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## Developmental Niche Construction

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Emma G. Flynn<sup>1</sup>, Kevin N. Laland<sup>2§</sup>, Rachel L. Kendal<sup>3</sup> & Jeremy R. Kendal<sup>3</sup>

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12 1. Department of Psychology, Durham University, UK

13 2. School of Biology, University of St Andrews, U.K.

14 3. Department of Anthropology, Durham University, UK

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16 § Correspondence

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## 24 Abstract

25 Niche construction is the modification of components in an environment through an  
26 organism's activities. Humans modify their environments mainly through ontogenetic  
27 and cultural processes, and it is this reliance on learning, plasticity and culture that  
28 lends human niche construction a special potency. In this paper we aim to facilitate  
29 discussion between researchers interested in niche construction and those interested in  
30 human development by highlighting some of the related processes. We discuss the  
31 transmission of culturally relevant information, how the human mind is a symbol-  
32 generating and artefact-devising system, and how these processes are bi-directional,  
33 with infants and children both being directed, and directing, their own development.  
34 We reflect on these in the light of four approaches: natural pedagogy, activity theory,  
35 distributed cognition and situated learning. Throughout, we highlight pertinent  
36 examples in non-humans that parallel or further explicate the processes discussed.  
37 Finally we offer three future directions; two involving the use of new techniques in  
38 the realms of neuroscience and modelling, and the third suggesting exploration of  
39 changes in the affects of niche construction across the lifespan.

40

41 Keywords: niche construction, pedagogy, activity theory, distributed cognition,  
42 situated learning, cultural evolution

## 43 1. Niche Construction Theory

44 Niche construction refers to the modification of both living and non-living  
45 components in environments through the metabolic, physiological and behavioural  
46 activities of organisms, as well as through their choices. For example, many species  
47 of animals manufacture nests, burrows, holes, webs, and pupal cases; algae and plants  
48 change levels of atmospheric redox states, and influence energy and matter flows by  
49 modifying nutrient cycles; fungi and bacteria decompose organic matter; bacteria also  
50 fix nutrients and excrete compounds that alter environments.

51 The niche-construction perspective in evolutionary biology explicitly  
52 recognizes environmental modification by organisms ('niche construction'), and its  
53 legacy over time (henceforth 'ecological inheritance'), to be *evolutionary processes*:  
54 that is, they cause evolutionary change by acting as sources of modified selection, as  
55 well as of modified phenotypes (Lewontin, 1983; Odling-Smee, Laland & Feldman,  
56 2003). This stance can be contrasted with the more tacit recognition of organisms'  
57 environmental impacts in standard evolutionary accounts.

58 From the niche-construction perspective, environmental modification is  
59 regarded as an evolutionarily significant process, and not just a product of other  
60 recognized evolutionary processes; as a cause, rather than an effect. This extension  
61 has produced a body of conceptual and formal theory, known as 'niche construction  
62 theory' (henceforth 'NCT'), which explores the ecological and evolutionary  
63 ramifications of niche construction (Boni & Feldman, 2005; Kendal, Tehrani &  
64 Odling-Smee, 2011; Kylafis & Loreau, 2008; Laland, Odling-Smee & Feldman, 1996,  
65 1999, 2010; Lehmann, 2008; Odling-Smee et al., 2003; Post & Palkovacs, 2009;  
66 Silver & DiPaolo, 2006). These insights from mathematical evolutionary theory  
67 provide unambiguous evidence that niche construction is likely to be of considerable

68 ecological and evolutionary importance, and suggest that NCT may have implications  
69 for adjacent disciplines.

70         Here we consider some of the ramifications of NCT for one such academic  
71 field – developmental psychology. The opportunities for a fruitful bi-directional  
72 transfer of knowledge between these two fields of enquiry are rich. This fertile  
73 exchange is underpinned by a long, and largely independent, tradition of  
74 ‘constructivist’ thinking in developmental psychology that resonates with the  
75 arguments inherent in NCT. For instance, Daniel Lehrman (1953, 1970) stressed how  
76 the animal mind does not consist of pre-specified programmes, but is built via a  
77 constant interplay between the individual and its environment. Likewise, the  
78 developmental biologist Conrad Waddington (1959, p1636) anticipated many of the  
79 key aspects of NCT, writing that ‘the animal by its behaviour contributes in a most  
80 important way to the nature and intensity of the selective pressures which will be  
81 exerted on it’. For Lehrman and Waddington, like many other developmentally-  
82 minded psychologists and biologists since (including Schneirla, Gottlieb, Bateson,  
83 Oyama, Gray, amongst others), individuals are construed to play an active role in  
84 shaping the conditions of their own development.

85         In the sections below we review this tradition and then attempt to draw out  
86 some commonalities between it and NCT, as well as opportunities for useful  
87 exchange and future directions. We begin by introducing NCT, describing how niche  
88 construction can both result from multiple processes, including developmental  
89 processes, and trigger feedback at a variety of levels, including at levels of analysis  
90 relevant to developmental psychologists.

91

92 *1.1 What is niche construction?*

93 The conventional view of evolution is that, through the action of natural selection,  
94 species have come to exhibit those characteristics that best enable them to survive and  
95 reproduce in their environments. Organisms are generally perceived as being moulded  
96 by selection to become suited to their world (Figure 1a). The niche construction  
97 perspective in evolutionary biology contrasts with the conventional perspective by  
98 placing emphasis on the capacity of organisms to modify environmental states. In  
99 doing so, organisms co-direct their own evolution, often but not exclusively in a  
100 manner that suits their genotypes, in the process modifying patterns of selection  
101 acting back on themselves, as well as on other species that inhabit their environment  
102 (Figure 1b). Organisms and environments are treated by NCT as engaged in  
103 reciprocally caused relationships (Laland & Sterelny, 2006; Laland, Sterelny, Odling-  
104 Smee, Hoppitt & Uller, 2011), that are negotiated over both ontogenetic and  
105 phylogenetic timescales, entwined in, to coin a very apt phrase from developmental  
106 systems theory, ‘cycles of contingency’ (Oyama, Griffiths & Gray, 2001).

107 In recent years this feedback from organisms’ activities has been subject to  
108 intense investigation through mathematical population-genetic analyses. It is now  
109 well established that the selection modified by niche construction can be  
110 evolutionarily important, and can generate rich microevolutionary dynamics. By  
111 modifying selection, niche construction can create new evolutionary outcomes, affect  
112 the stability of equilibria, generate timelagged effects (e.g., populations continue to  
113 evolve after selection has stopped), facilitate range expansion, generate self-  
114 perpetuating, acceleratory niche-constructing capabilities (Kylafis & Loreau, 2008;  
115 Laland et al., 1996, 1999; Odling-Smee et al., 2003; Silver & DiPaolo, 2006), as well  
116 as many other important consequences. In other words, the feedback that niche  
117 construction generates in evolution makes a difference to how organisms evolve.

118           One implication of NCT is that, because organisms are recognized to modify  
119 selection pressures in their own and in other species' environments, and in the process  
120 to introduce feedback to both ontogenetic and evolutionary processes, niche-  
121 constructing organisms cannot be viewed as merely 'vehicles' for their genes  
122 (Dawkins, 1976), or as passive victims of selection. Many researchers have suggested  
123 that this active, constructive conception of the role of organisms in evolution, and  
124 indeed in ontogeny, fits better with conceptualisations of human agency that are  
125 widespread within the human sciences (Bickerton, 2009; Gottlieb 1998, 2000, 2002;  
126 Kendal et al., 2011; Laland et al., 2000; Layton, 2010; O'Brien & Laland, in press;  
127 Odling-Smee et al., 2003; Oyama et al., 2001; Plotkin, 2010).

128           A second implication is that there is no requirement for niche construction to  
129 result directly from genetic variation in order for it to modify natural selection.  
130 Humans can and do modify their environments mainly through ontogenetic and  
131 cultural processes, and it is this reliance on learning, plasticity and culture that lends  
132 human niche construction a special potency (Kendal, in press; Kendal et al., 2011;  
133 O'Brien & Laland, in press; Smith, 2007). However, humans are far from unique in  
134 engaging in niche construction. Niche construction is a very general process,  
135 exhibited by *all* living organisms (Odling-Smee et al., 2003), and species do not  
136 require advanced intellect or sophisticated technology to change their world  
137 (Cuddington et al., 2010; Jones, Lawton & Shachak, 1994, 1997; Odling-Smee et al.,  
138 2003). Nonetheless, largely because of its reliance on culture, human niche  
139 construction is unusually potent – so much so that our species has been characterized  
140 as 'the ultimate niche constructors' (Smith, 2007, p. 188).

