Sketch for a Scientific Foundation for Constructionism: with a note of some difficulties

Mike Doyle

mikedoyle@logios.org

Abstract. TERECoP situates itself within the constructionist philosophy of pedagogy. This paper outlines a thesis that seeks to place constructionism in a Neo-Darwinian scientific framework. It is suggested that our capability to construct is a successful, data processing, evolutionary adaptation that is unique to our species. Instructionism, conversely, it is suggested, is associated with ancestral adaptations for group living, specifically language and memory. Reaction to certain ICT developments is considered from the viewpoint of this two-adaptation model. It is concluded that the model does offer the potential both to provide a scientific foundation for the constructionist approach and also offer a possible explanation of the tenacity of the instructionist approach.

Keywords: technology, constructionism, instructionism, language, evolution

1 Introduction

The TERECoP robotics education project of the EU Comenius Programme situates itself within a theoretical approach based on Piaget's constructivism as enhanced by Papert's constructionism set in a Vigotskian social context [1]. The authors noted that, a quarter of a century of ICT-based robotics notwithstanding, robotics had made few inroads into the school curriculum. As with mainstream ICT, robotics remains a tool for supporting other ends, such as science, mathematics and teamwork.

They contrast the constructionist approach with instructionist pedagogy. This latter is normally language and memory based, and focuses on the 'value' teachers add to pupils; e.g. see the English education system [2]. Both language and memory have been subject to extensive study. Construction is relatively little researched and poorly understood. Indeed, the academic default is that language is the catalyst of creativity: our lack of understanding of how we 'do' technology and science notwithstanding.

1.1 Two Cultures

Robotics, in common with science and mathematics, suffers from the Two Cultures [3] syndrome: an educated individual is expected to converse on Shakespeare but not on entropy. There is tension between word and graphic as information carriers [4]. In school, language has higher status than engineering. This suggests that the reluctance

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pp. 31-42

of education to incorporate robotics into the curriculum has a cause deeper than a lack of suitable training materials.

The aim of this paper is to give constructionism a firmer foundation by subjecting the constructionist/instructionist dichotomy to evolutionary, Darwinian, scrutiny. It is hoped this will begin to explain the relatively unregarded status of engineering in a technologically dependent culture controlled by an academic-administrative elite.

2 It’s not there! What’s not there?

By standing on the shoulders of giants, we see further through their eyes: but we find great difficulty in thinking their unthought thoughts. We tend to clone the unknown from existing knowledge:

> Something puzzling happened 50,000 to 100,000 years ago. The fossil evidence is patchy, but it seems that hominids suddenly developed brains that, in terms of size, were very much like ours. Yet this apparent growth spurt was not reflected immediately by any great cultural changes. That came 50,000 years later, when a whole variety of artefacts – tools and musical instruments and cave drawings – suddenly came on the scene.
>
> Something must have happened between the physical changes in the brain and the cultural expression of such changes. Most linguists now agree that the something was the development of language. I am sure that our ancestors had been communicating for a long time (half a million years or so) before they became linguistically competent, so perhaps there is something in language itself that led to this acceleration of cultural complexity.
>
> Or could it have been the other way round? Could cultural changes have brought about the development of language?

The importance of gossip, Maynard Smith [24:257]

2.2 Incremental change

Two words: *suddenly* and *language*, above, raise interesting questions.

- At speciation, the suite of characteristics that later distinguishes a species will only have reached the stage where interbreeding with the root population ceases to be desirable. There is no guarantee, indeed it is unlikely, that the incremental gene-driven process of phenotypic change will be complete.
- Technology, the creator of culture, does not magically appear. It progresses in precision and complexity over the generations, constrained by the amount of mental work and physical resource that are made available, i.e. by limitations enshrined in the second principle of thermodynamics.
- A neural mechanism to link language to technology is required. No such link is demonstrated, or even proposed. It is presumed.

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pp. 31-42

2.3 The missing knowledge

Introductory texts on psychology, e.g. Atkinson & Hilgard [5]: have a chapter on language, on perception, on social relationships, but nothing about our ability to draw and to construct. So we have no scientific foundation upon which to build pedagogy.

