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Developmental Niche Construction

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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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1217 *of the United States of America, 105*, 13690–13695.

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.

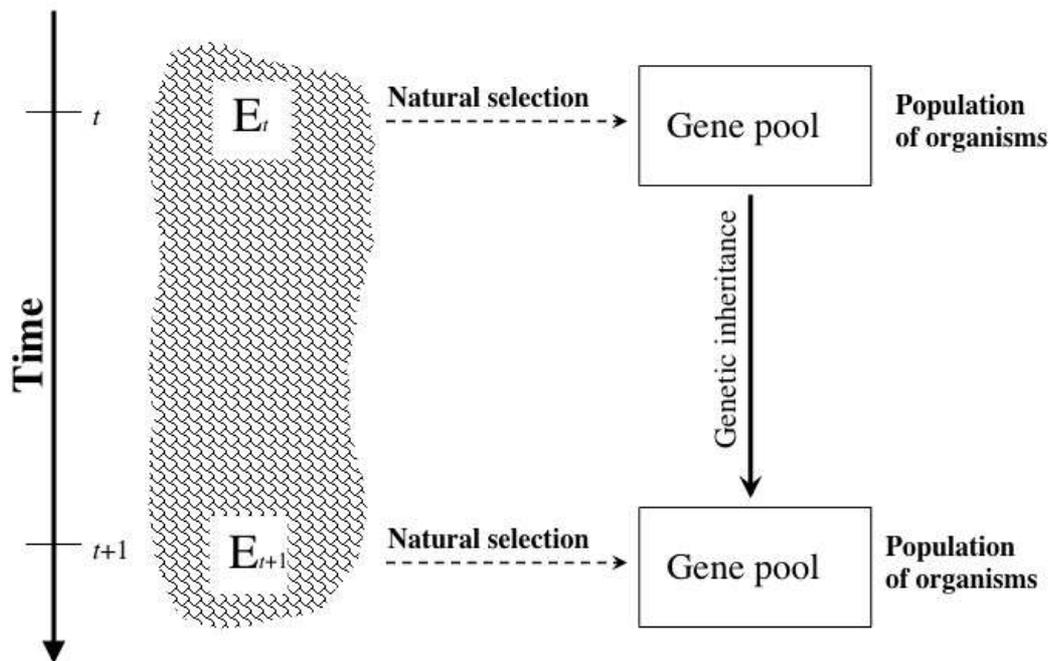
1236

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

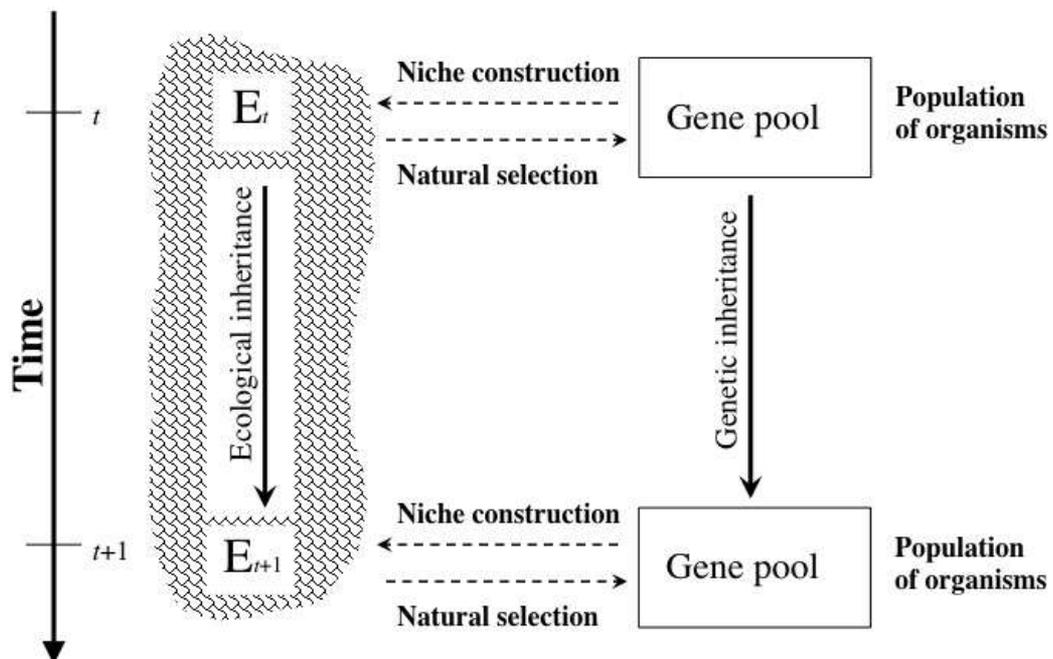
1241 Figure 4 The Tower of Nottingham, a wooden block construction task made from 21
1242 pieces and requiring a minimum of 20 moves to complete.

Figure 1a.