141           While the niche construction perspective is growing rapidly in followers,  
142 articles and recognition, it is not yet a mainstream view within evolutionary biology,

143 and remains the source of some controversy (Laland, Odling-Smee & Feldman, 2004;  
144 Laland et al., 2011; Laland & Sterelny, 2006; see <http://www.nicheconstruction.com/>  
145 for a discussion of some of the issues). Yet, there are reasons to anticipate that NCT  
146 might be regarded as less contentious, and of more overt immediate utility, to  
147 researchers studying human behaviour than elsewhere. That is partly because of the  
148 self-apparent potency of human niche construction. There can be no doubt that human  
149 culture, expressed in our tools, our engineering and our technology, has massively  
150 changed human environments. That fact, combined with the comparatively reduced  
151 role of genetic variation in causing human behavioural variation, means that human  
152 niche construction cannot be fully explained by prior natural selection. There are  
153 already many signs that evolutionarily-minded human scientists, including  
154 philosophers, archaeologists, anthropologists, psychologists, and primatologists are  
155 finding NCT useful (see Kendal et al., 2011 for an overview), and one message of our  
156 article is that there are likely to be similar opportunities for developmental  
157 psychologists.

158

### 159 *1.2 Multiple processes of niche construction*

160 Odling-Smee et al. (2003) describe how humans can acquire the knowledge that is  
161 expressed in niche construction through a set of information-acquiring processes  
162 operating at three different levels – population genetic, developmental and cultural  
163 (Figure 2). The three levels are distinct but interconnected with each interacting with,  
164 but not completely determined by, the others.

165 All organisms inherit genetic information from their ancestors, and this is the  
166 most fundamental source of information that underpins niche construction. However,  
167 some factors in the environment can potentially change many times within the typical

168 lifespan of the animal concerned, and natural selection has selected for processes  
169 allowing individuals to adjust on a within-lifetime basis, some of which are  
170 adaptations for acquiring knowledge. These secondary sources of information are  
171 complementary to the first; for instance, learning allows individual organisms to fine  
172 tune their behaviour.

173         Learning and development can be of considerable importance to evolution  
174 because learned knowledge can guide niche construction, the consequences of which  
175 can be inherited through ecological inheritance. This highlights one of the major  
176 differences that niche construction makes to the evolutionary process: acquired  
177 characteristics can play a role in evolution through their influence on the selective  
178 environment. In humans this ability is facilitated by a further set of processes, such as  
179 language, teaching, and prosociality that collectively underlie cultural processes,  
180 enhancing the efficacy of knowledge transfer (Boyd, Richerson & Henrich, 2011;  
181 Dean, Kendal, Schapiro, Thierry & Laland, 2012; Moll & Tomasello, 2009). Much of  
182 human niche construction is guided by socially learned knowledge and cultural  
183 inheritance, but the transmission and acquisition of this knowledge is itself dependent  
184 on pre-existing information acquired through genetic evolution, complex ontogenetic  
185 processes, or prior social learning (see Figure 2).

186

### 187 *1.3 Feedback at multiple levels*

188 Niche construction modifies selection not only at the genetic level, but also at the  
189 ontogenetic and cultural levels as well, to facilitate learning and mediate cultural  
190 traditions, with consequences that not only feed back to the constructor population,  
191 but modify selection for other organisms too. For instance, the construction of towns  
192 and cities created new health hazards associated with large-scale human aggregation,



193 such as the spread of epidemics (Diamond, 1997). Humans may either respond to this  
194 novel selection pressure, exclusively or in combination (i) through biological  
195 evolution, with the selection of resistant genotypes, (ii) at the ontogenetic level, by  
196 developing antibodies that confer some immunity, or (iii) ‘cultural evolution’, for  
197 instance by creating hospitals, medicines and vaccines (Laland et al., 2000; Laland &  
198 Brown, 2006; Odling-Smee et al., 2003).

199         Where a culturally transmitted response to human niche construction is not  
200 possible, perhaps because the population lacks the requisite knowledge or technology,  
201 then a genetic response may occur. An example is the coevolution of dairy farming  
202 and the allele for adult lactose absorption, where several lines of evidence now  
203 support the hypothesis that dairy farming created the selection pressures that favoured  
204 this allele in pastoralist populations (Burger, Kirchner, Bramanti, Haak & Thomas,  
205 2007; Durham 1991; Holden & Mace, 1997; Myles et al., 2005; Simoons, 1970).  
206 Cultural niche construction can also generate selection on other species, most  
207 obviously the domesticates. Beja-Pereira et al. (2003) established that the spread of  
208 dairy farming also affected geographical variation in milk protein genes in European  
209 cattle breeds, which covary with present day patterns of lactose tolerance in humans.

210         Humans are massive constructors of developmental environments. By  
211 modifying the world, human niche construction creates artefacts and other externally  
212 inherited resources that not only act as sources of biological selection on human genes  
213 but shape the learning opportunities and developmental trajectories of recipient  
214 organisms. Wheeler and Clark (2008, p. 3564) describe as ‘cognitive niche  
215 construction’ the fact that ‘animals build physical structures that transform problem  
216 spaces in ways that aid (or sometimes impede) thinking and reasoning about some  
217 target domain or domains’, and these physical and informational legacies ‘make

218 possible whole new forms of thought and reason'. We see this also in non-human  
219 animals. For instance, Frigaszy (in press) describes how capuchin monkeys create  
220 learning environments for youngsters, by transforming the environment in a manner  
221 that scaffolds their learning, and channels it towards established traditions (we discuss  
222 this further below). Social transmission maintained through inadvertent, or less  
223 commonly advertent, modification of the local environment is surprisingly common:  
224 it is known to underlie pine cone opening in black rats (Terkel, 1996), milk-bottle  
225 opening in various birds (Sherry & Galef, 1984), the learning of food sites through  
226 pheromone trails in ants (Denny, Wright & Grief, 2001), mate-choice copying in egg-  
227 dumping fishes (Goldsmidt, Bakker & Feuth-de Bruijn, 1993), and food preference  
228 learning through excretory products in rats (Laland & Plotkin, 1991, 1993). This  
229 facilitation of learning through the construction of developmental environments  
230 reaches its zenith in humans (Kendal, in press; Sterelny, 2012), as we detail in  
231 subsequent sections.

232

## 233 2. Developmental Niche Construction

234 In 2000, psychologist, Mary Gauvain, commented in support of Laland et al.'s (2000)  
235 niche construction review, but warned that amalgamation of biological and human  
236 social sciences 'will not be met unless the biological and evolutionary approaches are  
237 better integrated with theory and research in human psychological development'  
238 (Gauvain, 2000, p. 153). She pointed out that it is not coincidental that there is a  
239 strong assimilation of humanity's biological capabilities and their social and cultural  
240 context of development as this is essential for survival. Similarly, Boyd et al. (2011)  
241 argue that humanity's 'cultural niche' has allowed our species to settle in all corners  
242 of the world, through the transmission of cultural information necessary for building

243 shelters, sourcing food and staying safe and healthy in even the most inhospitable  
244 environments. Without cultural information and the resulting niche that is developed  
245 over generations, it is unlikely that humans would survive in hostile environments.  
246 This point is illustrated well by the unfortunate fate of extensively resourced  
247 explorers, Sir John Franklin and Robert Burke, who perished in the Arctic and  
248 Australian outback, respectively, despite both locations being inhabited by natives  
249 relying on cultural niche construction to live in these harsh environments (Henrich &  
250 McElreath, 2003).

251 In the following section, we present an illustrative set of examples of human  
252 psychological development in relation to developmental niche construction: we  
253 discuss the transmission of culturally relevant information between individuals, how  
254 the human mind is a symbol-generating and artefact-devising system, and how these  
255 processes are bi-directional, with infants and children being directed, and directing,  
256 their development. We also highlight pertinent examples in non-humans that parallel  
257 or further explicate the processes we discuss.