- We are ignorant of how human beings do technology.
- We do not know how children begin to able to draw.
- We remain prisoners of philosophies woven with words.

The cultural default is: because we have language we can make things – or vice-versa.

3 On being human

Over the centuries, various attributes have been used to define our uniqueness relative to all other species. Tool-use was an early identifier – but other species use tools and construct entities: the tools used by chimpanzees have been reckoned commensurate with the tool-kit of Tasmanians [6]; and termite colonies and the nests of birds are complex built artefacts. The current favoured identifier is language [7 8 9 10]. Again, other species, particularly primates, appear to have language capacity: bonobos have learned symbol systems. Similarly, the life-style of humanity has many ape parallels [11]. On the other hand, an attempt to teach a language-using bonobo to draw a line between two dots failed [12]. So, drawing might just be a valid index of difference.

3.1 Human evolution

The Homo lineage stretches back to our divergence from the chimpanzees over five million years ago. Homo sapiens sapiens is about 150,000 years old. Species related to our lineage are: Homo habilis, associated with simple stone tools; Homo erectus, with a sophisticated tool assemblage (including the characteristic bifacial 'hand-axe'), who used fire and ranged across Africa and Asia; Homo neanderthalensis ranged cold Europe whilst anatomically modern humans inhabited warmer Africa, meeting in the Levant 100,000 years ago and coexisting in ice-age Europe until around 30,000 years ago [13]. Both had similar toolkits. Both had brains as large as, or larger, than ours.

3.2 Speech

The first indicators of speech are seen in the first member of this lineage, around two million years ago. Speech anatomy is more pronounced in H erectus a million years later. The Neanderthals and their more slender African contemporaries had the full suite of anatomical modifications found in modern humans. This suggests that their common ancestor spoke articulately around half a million years ago. Hence, we are not the first species to speak. Indeed, language (Saussure's parole) may have been a highly developed evolutionary adaptation well before our speciation event occurred.

Why speak? **W**hy might language, once evolved, be adaptive? The answer appears to lie in our highly unusual social lifestyle.

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pp. 31-42

Lifestyle. The human lifestyle is biologically unusual and intrinsically unstable. The genetic Darwinian model [14 15] fits most lifestyles including parasitism; symbiosis; daughters forgoing reproduction to help raise siblings; and herd living. However, it neither explains human capacity for large group social living, cooperating with genetically unrelated people, and designing and making artefacts, nor cooperation between genes in cell nuclei. Evolutionary psychology [16] offers an explanation.

Reciprocal altruism. If I have an overabundance of resources at the present, it pays me to share the excess with you, provided that I can be sure that you will reciprocate when the situation is reversed. Similarly, it pays you to honour your contract with me. A reciprocally altruistic lifestyle is an evolutionary stable strategy for the individual in an economic climate of unevenly distributed resources. In adaptation terms, there is a mutual increase in the likelihood of grandchildren of reproductive age. Prisoner's Dilemma, a game theory model, demonstrates how a small guaranteed mutual gain is assured by working together; but that a defector can scoop the jackpot on any given occasion, so non-cooperation is always a tempting option. The reciprocally altruistic lifestyle, put simply, is trade. Our lifestyle is characterised by trade and negotiation.

Making it work. Reciprocity needs work. In a naïvely cooperative population, the (inevitable) evolution of non-co-operators soon results in the co-operators becoming extinct. For reciprocal altruism to be evolutionarily stable, the cooperators need a means of controlling non-co-operative behaviour (defection or freeloading). For sentient organisms, like us, there are three prerequisites:

1. the ability to recognise oneself and other individuals;
2. a good memory for past events; and
3. a mechanism for sanctioning defectors.

The first two are functions of the nervous system that emerged with higher primates.

Defection control. A 'tit-for-tat' algorithm [17] is sufficient to assure reciprocity. The rule is: Cooperate on first meeting; thereafter reciprocate only if the other does. When implemented in a (computer) model, non-co-operators decline to a small proportion of the population – commensurate with the 'cooperate on first meeting' loophole.

