific orientation, and of specific length; colour neurones distinguish between blue and yellow, red and green, and dark and light; and motion neurones that detect movement in a particular direction. In primary auditory cortex, neurons respond to notes of specific pitch. Here is elemental data from which more complex entities might be constructed.

Prefrontal to primary sensory connection is feasible. Some neurologists presume a connection. Though, such connectivity is not apparent in the primate (Crick and Koch 1995). Let us suppose there is direct prefrontal connection to primary sensory cortex. Elemental feature information could be accessed, assembled and combined in prefrontal cortex, as if it were a stored memory. Here is a neural mechanism for the technology improvement-cycle, geometry and mechanisms.

Drawing

Unlike the words of language, elementary sense-data are not arbitrary symbols. They are reality abstracted. This is why I have made drawing stand proxy for our technological capability.

No other animal draws. Children and chimpanzees scribble, but even a chimpanzee that had symbolic language failed to learn reliably to join dot to dot (Iverson and Matsuzawa 2001). Children’s drawings cover classroom walls. This indicates that drawing relies on some peculiar organisation of the human brain. During child development, drawing follows language. But unlike language, graphic development is gradual with competence not appearing until puberty. This suggests co-development with prefrontal cortex. Primary visual cortex provides the line-elements needed, prefrontal cortex the planning and pleasure. Below, figure 1, are two drawings.



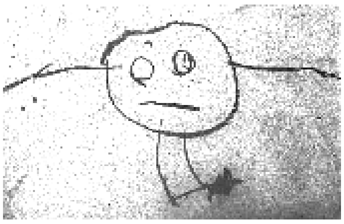


Figure 1a. (Left) Trevithick's drawing of a steamboat with paddle wheel amidships, 1806.
Figure 1b.(Right) A 'tadpole' drawing from the Kellogg online collection (age 3 to 4 years).

On the left is a sketch by a professional engineer, on the right an infant's figure. Is there not an essential similarity? They use the same graphic elements; and both show only relevant features.

Goodenough (1926:12) noted that:

> *… a child draws what he knows, rather than what he sees …*

To which we might respond – and so does the engineer! If the child is not drawing what s/he sees: from where within the nervous system does the knowledge come? The human brain has a specific area for recognising faces (Carter 2000:196). So, facial-feature knowledge might be sourced from the facial recognition system. But where do lines and circles reside in the brain?

Childhood evidence

What is the evidence from the kindergarten? Below, figure 2, are examples of infant material:

Figure 2. Kindergarten equipment showing elemental colour, line and pitch features.

Do they not reflect the fundamental features into which our brain decomposes the visual image? Is it conceivable that the toys we give to toddlers actually help the brain to connect to primary sources of sensation? The colours are right. The shapes are right. They are simply and regularly combined, even in the three-dimensional building blocks and the wheel – archetypal technology.

Whilst this evidence is indirect, it supports the notion that the way we structure learning in early years education helps human infants to develop skills in abstracting elemental information.

Archaeological evidence

McBrearty (2007) is insistent that modern human behaviour began to appear 300,000 years ago. She cites presence of bright red ochre and grindstones at living sites. Its use is thought to be like that in some modern cultures – symbolic representation of menstrual blood (Power 1999). But it also suggests 'knowledge' of pure red, i.e. a prefrontal-sensory connection. More persuasive are flints knapped into simple geometric forms to make compound tools, from 200,000 years ago.

Experimental evidence

The earliest mathematics appears to have been geometry. Below, figure 3, are two squares.

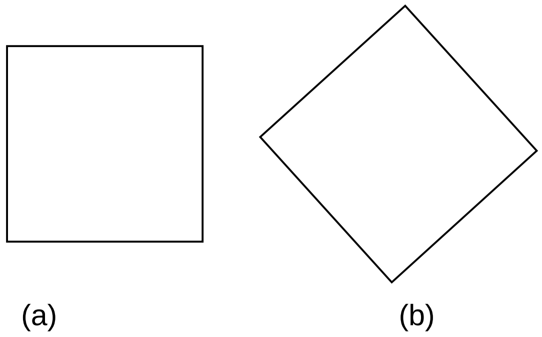


Figure 3. Object-constancy breaking forms

We can do a neat experiment with a square. Show someone drawing (a) and they will name it as a square. Rotate it by one eighth turn to (b) and the word 'diamond,' previously unthinkable, will come to mind. This does not happen with a picture of a cat. Object constancy is a perceptual mechanism that keeps the world the same from different viewpoints. The experiment reveals our capacity to construct forms that by-pass this mechanism. I suggest that humans, uniquely, can create shapes within prefrontal cortex from data available at the neurones of the primary visual cortex. The square is particularly interesting, because lines separated by 90° excite totally different neurones (Hubel 1995). Therefore, there is primary visual data to construct a precise rectangle. I.e. we carry around the Platonic 'ideal' square in the structure of our nervous system.

Technology

I suggest prefrontal to primary sensory connectivity began to develop in a direct ancestor and that it led to a speciation. A process of generational learning accompanied by the capacity to make design improvements could lead to increasingly sophisticated technology. The capacity for 'design improvement' resides in the function of the prefrontal cortex, particularly the lateral convexity. It makes practicable the atrophy of the genetic tool-template through an ability to visualize modified tool designs. This is the evolutionary adaptation for which I use the word technicity. We, alone amongst animals, can imagine a different environment. But our conception is far simpler in form than is nature. Houses, tools, and fields are geometric. Colour is uniform. Music has notes. Children's drawings are not just art precursors; they reveal a capacity for engineering, for graphic technologies, for simplifying and extracting the essence. Surely, surprisingly, may not the foundation of science be discovered in this abstraction of simplicity?