258

259 Before a baby is born, behavioural indices of differences in heart rate and leg  
260 kicking show that during the final trimester, a foetus can discriminate different sounds,  
261 languages, forms of music, and voices (Hepper, 1989, 1991). Simultaneously, parents  
262 are typically structuring an environment for their imminent arrival that, unparalleled  
263 in any other species, facilitates the baby's rapid cognitive development and the  
264 acquisition of cultural information. A premise for much work by developmental  
265 psychologists is that this relationship between cognitive development and the  
266 constructed environment is dynamic. Here we present four processes, *natural*  
267 *pedagogy*, *activity theory*, *distributed cognition* and *situated learning*, in which we

268 focus on how the construction of a learning environment by culturally knowledgeable  
269 others affects the acquisition of beliefs and practices by novices, and consider how  
270 cultural novices are active participants in this process. Our aim is to provide an  
271 illustration of possible interfaces between NCT and developmental psychology, in the  
272 hope of facilitating discussion between the two.

273

### 274 *2.1 Natural Pedagogy*

275 Typically, infants are born into cultural environments ('niches') and are  
276 surrounded by individuals performing cultural behaviour. A critical question is how  
277 cultural novices acquire this information? Gergely and Csibra (in press) argue that for  
278 a naïve learner to acquire cultural information solely through observational learning  
279 would be extremely arduous. First, cultural behaviour is often cognitively opaque,  
280 such that it is not obvious why an action is performed in a specific manner, nor which  
281 action to copy. Second, cultural information can be generic, involving a behaviour  
282 that can be generalised across a group of similar artefacts or contexts, and so an infant  
283 needs to extrapolate what she has learnt from the immediate context to related  
284 situations.

285 In order to acquire cultural behaviour, Gergely and Csibra (in press) propose  
286 that humans have a social communicative learning mechanism, 'natural pedagogy', in  
287 which culturally knowledgeable individuals (usually adults) assist novices in  
288 acquiring cultural behaviour through ostensive-referential demonstrations of the  
289 relevant aspects of the behaviour. Infants' preferences for eye contact, infant-directed  
290 speech and infant-directed contingent reactivity (that is behaviour made in response to  
291 an infant's behaviour) show that the proposed ostensive cues are relevant to infants  
292 from a young age (Csibra, 2010). These attention-gaining cues then allow gaze-

293 following of a knowledgeable individual's focus to a referential target and their  
294 actions upon it (Senju & Csibra, 2008; Senju, Csibra & Johnson, 2008).

295         According to Gergely and Csibra (in press), what makes their proposal unique  
296 is that infants encode the information they receive from an ostensive-referential  
297 communication qualitatively differently than if acquired in a non-communicative  
298 situation. Ostensive-referential communication allows infants to learn referenced  
299 features of an object more quickly than non-referenced features (Yoon, Johnson &  
300 Csibra, 2008), to encode the demonstrated functional property of an artefact-kind  
301 (Futó, Téglás, Csibra & Gergely, 2010), and to learn novel means-end actions despite  
302 their apparent cognitive opacity (Gergely, Bekkering & Kiraly, 2002). Thus,  
303 ostensive-referential information presented by culturally knowledgeable others allows  
304 cultural novices to learn and apply referenced features to their own behaviour rapidly.

305         Natural pedagogy suggests that cultural experts construct a cultural niche,  
306 facilitating the acquisition of cultural knowledge by the novice by gaining their  
307 attention, through processes such as motionese (Brand, Baldwin & Ashburn, 2002),  
308 motherese (Newport, 1977), calling their name, and use of ostensive cues to highlight  
309 relevant aspects of the behaviour. As the term 'natural pedagogy' suggests, the  
310 predisposition to employ such cues is assumed to be universal amongst humans, yet  
311 the manifestation of these cues and the learning environment to which the recipient is  
312 exposed may be culturally variant. Variability in natural pedagogy across cultures is  
313 expected as cultures differ in many features including their child-rearing practices, the  
314 means deployed to allow transmission of culturally relevant behaviour, and the extent  
315 of cognitive opacity of local traditions and artefacts.

316 In contrast, chimpanzees and orangutans do not appear to understand the  
317 intention of another to impart useful information through pointing and/or gaze  
318 alternation between the ‘learner’ and referential target (Hare & Tomasello, 2004;  
319 Hermann, Call, Hernández-Lloreda, Hare & Tomasello, 2007; Tomasello, Call &  
320 Gluckman, 1997), whereas even pre-linguistic children do (Behne, Carpenter &  
321 Tomasello, 2005). Indeed, the human-specific propensity for developmental niche  
322 construction is likely to go far beyond the role of pedagogy. For instance, Tomasello,  
323 Carpenter, Call, Behne and Moll (2005) describe how humans engage in species-  
324 unique forms of cultural cognition and evolution, enabling everything from the  
325 creation and use of linguistic symbols to the construction of social norms and  
326 individual beliefs to the establishment of social institutions. This encompasses a  
327 species-unique motivation to share emotions, experience, and activities with other  
328 persons, greatly enriching what West, King and Arberg (1988) term, the *ontogenetic*  
329 *niche*. Cultural niche construction theory can coalesce our understanding of  
330 developmental mechanisms affecting the constructed learning environments and the  
331 influence of evolutionary dynamics on such environments. The developmental  
332 outcome is children’s ability to construct dialogic cognitive representations, which  
333 enable them to participate in collective human cognition, a topic discussed below.

334

## 335 *2.2 Activity Theory*

336 Within activity theory, which derives from the work of twentieth century  
337 Soviet psychologists, particularly Vygotsky and Leont’ev, an ‘active’ learner is  
338 placed within a wide social, historical and political context (Vygotsky 1962, 1978),  
339 that is, a cultural-historical niche. This bears some resemblance to the perspective of

340 those primatologists influenced by ecological psychology, who view organism and  
341 environment as a combined whole or integrated system (Gibson 1979, 1986), and who  
342 suggest that an understanding of how behavioural traditions are maintained across  
343 generations requires, ‘a dynamic conception of the individual as *engaged* with its  
344 world, both social and asocial elements, in ongoing commerce’ (Fragaszy &  
345 Visallberghi, 2001, p.84, italics added).

346         As we will see for distributed cognition, activity theory transcends an actor’s  
347 boundary and investigates change both within and between individuals. It considers  
348 behaviour to be goal directed, and both for development to be mediated by social and  
349 cultural history and visa-versa; thus the unit of analysis is the socially organized  
350 activity (Leont’ev, 1981). This approach is pertinent to NCT, where elements of the  
351 socially-constructed niche such as tools, norms, schooling practices are culturally or  
352 ecologically inherited, influencing the learner’s activities and, at a population level,  
353 affecting cultural selection.

354         Similarly, in the animal kingdom the activities of others alter the learner’s  
355 relation with objects in their environment. For instance, Fragaszy (in press) describes  
356 how capuchin monkeys (*Cebus spp.*) create learning environments for youngsters  
357 through enduring alterations of the physical environment. The discarded palm nut  
358 shells and stone hammers (Otoni & Izar, 2008), ripped bamboo canes resulting from  
359 extraction of beetle larvae (Gunst, Boinski & Fragaszy, 2008) or spilt traces of juice  
360 (Craet, Hardy & Fragaszy, 2010) are attractive to young monkeys and act as key  
361 artefacts which support persistent practice thus facilitating the acquisition of the  
362 extractive foraging behaviour. Likewise Leca, Gunst and Huffman (2010) report that  
363 piles of stones resulting from stone-handling activities in Japanese macaques are

364 attractive to others, supporting re-use and even transport of such ‘favoured’ stones by  
365 group members. In these examples, learning is thereby stimulated and channelled  
366 towards established behavioural traditions even without direct observation of the  
367 behaviour.

368         In some cases, children may achieve the same end point, such as being able to  
369 undertake mathematical transformations through division and multiplication, but the  
370 specifics of their social environment may mean they learn and express these skills  
371 through different activities. For example, Brazilian street children are able to  
372 complete complex arithmetic calculations when presented in the familiar context of  
373 selling sweets/candy but when similar problems are presented in a more formalized  
374 manner, they fail to do so (Carraher, Carraher & Schliemann, 1985). Thus the  
375 learning and execution of a skill needs to be seen in context, as being constructed  
376 within, and supported by, a culturally-constructed niche.