Negotiation. In a population of real people, the first two prerequisites turn this simple algorithm into an affective mechanism of great subtlety. It is necessary to remember what favours you did to whom and when, and vice-versa. In the complex lifestyle of higher primates, including our Homo predecessors, negotiation and re-assurance of fidelity go hand in hand. We see the naissance of this in the grooming behaviour of primates. Dunbar [18] argues that the purpose of language is gossip. Anthropologists and linguists find that language is used precisely for such purposes. It is not used for technical discussions [19]. The most elegant and economical explanation of language evolution is in the pivotal role that negotiation has in a reciprocally altruistic society.

Language diversity. Thus, it seems that speech evolved as a facilitative mechanism for a reciprocally altruistic lifestyle. Language diversity [20] – the panoply of lexical, grammatical, phonetic, prosodic, pragmatic, and personal characteristics – may be seen as the outcome of an 'arms race', where speech is variously used to: differentiate

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pp. 31-42

between and integrate within tribal groups, detect non-co-operators, test for reliability, cement interpersonal relationships, persuade, gain confidence, cheat and exploit.

3.3 Whence creativity?

It is difficult to see how our capacity for creativity could have evolved from this language capability. There is nothing within language that suggests any connection to technology. The adaptation itself is entirely contained within the phenotype, which is modified to facilitate language use. Neurologically, language is primarily located in areas of the brain that evolved well before our prefrontal cortex expansion. All languages in all cultures are equally powerful and expressive, unlike the technologies of different cultures. The importance of language to our lifestyle, its story-telling complexity entailing intensions, time, place and events, plus its capacity for infinite combination, is compelling, at face value: but speech has no precursor for technology.

Extended phenotype. Let me be very precise about what a precursor of technology might be. The extended phenotype [15] goes beyond genetic phenotypic hijacking and symbiosis: parts of the material world are also annexed. The phenotype is ‘extended’ into the environment to the advantage of the organism. A cadis-fly larva’s house is made from grains of sand; a wasp’s paper comb and birds’ nests use environmentally available materiel. But these artefacts are no less an evolved adaptation than are the webbed feet of a duck. Some primates, notably chimpanzees, do exhibit to a small extent the learned use of tools, such as hammer and anvil stones to crack nuts. Yet, a language-using bonobo was unable to learn to draw a line between two dots.

Technology. We require a precursor to the behaviour of a species that, in its 150K year existence, progressed to study the origins of the universe and its own psyche. A technological precursor would be an extension of the chimpanzee learned-tool-use to a level where design and development are seen. We seek a veritable phase-transition. When the tool assemblages of all prior species, including the Neanderthals, are examined, the most notable characteristic is their stability. The bi-facial hand-axe of H erectus remained unchanged throughout its range for over a million years. The most notable change in stone tool construction was the use of small geometric components. The earliest date given for artefacts that show evidence of design and component-based construction is about 250,000 years ago [21]. This is a quarter of a million years after full speech anatomy development, and approaches our point of speciation.

Geometrics. We require an evolutionary process that led to a speciation event and which accelerated once the gene pool ceased to be diluted by interbreeding with the extant population. As this workshop revolves around products of the LOGO® Group, let us consider a brick. The LEGO brick is a cuboid with cylinders atop designed for assembly. This links back to ancestral geometric flints and component built tools. But, whence came the geometric forms? They are hardly present in the organic world.

What evolved? Geometric forms, the Platonic view aside, can only originate within our brains. The question is: How? The answer must lie with neurological changes that

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pp. 31-42

took place, and may still be taking place [22 23], in our cortex. The prefrontal cortex of human beings is over a quarter of the whole brain and is massively connected to other parts of the brain, including the oldest [8 24]. It is where planning, personality and consciousness reside. Activity levels here are associated with mental conditions such as autism, schizophrenia, bipolar disorder, and artistic flair [25]. The aspect that I wish to focus upon is none of these. It is more 'What's in a Square?' [26].

Square-diamond. The square is a fascinating shape. Cubed, it builds. It changes its name when rotated. This last is rather odd, because we have object-constancy firmly built into our perceptual system: My cat remains recognisably my cat from whichever viewpoint I see him, or part of him. A square, on the other hand, rotated by a quarter turn, becomes a diamond. This effect pops up in the mathematics classroom, where children have difficulty accepting that a square pointy way up is the same as a square on edge. Adults, when shown each orientation in isolation will name them differently, sometimes consciously correcting themselves when they recall their school geometry.