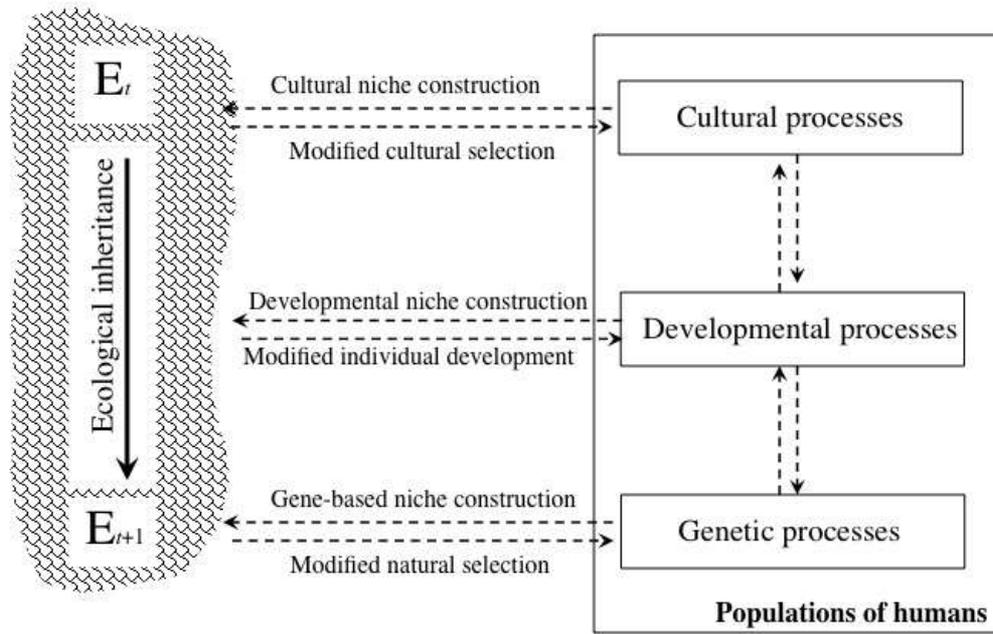
1243

Figure 1b.



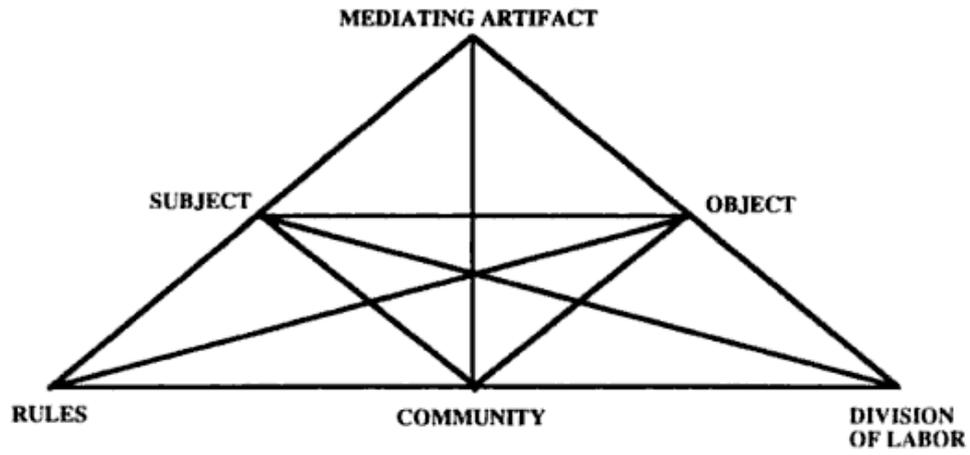
1244

Figure 2.



1245
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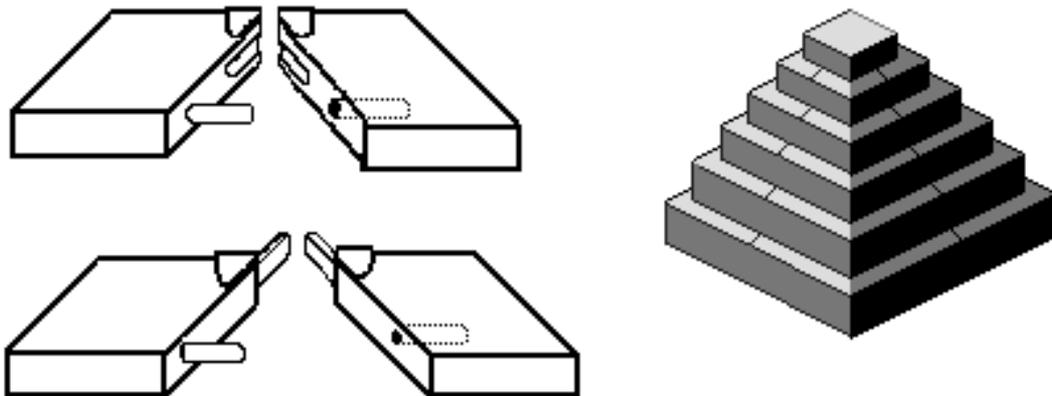
1247 Figure 3



1248

1249

1250 Figure 4



1251