377         The relation between activity theory and niche construction is illustrated by  
378 the ‘mediational triangle’ (Cole & Engeström, 2001, Figure 3, published in relation to  
379 *Distributed Cognition* which we discuss next, but relevant to the point we wish to  
380 make here), which expresses the complex relation between artefacts, norms,  
381 communities, objects and subjects. For example, mediation through cultural practices  
382 and understanding alters the ‘intramental plane’, that is the participant’s relation with  
383 an object. An example of cultural (and historical) mediation of the intramental plane,  
384 used by Leont’ev (1981), is the disparity in the way traders and geologists learn to  
385 view gem-stones, with one seeing them as valuable assets, and the other viewing them  
386 in terms of their geological properties. Thus, in relation to the intramental plane,



387 'collective activity shapes the object and possible responses to it' (recounted by  
388 Edwards, 2005, p. 4).

389 Cases of social learning in non-humans may be consistent with the activity  
390 theorists' notion of culturally specific mediation on the so-called intramental plane.  
391 For instance, Gruber, Muller, Reynolds, Wrangham and Zuberbühler (2011) show  
392 that two populations of chimpanzee (*Pan troglodytes Schweinfurthii*), react differently  
393 to the affordances of a multi-functional leafy-twig tool, such that chimpanzees from  
394 Sonso (who have a leaf technology) found the leaves most salient while chimpanzees  
395 from Kanywara (who have a probing technology) focussed on the stick part.

396 Vygotsky's work is particularly useful as he developed measurable concepts  
397 to capture the effect of mediation on learning; specifically, the Zone of Proximal  
398 Development (ZPD), defined as '*the distance between the actual developmental level*  
399 *as determined by independent problem solving and the level of potential development*  
400 *as determined through problem solving under adult guidance or in collaboration with*  
401 *more capable peers*' (Vygotsky, 1978, p. 86, emphasis in the original). The intention  
402 was that this concept could be applied to learning across a variety of contexts, and  
403 relate to qualitative changes in the learner's cognitive development (Chaiklin, 2003).

404 In line with the concept of the ZPD, adults frequently attempt to structure a  
405 child's learning environment, providing a learning niche for them, as described by  
406 Wood (1998, p. 97):

When we help a child solve a problem, we are providing conditions in  
which he can begin to perceive regularities and structure in his  
experience. Where, left alone, the child is overcome by uncertainty and

does not know what to attend to or what to do, instruction can help in a number of ways. When we point things out to the child, we help to highlight what he should attend to. By reminding children we are helping them to bring to mind and exploit those aspects of their past experience that we (as experts) but not they (as novices) know to be relevant to what they are currently trying to do.

407 Through his work using The Tower of Nottingham, (ToN; see Figure 4) Wood and  
408 colleagues have investigated tutoring and learning situations (Wood, Bruner & Ross,  
409 1976; Wood, Wood & Middleton, 1978). Children younger than seven years could not  
410 build the ToN without help, but, after instruction from an adult, children as young as  
411 three years were able to complete the ToN alone. Adults scaffolded the children's  
412 learning experience by highlighting the mechanics of specific aspects of the task,  
413 selecting pertinent pieces, orienting objects so its pertinent parts were easily viewed  
414 and removing elements not critical to learning at that time. Yet, some forms of  
415 tutoring, such as demonstrating full assembly of the ToN or providing complex verbal  
416 instructions, were not successful as they overloaded the learner. Accordingly, Wood  
417 and colleagues coined the concept of 'contingent tutoring' as the most effective form  
418 of instruction, relying on two rules: when a learner is in difficulty provide more  
419 assistance, and when a learner is succeeding provide less.

420 Although advertent social learning, or teaching, is extremely rare in non-  
421 humans and its distribution likely linked to cooperative breeding rather than  
422 taxonomic affinity to humans (see Hoppitt, Brown, Kendal, Rendell, Thornton,  
423 Webster and Laland, 2008) one case merits discussion regarding 'contingent  
424 tutoring'. Thornton and McAuliffe (2006) elegantly demonstrated that in meerkats

425 (*Suricata suricatta*) non-productive ‘helpers’ teach young pups how to handle  
426 aggressive and toxic scorpions which form part of their diet. The behaviour of the  
427 tutor helpers appears to be contingent in that, upon provisioning a scorpion, they  
428 monitor the pup and nudge the scorpion with their paws or nose if the pup fails to  
429 attempt to handle it; a behaviour which seemingly attracts the pups attention and  
430 enhances consumption success. Likewise the provision of increasingly intact (and  
431 thus difficult/dangerous to handle) scorpions to pups as they increase in age would  
432 also appear contingent. However, it was found (Thornton & McAuliffe, 2006) that  
433 here the behaviour of the tutor was contingent upon the vocal cue of age-related  
434 changes in pup begging calls rather than the pups’ changing competence. This  
435 situation perhaps being reminiscent of formal education being largely age, rather than  
436 performance, based in humans.

437         Two important points that are particularly evident in human populations are  
438 that children are not passive recipients of an adult’s instruction and that instructors are  
439 not always adults. In relation to the former, in naturalistic settings it is often the child,  
440 not the adult, who initiates interactions and sets the goal (Carew, 1980; Wells, 1981).  
441 Thus, to a degree, and consistent with NCT, children direct their own learning by  
442 shaping their own learning environment. Also in natural settings, children often learn  
443 from other children (see Dean et al., 2012; Flynn & Whiten, 2010; Whiten & Flynn,  
444 2010). For instance, Wood and colleagues extended their investigation to children’s  
445 peer tutoring, finding that the rate of contingent tutoring increases with age from 3 to  
446 7 years (Wood et al., 1995) and it appears that different forms of social learning (e.g.  
447 observational learning or reasoning regarding the intentions of tutors) may be  
448 pertinent at different ages (Ellis & Gauvain 1992; Flynn, 2008; Selman 1980; Whiten  
449 & Flynn, 2010). A child’s cognitive development will, in part, influence the type of

450 interaction most pertinent to their learning; cognitive development informs the  
451 learning niche that a child experiences.

452         Recent research has investigated the bi-directional relation between cognitive  
453 development and social learning. Theory and evidence suggest that more  
454 sophisticated mental state understanding leads to more effective peer tutoring (Flynn,  
455 2010; Strauss, Ziv & Stein, 2002; Tomasello, Kruger & Ratner, 1993). Yet the reverse  
456 is also true; more sophisticated interactions lead to more complex mental state  
457 understanding, as well as more refined skills in other areas, such as executive  
458 functioning. For example, contact with adults or older siblings appears to have a  
459 positive effect on theory of mind development (Lewis, Freeman, Kyriadidou,  
460 Maridaki-Kassotaki & Berridge, 1996; Ruffman, Perner, Naito, Parkin, & Clements,  
461 1998). Similarly, wider cultural norms of a society can affect cognitive development.  
462 For instance, Japanese children have been shown to pass theory of mind tasks later  
463 than their Western counterparts (Naito, 2003), a trend that may be due to a cultural  
464 focus on social rules, and less on mental states, in Japanese society (Naito & Koyama,  
465 2006). In contrast, Asian children perform better than North American or British  
466 children on tests of executive functioning (Chen et al., 1998; Sabbagh, Xu, Carlson,  
467 Moses & Lee, 2006), perhaps due to differing cultural emphases on control of  
468 behaviour in social settings.

469

### 470 *2.3 Distributed Cognition*

471         While cognition is generally seen as a process that occurs within an individual,  
472 albeit with theoretical positions suggesting that environmental factors may facilitate  
473 this context, distributed cognition (DC) emphasises the dispersed nature of cognitive  
474 phenomena across individuals, artefacts and internal and external representations. In

475 this respect it resembles the cognitive niche construction of Wheeler and Clark (2008).  
476 Cultural processes transcend the boundaries of the individual and so need to be  
477 understood in context with the single or multiple actor's/s' interactions with the  
478 artefacts being used within the given activity. Distributed cognition is critical in  
479 developmental niche construction as it allows children to work with others to learn,  
480 undertake and develop cultural practices, relying on coordination across a group.

481 Developmental systems theory strongly contradicts a purely 'genocentric  
482 account of heredity' (Griffiths & Gray, 2001) as many resources persist across  
483 successive generations and are part of the explanation for heredity. Likewise, NCT  
484 includes the notion that an inherited 'niche' constitutes an organism-environment  
485 relationship, which can consist of the inheritance of resource and semantic  
486 information both internal and external to the organism (Odling-Smee et al., 2003).  
487 These perspectives allows us to understand how people learn to design and use  
488 artefacts that have evolved through the process of cumulative culture and also how  
489 individuals learn to participate in cultural activities that require collaboration and  
490 cooperation (e.g. flying an aeroplane, Hutchins & Klausen, 1996).