If we were able to explain why object constancy breaks down in this case, we might take a first step on the path to understanding technology: because the capability to break down the whole into parts is prerequisite for component-construction.

Data? The source of data within the brain on features of objects such as: colour, line, tone, etc. is the mammalian cortex. For instance, the visual cortex has neurones that specialise in processing lines of varied angle [27]. Those handling diagonal lines are different from those dealing with the horizontal and vertical. Let 'geometry' be a prefrontal cortex creation, sourcing data from the visual system. The two orientations are derived from different data, so 'are' (and are named as) different objects.

Our adaptation? Is it feasible that the prefrontal cortex might be parasitic on the rest of the brain? Neurones that do not receive input die. Many are pruned in normal development. However, it is in the 'selfish interest' of the neurone gene to multiply its representation in the community of cells that make the phenotype. The phenotype will only accept a greater proportion of a specific cell type if adaptive advantage ensues. A known role of prefrontal neurones is to analyse the world and reconstruct it explicitly. (E.g. people with Asperger's syndrome use a part of the prefrontal cortex to analyse and reconstruct the rules of social behaviour that come so naturally to others.) There is no direct evidence that the brain pre-frontally constructs novel mental entities from internal data. The circumstantial evidence, however, is significant. We do isolate the atoms of shape, colour, and sound. We do reconstruct the world on a massive scale, as Heidegger [28] observed with concern. Agriculture, clothing, and housing (setting art, science and writing aside) are a sufficient demonstration of the adaptive advantage

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pp. 31-42

that the capability to construct has given us. And, art (colour and line), music (sounds and sequence), dance (movements and space) and syntonicity (Logo) offer support.

4 Instructionism

Given that the human brain works as proposed, then our natural learning style will be constructive. Children's capacity to draw and construct starts to develop in school from the age of four and continues to about the age of ten, coinciding with the onset of pre-puberty. (Our constructive prefrontal lobes continue to develop well beyond our mid-twenties.) During this phase, when the prefrontal cortex begins to be active, children become highly imaginative, construct impossible worlds, and create fictitious friends. Why, then, is verbal instruction and rote learning so valued? The answer is: language. Language and memory underpin our lifestyle and society; language evolved for trade and gossip before we became a distinct species. This communication currency emerges before our constructive capacity begins to develop. It is established by the age of four. Language is available when children start school learning. Given the emphasis in society on early literacy and numeracy, and the susceptibility of number and reading to language-based method, it is unsurprisingly the default option.

4.1 Talk, memory and threatening technology

The pedagogue's craft uses the story and spoken sums. The fairy-story ties emerging imagination to a child's gossip capability. Mental arithmetic rides on the memory that supports reciprocal altruism. It would seem natural to base early education on the fully developed language capability rather than on the emerging constructive capacity. However, it may be argued that by anchoring early education to language there is a danger that children will be deflected from developing humanity's unique and more recently evolved capabilities. Unfortunately, education is under philosophical rather than scientific control. And language is the tool of philosophers and politicians. So, it should not be surprising that attempts to constrain the use of language and increase the constructive content of schooling have stalled. Comenius [29], Montessori [30], Feuerstein [25], and Logo [31] are examples of innovation that survive now only in niches. The lie is given by the elementary classroom walls, covered with children's drawings and designs, which are testament to what the children are really learning.

Technology has an uncomfortable relationship with teaching, which I would like to illustrate tangentially with an example of a technology that threatens speech primacy.

Mental arithmetic. Geometry exists on the back of the straightedge and compass. The 'simple' step of representing the abacus in writing transformed mathematics, and led to the stored program digital computer[1]. Yet such is the thrall of language and the

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[1] The first electronic stored program digital computer successfully to run a program did so in Manchester, England on 21st June 1948 just after 11am. The Turing Machine / Lambda Calculus is its symbolic (graphic, imaginative) counterpart.

memory skills that underpin our lifestyle, that skill in mental arithmetic is an academic touchstone. But the four-function electronic calculator is not my example.