School matters

We are literate and write what we mean. Mathematics and technology march in step (Hawking 2005). The earliest known schools taught the 3Rs 4,000 years ago in Sumer (Kramer 1981).

Two modes of learning

It should now be clear that human beings have two learning modes: a) a robust speech/memory combination, of evolutionary depth serving reciprocal altruism; b) a recent (risky) constructive technicity, expressed in technologies that extend our physical and mental phenotype. Both use a prefrontal capacity for creativity. Only technology progresses – through generational learning.

The computer as an educational medium

Some (Papert 1980) see the computer as a revolutionary agent; others as a means of better teaching the existing curriculum. The latter prevails. Alexander (2009) is fearful of ICT, whilst Rose (2009) sees 'technology' as a skill. Neither sees the computer for what it is: a medium. This is surprising because it has unique characteristics, compared with the oral and textual.

Oral methods rely on human memory. Mnemonics, chant, and ballad aid retention and recall.

Writing is an external memory store. Books are an advance on oral method because they can contain drawings and other notations, as well as words. Euclid took advantage of this.

The computer constructively extends our phenotype by processing information. It is a far larger medium-transition than was writing. Writing and drawing externalized human memory – beneficially. Our new capacity to emulate mental processes, many made necessary by writing, should similarly be beneficial. But conflict has arisen because the computer can mechanically perform "mental" operations – of numeracy and literacy – that are basic in the extant curriculum.

Literacy

Speech fades to imperfect recollection in a breath of air. The meaning of words can be denied by tone of voice. But, by drawing the words of speech we make them open to public scrutiny. We construct writing systems that extract the essence of speech (Robinson 1995). Once words are concrete, a wordsmith can combine them is novel ways, to tell of verbal duplicity (Chang 1991); a psycholinguist can analyse them as a window on thought (Pinker 2008). Literacy gives us a measure of control over speech (Oppenheim 1992). Why is literacy not taught as a technology?

The thrall of speech leads to methods that map spelling to the sounds of a language (Gupta 2001); and to the computational absurdity of speech from text (Taylor 2008). Yet, the English alphabet refines articulatory complexity to 26 letters, simplifying dialect vowel variation to 5: very close to the essential sounds for speech intelligibility (Jenkins 2000). Why does literacy method not now use auditory technology that lets children construct what they see, not what they say?

Numeracy

Accounting with numbers is not natural. We prefer to distinguishing features and name things. Gallistel et al (2005) found that, in common with primates, we naturally use real number. Societies that do account appear to construct number vocabulary according to Miller's (1956) "Magic number 7±2." We mentally 'bundle-up' number concepts at the level of hands-full.

Language expresses mental chunking at the count of ten. Grouping objects does not. The technology of graphic number representation has improved in design over time. Roman numerals, for example, are closer to physical grouping than to the Latin language. The later Hindu-Arabic place-value numeral system is fully in step with language, including Latin. But it is not congruent with physical object counting. Consider the counting square below, figure 4:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	2	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

Figure 4. Hundred square

Figure 5. Gear-wheel counter

If good mathematics is elegant, then there is something anti-mathematical about the hundred-square, popular in schools: The numerals don't fit. (Roman numerals do – try them.) The final column does not model 'bundling up' at each ten. So, it is probably out of step with thought: A source of confusion for children? A physical number representation congruent with both modern numerals and language is available, figure 5. It meshes with the gears of Papert's (1980:viii) childhood. And it nicely illustrates “borrowing” and “carrying”. This, a simple adding machine, is more in tune with children’s minds than error-prone counting. Why is the constructive capacity of the computer to represent number operations not now a route to number understanding?

Method

Teaching has helped children to construct meaning from books – from external memory. Is there not now a pressing need for education to step up to the challenge of a constructive medium?

In summary

The absence of any scientific basis for our constructive and technological capability is the largest inhibiting factor in developing a sound species-level theory of education. I hope the argument I have outlined has enough detail to convince you that there can be a science of Constructionism.

I suggested that language evolved in a precursor species; as a prerequisite for a reciprocally altruistic life-style. An excellent memory is similarly prerequisite. Is it possible that instructionism, with its language basis and memory cramming tendencies, employs primitive evolved features?

Prefrontal cortex connectivity and maturation is at undoubtedly at the heart of primary education, and developing individuality. I argue that Technicity, our species-specific unique constructional capability, is rooted in neural primary sensory data / lateral prefrontal connectivity.

Research implications include language as a window on thought, as well as communication.

Implications for teaching method include a more constructional focus from kindergarten through primary education. The stored program digital computer is arguably humanity’s greatest physical and intellectual construction. As a medium it carries out processes that were previously mental. This challenges traditional method in primary education, particularly in literacy and numeracy.

The technicity hypothesis suggests that making learning easier should be natural and beneficial. progression. I offer a species focus rather than a cultural view of primary education, eschewing philosophy. The view of technology and learning presented is novel. I looked at its pointers to teaching method, raising questions. I hope that it offers a basis for furthering constructionism.

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