491 One cognitive function that facilitates distributed cognition, and has been a  
492 recent focus of research in developmental and comparative psychology, is 'we-  
493 intentionality' (Plotkin, 2003) or shared intentionality (Tomasello & Carpenter, 2007).  
494 In this regard, Moll and Tomasello (2007, p. 1) coined the Vygotskian Intelligence  
495 Hypothesis, noting 'that the unique aspects of human cognition - the cognitive skills  
496 needed to create complex technologies, cultural institutions and systems of symbols,  
497 for example - were driven by, or even constituted by, social cooperation.' Thus social  
498 cooperation most likely provides a key component of the mediation process and the  
499 construction of a distributed niche. In contrast, non-human primates would appear to

500 lack the same degree of pro-sociality (Dean et al., 2012) and typically fail in tasks that  
501 require coordinated collaboration, whether the goal is ‘social’ (Warneken, Chen &  
502 Tomasello, 2006) or a food-based reward (Jensen, Hare, Call & Tomasello, 2006; Silk  
503 et al., 2005).

504         Symbolic representation systems often form critical components of culturally  
505 constructed learning environments. For instance, the Sapir-Whorf hypothesis  
506 concerns the degree to which cognitive development is constrained by language  
507 (Whorf, 1956). Miller, Smith, Zhu and Zhang (1995) and Miller and Stigler (1987)  
508 investigated the acquisition of learning of mathematical notation for Chinese and  
509 American children. No difference was found for the acquisition of the numbers from  
510 0 to 10; however, from 11 to 20 American children performed relatively poorly. It is  
511 thought that this is due to the relative irregularity of the number system (from 11 to  
512 20) for English speakers. However, the language of a culture is entwined with other  
513 cultural practices, thus it would be premature to conclude that differences in thought  
514 are due entirely to the form of symbolic representation used. Furthermore, the  
515 distinction of ontogenetic and culturally specific cognitive, emotional, and identity-  
516 related characteristics can, themselves, be reflected and retained in linguistic cognates  
517 (Malik, 2000). In this context, NCT provides a framework to examine explicit  
518 relationships between the cultural evolution of symbolic representation systems and  
519 cognitive development. Crucially, NCT draws attention to the effect of the ecological  
520 inheritance of both information and resources on development.

521         The field of distributed cognition considers cognition in terms of the change in  
522 relational structures, including components that are internal and external to the mind.  
523 Hence, the focus is on the interaction of people and artefacts, rather than just  
524 assessing individual cognition ‘within the head’ (Nardi, 1996). Hutchins (1995)

525 criticizes the cognitive sciences for not incorporating the cultural process, which  
526 generates artefacts, in their understanding of the individual. He asserts that this can  
527 lead to the over-attribution of intelligence (or aspects of cognitive facility) to the mind  
528 in order to explain observed behaviour, which instead, should be considered  
529 properties of sociocultural systems that include both biotic and abiotic phenomena.  
530 For instance, Hutchins argues that computation that results from a mathematician  
531 manipulating symbols on a chalk board is not occurring inside the head of the  
532 mathematician, but rather as a consequence of interaction with the external symbols.  
533 Computational tools that automate these sequences of symbolic manipulation are  
534 models of a sociocultural system rather than cognition internal to the mathematician.  
535 On this basis, Hutchins (1995) criticizes cognitive scientists and artificial intelligence  
536 research that have attempted to use the computer as a model for the human mind.  
537 NCT can be used to examine the developmental and evolutionary feedback between  
538 internal mental facility and external resources that make up the sociocultural system.

539       Taking the position that the development of cognition is affected by learned  
540 rules or axioms in conjunction with artefactual symbolic representation in material  
541 culture is equivalent to developmental systems theorists' advocacy of a *parity thesis*  
542 in biology, that 'the roles played by the many causal factors that affect development  
543 do not fall neatly into two kinds, one exclusively played by DNA elements the other  
544 exclusively played by non-DNA elements. . . . Instead, there are numerous important  
545 distinctions to be drawn amongst the causal roles played by developmental factors'  
546 (Griffiths & Gray, 2005, p. 420).

547

548 *2.4 Situated Learning*

549           The niche into which we are born will, in part, dictate what we learn. The  
550 authors of this article do not know how to build an igloo, or cook the perfect  
551 spanakopita, but all of us have learnt the art of playing rounders (a common primary  
552 school game in the UK). Developmental niche construction may not only dictate what  
553 we learn through careful signalling, scaffolding or the presentation of culturally  
554 relevant tools, but also through the presentation of opportunities to learn activities  
555 through participation. In its simplest form, regarding the physical environment, even  
556 animals who provide no parental care (Stamps, 2003), select a natal habitat for their  
557 eggs which provides a broad range of environmental conditions which influence  
558 development from laying to hatching and, where individuals remain in their natal  
559 habitat for extended periods, throughout juvenile development (West & King, 1987).  
560 Such spatial ‘ecological inheritance’ has evolutionary consequences due to the  
561 feedback it generates; through ‘preference induction’ (Stamps, 2003) individuals who  
562 experienced a certain niche during development are themselves likely to select it as a  
563 natal habitat for their offspring – a form of extragenetic inheritance.

564           The social aspect of situated learning has been highlighted by Sterelny (2012)  
565 who illustrated the point with another example from the animal kingdom. Some  
566 dolphins in Shark Bay, Western Australia, forage with sponges over their snouts  
567 likely as protection but also to increase foraging efficiency (Mann & Sargeant, 2003).  
568 Although group differences in sponge use have been reported, Sterelny (2012) points  
569 out that dolphins who use sponges spend longer in deep channels than those  
570 exploiting shallow waters off beaches. As calves accompany their mothers while  
571 foraging, the calves of sponge-users experience different environments to calves of  
572 beach-exploiters. Thus, being exposed for longer to the deep channels (irrespective of  
573 witnessing any use of sponges) may support trial and error learning of sponge use,



574 through encountering sponges and spending longer in environs where sponge use is a  
575 beneficial foraging technique.

576           There are other prominent examples in non-humans, where the inherited social  
577 niche influences individual's social skill development. Sapolsky and Share (2004)  
578 reported the establishment of an atypical 'pacific culture' in a wild group of olive  
579 baboons (*Papio anubis*) which experienced a complete loss of the most aggressive  
580 group males. The peaceable culture of the group was maintained for at least a decade,  
581 representing complete turnover of the original males who died/emigrated. This is  
582 thought to be due to the participation in group life of immigrant males (often  
583 adolescent) resulting in adoption of the group tradition of a relatively 'relaxed'  
584 dominance hierarchy. More commonly, within old world primates the inheritance of  
585 rank, through being born into a matriline (or lineage) of a specific relative rank,  
586 influences the rates and types of agonistic interactions individuals experience, which  
587 in turn through 'ontogenetic ritualization' (Tomasello & Call, 1997) influences  
588 development of their social skills. Finally, Flack et al. (2006) showed how, in captive  
589 pigtailed macaques (*Macaca nemestrina*), impartial intervention in conflicts  
590 ('policing') by a few dominant individuals, served to stabilise social groups allowing  
591 individuals to develop within, and construct their own, social niches in ways that  
592 enhance the advantages of group-living. For example, individuals were involved in  
593 social networks that were large, and diverse in terms of partners; circumstances  
594 thought to facilitate the emergence of cooperation and behavioural traditions (Flack et  
595 al. 2006; Hill et al. 2011).

596           Despite these examples, situated learning is normally a term reserved for  
597 human learning. Karmiloff-Smith (2009) highlights how parents alter the environment

598 for children who have a developmental disorder compared to their typically  
599 developing siblings. She states (2009, p. 60) that:

Informal observations of families who visit our lab reveal that parents of infants and toddlers with genetic syndromes find it difficult (compared to parents of typically developing children) to allow their atypically developing offspring to mouth objects freely and to crawl/walk uninhibited in order to fully explore their environment. This reticence is probably because of greater fear of potential danger and accidents, but it results in a less richly explored environment.

600

601 She illustrates her point further with the example of parents of children with  
602 developmental disorders who, by quickly correcting mistakes, inhibit the common  
603 overgeneralization in language acquisition seen in typical development. Such  
604 inhibition of this overgeneralisation may create the delayed category formation seen  
605 in some developmental disorders along with presenting less variation in linguistic  
606 input, shorter sentences, and in general a less richly varied environment. Thus,  
607 learning opportunities about culturally relevant behaviour may not only arise through  
608 natural pedagogy, contingent tutoring or distributed cognition and the use of tools, but  
609 simply by having certain learning opportunities, and not others, available.