Reading aloud. In school, the skills of reading and writing are assigned the highest priority. Literacy development entails a set of complex mental operations. The sound stream of speech is segmented into minimal meaning units. All the personal and prosodic information is stripped out. Segmentation and abstraction completed, the information is mapped to a set of graphic symbols. Speech drifts and accents vary, so mapping is not 1:1 [31 32 34]. For English: the Romanisation has no letter for schwa, so several vowel graphemes substitute. English spelling was standardized when its speech sounds were different. Consequently, text became a quasi-independent system.

Text-to-speech synthesis [35] renders text audible. But clients want a human voice, preferably with a high-status regional accent. The data for this is not in text. Letter to phoneme rules [36] do produce intelligibility. Naturalness, however, entails extracting elements from speaker recordings; mapping the lexicon to a pronouncing dictionary; and generating prosody by rule. This destroys the lexical information and stitches in the elisions, assimilations, sex, social status and prosody of someone's speech.

Such TTS has no pedagogical value. A phonic system is wanted, one with text as referent – the robotic sound of writing [37]. It could be built, but it has been rejected.

4.2 Technicity

At the heart of education lies graphics, not only as the means of noting knowledge, representing music or electric circuits but also the means of studying language itself. It becomes obvious (in the mathematical sense) that we have evolved a capability beyond the language adaptation. I have used variations on 'construction' to connote humanity's unique and recently evolved adaptation. However, *technicity* (coined by Heidegger [38] as translated by Dreyfus) is the better term for denoting the capability. Playwrights, novelists, poets and philosophers use the technology of writing to work words to their purpose; and linguists use writing to make speech available to scientific scrutiny. The description of language in notation proves the superiority of the graphic.

4.3 Constraints on Construction

We may now consider why constructionist approaches [40] have limited acceptance. I have suggested that language (a primitive evolved characteristic) coupled with a good memory may be an inhibitor. Whilst educators emphasise the directive role of (inner) speech as a learning facilitator, caution is needed. Recall that the Renaissance medical books juxtaposed anatomical drawings from the Leonardo school with Galenic text. The graphic contradicted the word, but the latter continued to be believed. Engineers do discus – but with a pencil in hand ready to sketch, as the illustration below shows.

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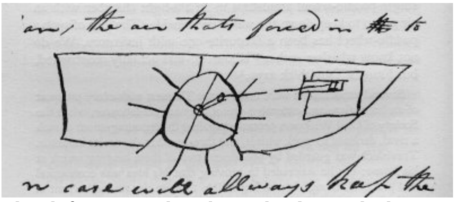
Venice(Italy) 2008 November,3-4
ISBN 978-88-95872-01-8
pp. 31-42



Sketch for a steam boat by Richard Trevithick, 1806

And mathematicians, who talk of the “language of mathematics” have blackboards to cover in graphical notation rather than a bank of tape-recorders to talk into.

Words. The word is unreliable: the currency of politics. Consider the pitfalls of questionnaire design [39]. It is also our primary system of communication. Given that education is a social enterprise, language (including mentalese) will, by default, predominate. The consequence is that where conflicts between text and construction arise, there will be a tendency for text to be credited over construction.

Language is not scientific; words are used loosely: ‘language of mathematics’ is a figure of speech, not an assertion that mathematics is a flavour of Sausure’s ‘langue’. Yet, this usage may mislead us into believing that it is truly a language.

This inexactitude is exacerbated by the nature of technology, which creates novelty for which words may not exist, with a consequent inhibition of articulate description.

Décalage. Technicity is recently evolved and hence may not be evenly represented in the population. Given that creative construction relies on connections to older parts of the brain for its data, the information available to individuals may vary significantly – a potential source of personal talent and expertise. There is possibly some support for this in work associated with ability measurement: Elliott [41] reports that Piagetian conservation tasks failed to scale, a consequence of inconsistent horizontal décalage.

Cost. Materiel is, of course, the major inhibiting factor. The materials, cf. science and cookery, are considerably more costly than those of traditional text-based instruction. Because assessment of educational progress is based on instructional techniques it is impossible to demonstrate superiority of outcome for construction over instruction. Hence, the economics of construction do not appear to be favourable. (This will alter as ICT costs decrease.) Note: this parallels the historical resource-dependency of technological development, which results in expenditure being targeted to ‘key’ areas.