610 Lave and Wenger (1991) describe the process of becoming mature members  
611 of a 'community of practice', or social formation of individuals engaged in a  
612 particular kind of activity, as 'legitimate peripheral participation'. Newcomers begin  
613 in a position that is not central to the learned practice within a community, and yet

614 their participation is legitimate, meaning that the newcomers take on established or  
615 recognised activity within the community during the learning process. For instance,  
616 tailor apprentices typically start their legitimate peripheral participation with initial  
617 preparation work and finishing details on completed garments. Then, the apprentice  
618 slowly moves backwards through the production process as skills develop, before  
619 being given crucial cloth cutting jobs.

620 Lave and Wenger assert that learning through legitimate peripheral  
621 participation occurs *in situ*, through participation in the community activity,  
622 emphasising the acquisition of cultural knowledge through participation and  
623 involvement rather than ostensive teaching and instruction (see Rogoff et al., 2007  
624 and Rogoff, Paradise, Mejía Arauz, Correa-Chávez and Angelillo, 2003, for a similar  
625 process which they label ‘learning through intent community participation’). Thus the  
626 process is not concerned with a knowledgeable individual transmitting information to  
627 a less knowledgeable individual (as discussed above), rather, seeing both individuals  
628 as parts of a larger community, with artefacts, symbols and social norms which  
629 support the novice’s development in a community of practice. For example, López,  
630 Correa-Chávez, Rogoff and Gutiérrez (2010) found that Mexican children with  
631 experience of indigenous practices paid more sustained attention than their American  
632 Mexican-heritage counterparts to the instructions being given to another child about  
633 how to make a toy. Learning environments can be structured through a dynamic  
634 apprenticeship process, and this processes may vary culturally, with some cultures  
635 being more attuned to paying attention to ongoing events (Indigenous / Indigenous-  
636 heritage communities of the Americas), while others (Europeans) tend to focus on one  
637 event at a time, seemingly unaware of other co-occurring events (Chavajay & Rogoff,  
638 1999; Correa-Chávez, Rogoff & Mejía Arauz, 2005; Rogoff, Mistry, Goncu &

639 Mosier, 1993). Taking a cultural niche construction perspective in the context of  
640 situated learning, the behaviour of the community of practice provides the constructed  
641 learning environment, which affects, during legitimate peripheral participation, the  
642 cultural selection of normative expectations, habits and values adopted by the learner.

643         While situated learning is principally concerned with the developmental  
644 learning process, Lave and Wenger (1991) situate their descriptive model within what  
645 is the equivalent of an evolutionary context. The idea of ecological inheritance of an  
646 environment modified by niche construction is inferred by their observation that,  
647 ‘reproduction cycles . . . leave a historical trace of artefacts – physical, linguistic, and  
648 symbolic – and of social structures, which constitute and reconstitute the practice over  
649 time’, resulting in the ‘continuity of roles while displacement of individuals’ (1991, p.  
650 59). However, they also recognize potential for the evolution of novel behaviour and  
651 change in the community of practice over time, referring to this as, ‘developmental  
652 cycles of communities of practice’ (p. 121). They note that this can result from a  
653 conflict of interest between master and apprentice, and a change in resources such as  
654 the technology used in a particular trade (e.g., dairy farming technology in French  
655 Alpine villages; Layton, 2000).

656         The situated learning perspective of the evolution of a community of practice  
657 would appear consistent with that of niche-construction theory and developmental  
658 systems theory. The latter argues that ‘evolution is change in the nature of populations  
659 of developmental systems. This change is driven both endogenously, through the  
660 modification by each generation of developmental systems of the resources inherited  
661 by future generations, and exogenously, through modifications of these resources by  
662 factors outside the developmental system’ (Griffiths & Gray, 2001, p. 207).

663

664 *3 Future Directions*

665 We offer three areas for future directions, two of these involve the use of new  
666 techniques (neuroscience and modelling) and the other exploring the niche across the  
667 lifespan.

668 *3.1 Neuroscience, Culture and Niche Construction*

669 The brain's plasticity means that it can be shaped by environmental input, and  
670 this plasticity is not simply available to the young (see Hertzog, Wilson, Kramer &  
671 Lindenberger, 2009; Li, 2003; Lövdén, Bäckman, Lindenberger, Schaefer &  
672 Schmiedek, 2010 for reviews). Recent technological developments, such as brain  
673 imaging, have allowed empirical investigation of the interplay between brain,  
674 behaviour and socio-cultural contexts (Miller & Kinsbourne, 2012). The work of Shu-  
675 Chen Li (2003, 2008, in press) has been central in understanding the biocultural co-  
676 construction of brain plasticity across the life-span. She presents development within  
677 three scales, human phylogeny, ontogeny and microgenetic times, and views these  
678 from social-cultural, behavioural, cognitive, neural and genetic perspectives.

679 Brain differences due to experience have been seen in the visual cortex in  
680 congenitally blind individuals who are skilled Braille readers (Pascual-Leone, Amedi,  
681 Fregni & Merabet, 2005), in the primary motor cortex and auditory cortical  
682 representations of expert musicians (Elbert, Pantev, Wienbruch, Rockstroh & Taub,  
683 1995; Pantev et al., 1998), and in, the now famous study by Maguire et al. (2000) of  
684 an increase in the posterior hippocampi in individuals who have professions requiring  
685 navigating complex spatial environments. Although plasticity appears across the life

686 course, there are periods of sensitivity, and the extent of plasticity in old age is  
687 reduced in comparison to young adults (Erickson et al., 2007). Cross-cultural studies  
688 have also supported a ‘use-it-or-lose it’ approach to cognitive aging (Park &  
689 Gutchess, 2006, p. 107). Gutchess, Welsh, Boduroglu and Park (2006) compared  
690 Chinese and American young adults on an object processing task, finding that  
691 American participants showed more engagement in the ventral visual cortex.  
692 Furthermore, by comparing elderly Singaporeans with American counterparts, it was  
693 found that this deficit increased more so for the Singaporeans (Chee et al., 2006).  
694 Gutchess et al. (2006) suggest that the difference seen in object processing of the two  
695 populations, Asian and America young adults, may be due to cultural differences such  
696 as the number of objects in the environment, arguing that as Eastern environments  
697 contain more objects than American environments the distinction between object and  
698 background may be less clear for the Chinese participants. Equally, differences may  
699 be due to cultural variability in the level of attendance made to different levels of  
700 information in one’s environment, as highlighted by López et al. (2010) above, in  
701 this case with Chinese participants attending more broadly to their environment.

702 As Li (in press, p. x) points out, ‘findings regarding socio-cultural influences  
703 on life-long neurocognitive development are still very limited and leave many gaps  
704 between the different domains of analyses’; we completely agree. Thus there is much  
705 potential to explore the inter-relations between the cultural niche and neurological  
706 underpinnings of behaviour across the lifespan within many domains. Such  
707 exploration is extremely fruitful in the light of an ageing population, many of whom  
708 will suffer from cognitive decline, which may be alleviated with an appropriately  
709 constructed niche.

710 *3.2 Modelling*

711 Mathematical modelling and simulation can be used to explore the interaction  
712 between developmental and cultural-evolutionary dynamics. As we have emphasised,  
713 the developmental dynamics may often be heavily influenced by the socio-cultural  
714 environment. Niche construction models have already been developed to consider the  
715 affects of ecological inheritance and change in constructed resources on selection  
716 (Laland et al, 1996, 1999, 2000; Lehmann, 2008). In the current context, similar  
717 models can be used to account for the cultural inheritance of material culture and  
718 systems of symbolic representation on development (Fragaszy, in press; Hazelhurst &  
719 Hutchins, 1991; Kendal, in press). Of course, development affects individuals'  
720 behaviour and thus their contribution to the socio-cultural environment. Thus  
721 modelling is required to clarify how particular forms of ecological inheritance interact  
722 with mechanisms of cognitive development.

723 We have emphasised the role of a knowledgeable-other's behaviour, and not  
724 just the influence of material culture, in constructing a learning environment affecting  
725 development. We can also expect interesting interactions between developmental and  
726 cultural-evolutionary dynamics in these cases too, where for instance, scaffolding  
727 traditions of a master affect the learning end-state of an apprentice (van Geert, 1991;  
728 van Geert & Steenbeek, 2005), or where there is continuous interaction between the  
729 dynamic learner's cognitive state and the socio-cultural learning environment to  
730 which they contribute. Where appropriate, these models can account for the effects of  
731 differential survival and reproduction and of gene-culture coevolutionary dynamics.

732

733 *3.3 Culture, Peer Interaction and Niche Construction Across the Life Span*

734 Differing social norms influence how an individual progresses within a niche.  
735 For example, in Western societies shyness is viewed as problematic, while in Chinese  
736 culture, shyness denotes a level of maturity and understanding (Chen, 2010). These  
737 norms manifest themselves in peer interactions, and result in differing temperamental  
738 dispositions being reflected in the social niche in which one finds oneself. Chen,  
739 DeSouza, Chen and Wang (2006) observed 4-year-olds in a free play setting in both  
740 Canada and China. In Canada when a shy peer initiated an interaction children  
741 ignored these advances or overtly refused them; however, in China children were  
742 more positive to advances from shy children. Similarly, shyness was associated with  
743 peer rejection in Canada, and peer acceptance in China (Chen, Rubin & Li, 1995).  
744 Thus, the value placed by society on behavioural tendencies is transmitted early to  
745 young children. As a result children's experiences in their social circle are very  
746 different, such that shy children in China grow in self-confidence (Chen, Chen, Li &  
747 Wang, 2009), while shy children in North America who cannot regulate their  
748 behaviour to improve their peer status experience frustration and distress. Thus,  
749 variation in formative attitudes to shyness can provide a constructed environment that  
750 influences emotional development.

751 Interestingly, and in line with the activity theory position in which  
752 development and learning must be placed within a societal, political and historical  
753 context, Chen (2012) points out that as China has shifted in recent years to a more  
754 competitive economy adapting more individualistic values (thus its cultural niche has  
755 changed), children's shyness has increasingly been associated with peer rejection.  
756 Equally, in Western societies, where autonomy is valued, as children reach early  
757 adolescence their desire for independence from the family increases (Rubin,  
758 Bukowski & Parker, 2006), with peer, as opposed to family, support becoming a



759 significant aspect through which they gain self-worth (Sullivan, 1953). Thus the  
760 interplay between the socio-political environment, that contributes to the cultural  
761 niche, and dispositional factors, such as temperament, need to be investigated across  
762 the life span, as early factors will influence the differing cultural niches an individual  
763 progresses through during their life. Conversely, the activity and interaction of  
764 individuals contributes to the socio-political environment. NCT provides a framework  
765 to consider the dynamic interaction of psychological development and socio-cultural  
766 environment within and across generations.

767

#### 768 4. Conclusions

769 Our aim in this paper has been to meet the challenge set by Gauvain (2000) to better  
770 integrate the biological and social sciences in terms of theory and research in human  
771 psychological development in the light of humans as the ultimate niche constructors.  
772 We agree with Li (2003, 2007, in press) that more work needs to consider the  
773 biocultural co-constructive influences on life-span cognitive and behavioural  
774 development. It has not been possible to include discussion of all the time scales and  
775 levels of analysis highlighted by Li (2003) but we have nonetheless reviewed some of  
776 the parallel lines of thinking across developmental psychology and NCT, and it is  
777 immediately apparent that these are extensive.

778         This reflection has considered niche construction in dyadic settings, in which  
779 culturally-knowledgeable others transmit information to culturally-naïve individuals  
780 (natural pedagogy and activity theory), thus teaching them how to survive and thrive  
781 within the niche. It has also considered group behaviour within a niche, reviewing  
782 work on distributed cognition and situated learning, demonstrating that human infants  
783 become part of a community (a niche) and can draw from many different sources

784 (peers, adults, constructed opportunities within the environment, cultural tools such as  
785 books or artefacts) to become an active member of that community. Children (like  
786 adults) are not passive recipients of biological and cultural inheritance but active  
787 agents, influencing what is learnt through changes in their cognitive development, and  
788 their active pursuit of knowledge.

789         Of course, identifying like-minded researchers, or sympathetic bodies of  
790 theory, in other fields is one thing, and fertile exchange is another. In what ways  
791 could NCT be useful to developmental psychologists? Three points come to mind.  
792 NCT has heuristic value in drawing attention to the active agency of humans as a  
793 source of environmental and social change, as well as to the evolutionary, ecological,  
794 and social ramifications of human niche construction. By foregrounding niche  
795 construction, NCT both reduces the likelihood that it will be neglected (Laland &  
796 Sterelny, 2006) and provides theoretical justification to those who find their emphasis  
797 on that agency is under-appreciated. Second, NCT offers conceptual tools for  
798 understanding phenomena within the Human Sciences, including a variety of  
799 experimental and theoretical methods for establishing where niche construction is  
800 consequential and quantifying its impact (Odling-Smee et al., 2003). These tools also  
801 encompass an overarching conceptual framework that embraces evolutionary theory  
802 and sets human development in a comparative perspective, but at the same time is  
803 explicit in emphasizing the active agency of humans in constructing their world, and  
804 thereby shaping their development. Third, NCT offers theoretically and empirically  
805 derived insights into the dynamics of evolving systems under the influence of niche  
806 construction. Potentially scientists working in the human realm can draw from these  
807 established findings to understand better the complex dynamics of their own study  
808 systems. More generally, we suspect that there are likely to be many contemporary

809 developmental psychologists who are unfamiliar with NCT but who nonetheless can  
810 be regarded as ‘kindred spirits’, and who we hope will find it useful to engage with  
811 and employ NCT in new inter-disciplinary endeavours (Kendal et al., 2011; Laland et  
812 al., 2011; O’Brien & Laland, in press).

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1218 Figure legends

1219

1220 Figure 1. (a) *A conventional view of the process of adaptation through natural*  
1221 *selection.* Causation is primarily linear: it starts with selection pressures stemming  
1222 from the environment and ends with changes in the organism. Reciprocal causation is  
1223 recognized only in some ‘special cases’ where the source of selection is biotic (e.g.  
1224 sexual selection, predator-prey coevolution). (b) *The niche construction perspective.*  
1225 Niche construction is explicitly recognized as an evolutionary process. The match  
1226 between organism and environment results from interactions of natural selection  
1227 pressures in environments and the niche-constructing activities of organisms.  
1228 Inheritance is expanded to comprise both genetic and ecological components (i.e.  
1229 legacies of selection pressures previously modified by niche construction). Causation  
1230 is primarily reciprocal, with selective environments shaping organisms, and  
1231 organisms shaping selective environments, either relative to themselves, or other  
1232 organisms.

1233

1234 Figure 2. There is selective feedback at multiple levels from multiple niche-  
1235 constructing processes.

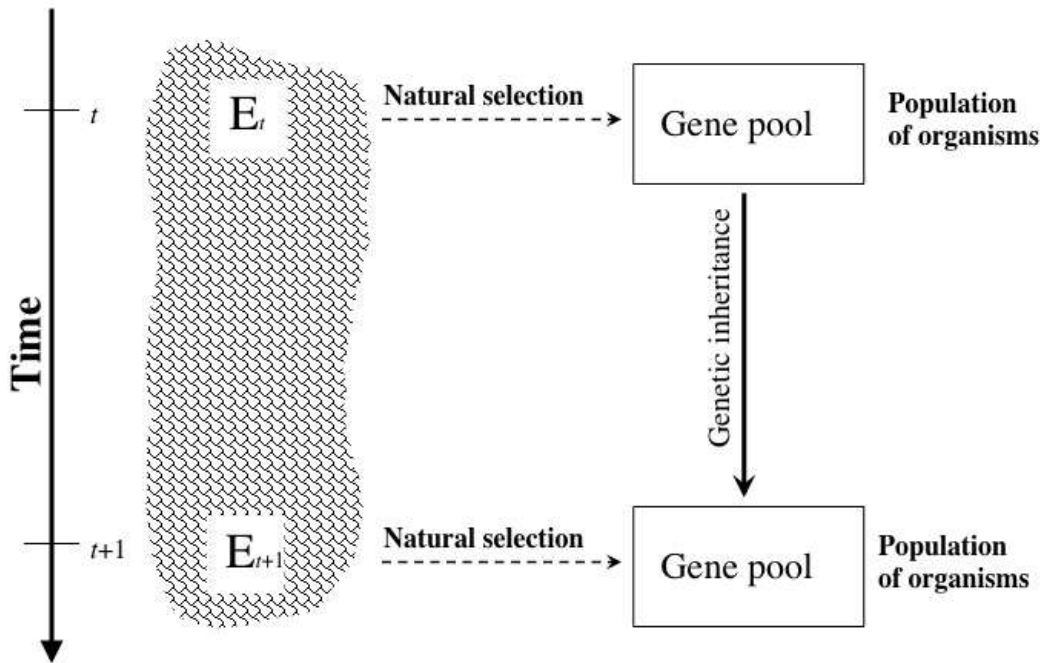
1236

1237 Figure 3. The relation between activity theory and niche construction is illustrated by  
1238 the ‘mediational triangle’ (Cole & Engström, 2001), which expresses the complex  
1239 relation between artefacts, norms, communities, objects and subjects.