Craft. However, the real constraint on the development of constructionist approaches is the weight of pedagogical craft and tradition: listen and recall; which has been supplemented, since Gutenberg in the 15th century, by the text-book and written assessment. The pedagogy of ICT is being developed in a few, innovative, locales; whilst the technology itself is largely being assimilated to extant instructional method.

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Venice(Italy) 2008 November,3-4
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pp. 31-42

5 Discussion

This sketch outlines a possible scientific basis for constructionism. The model posits two adaptations.

- Firstly, it is suggested that we inherit language and social organisation from a predecessor species; teamwork facilitated by the primitive hominine language adaptation lead initially to a reciprocally altruistic lifestyle, which later extended to large-group cooperative action and trade, in technology-based environments.
- The second, our species' unique adaptation, which I term technicity, is a derived characteristic stemming from neurological expansion in the pre-frontal cortex. This enables us to reconstruct deconstructed sense data creatively. It is the fount of technology and science, and the mechanism of construction.

Conversation. Vigotsky [42] suggests that we internalize speech after it develops to give ourselves an internal language (Pinker's mentalese [43]), with which we can hold conversations with ourselves and thereby think. No mechanism it proposed for this process. The model proposed here does propose a mechanism. Because 'technicity' is able to reconstruct almost any mental data, it may be the mechanism for Vigotsky's internalization of language. This implies disjunction of thought and language. It suggests that our cognitive processes co-opt and recreate speech as an instrument of communication, with others and ourselves. This is consistent with our capacity to create sign language and writing. But it also implies that language operates on two levels: a 'gossip' level [18] and a mode of communication of ideas. Crosstalk between these two may occur and might contribute to misunderstanding and misconception.

Cooperation. Human history since the transition to agriculture evidences a shift from competition to cooperation coupled with a trend towards role differentiation and trade specialisation. The social focus of Vigotsky is, therefore, best considered in a context of the evolutionary stable strategy of reciprocal altruism as implemented by a creative species. Cooperation, particularly in the field of technology, becomes a celebration of diverse talent, each developed to the maximum, contributing to a communal project.

Pedagogy. The psychology of teaching and learning is a highly confused panoply of competing theories [45]. Whilst extrapolations from animal learning behaviour have been widely applied, competing viewpoints, such as constructive/ionism remain in the realm of philosophy rather than science. Hence, the absence of a scientific alternative makes it unsurprising that pedagogy defaults to face-valid memory and language.

Transition. Whilst there is never discontinuity, phase transitions (the consequences of which are unpredictable from within the preceding phase) are common in nature. Transitions have been proposed within the biological realm [45]. Modern human thought (Piaget's constructivism expressed in Papert's constructionism) is clearly one.

TERECoP. Whilst it is accepted that this rough sketch and note will contribute only peripherally to the TERECoP workshop it may have practical offerings such as:

- suggesting that the process of construction is an uniquely human attribute and thereby exercises our highest intellectual capability (technicity).
- situating speech and memory in pre-human history and thereby signalling a need for caution in the use of discussion in learning: Consider carefully the objectives of language use because it may work to constrain creative thought.
- recognising that cooperation may have a genetic basis and that capacity for working cooperatively might well vary between individuals.
- accepting that physical construction is resource intensive and will therefore be economically constrained. Consider how ICT graphical media might achieve the constrictive objective with a lower resource demand.

In conclusion. I use the term *technicity* for our recently evolved creative capability, beneath which lies anatomically modern humanity's recall and recognition skills and language capability: adaptations prerequisite for a reciprocally altruistic lifestyle.

If this speculative thesis, further developed and researched, proves to be fruitful, it may provide a framework for re-constructing the school curriculum to offer a better balance between speech and technicity. At minimum, the two-adaptation model offers a framework for re-conceptualisation. If the analysis turns out to be a good model of reality, it should be possible to prove the constructivist/constructionist method to be the more powerful – provided appropriate measures of educational outcome are used. It also helps explain the Two Culture phenomenon. In the context of the TERECoP project, it is hoped that it will be a positive contribution to its theoretical foundation.

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