1240

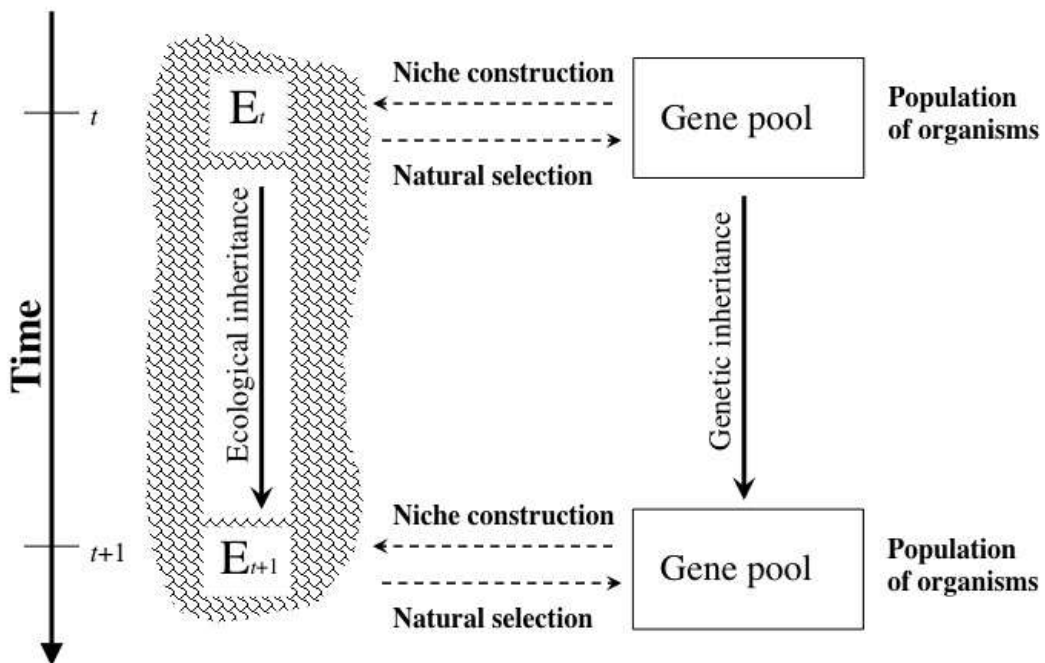
1241 Figure 4 The Tower of Nottingham, a wooden block construction task made from 21  
1242 pieces and requiring a minimum of 20 moves to complete.

Figure 1a.



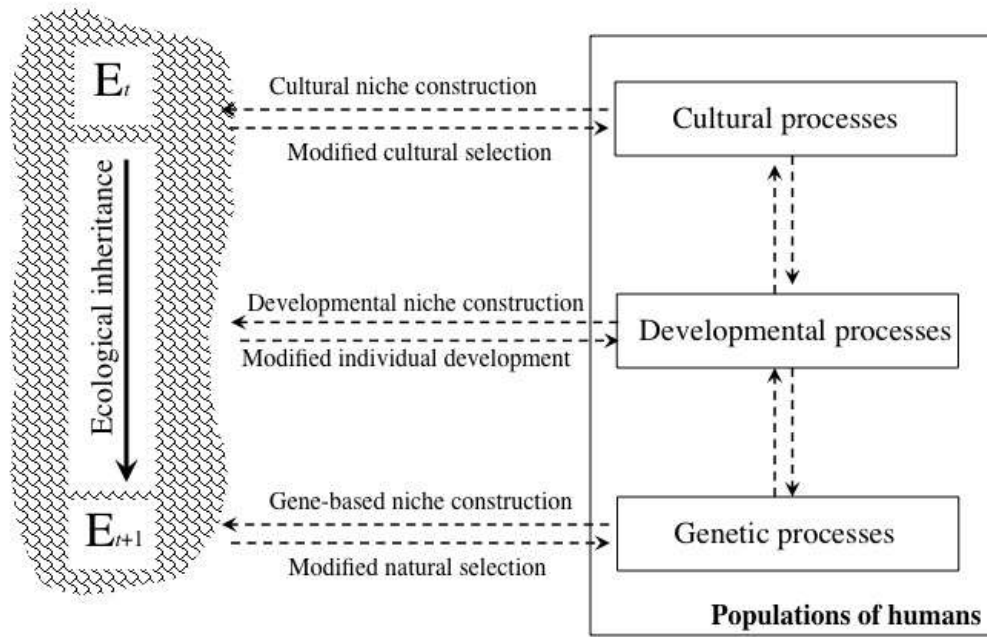
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Figure 1b.



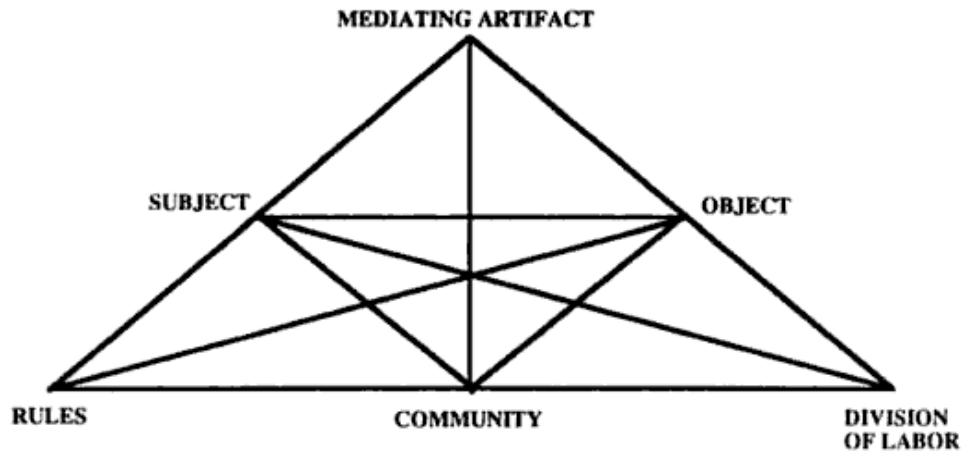
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Figure 2.



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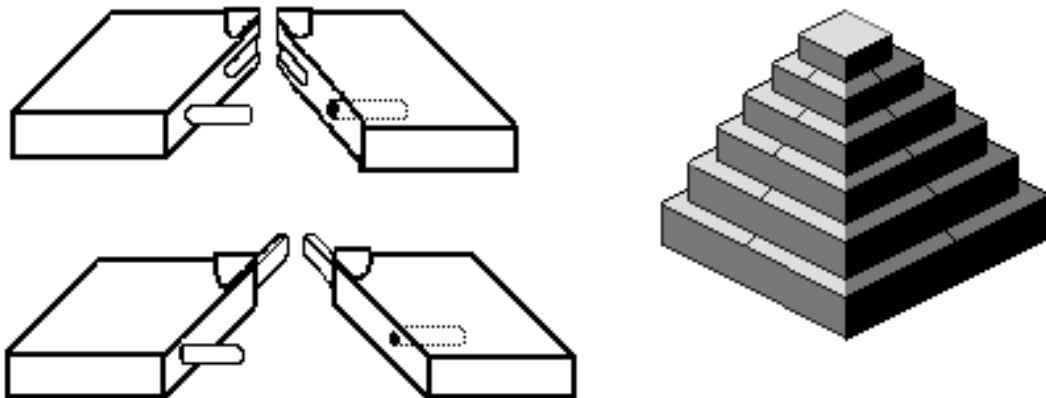
1247 Figure 3



1248

1249

1250 Figure 4



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