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## Limits of Methods or Limits of Cognition? On Research Narcissism and the Search for New Tools in Animal Sciences

Пределы методов или пределы познания?  
Об исследовательском нарциссизме  
и поиске новых инструментов  
в науках о животных

Limits of Methods or Limits of Cognition?  
On Research Narcissism and the Search  
for New Tools in Animal Sciences

### Абстракт

В статье критикуется антропоцентризм в сравнительной когнитивистике, где методологические ограничения ошибочно принимаются за пределы познания животных. Линейная модель эволюции (*scala naturae*) и поиск исключительно человеческих черт препятствуют объективной нейробиологической и этической оценке. Опираясь на нелинейную концепцию «пространства возможных разумов» и воплощенного интеллекта (на примере исследований шмелей и осьминогов), автор предлагает новый «набор исследовательских инструментов» (включая, в частности, *signature testing* и *failure points*). Эта методологическая рамка смещает акцент с демонстрации успехов на системное картирование когнитивных пределов. Отказ от антропоцентрических мер в пользу видо-адекватного подхода (*species-adequate approach*) позволяет достоверно понять уникальные способы, которыми животные воспринимают собственный мир.

### Abstract

This article critiques anthropocentrism in comparative cognitive science, where methodological limits are often misidentified as actual limits of animal cognition. The linear *scala naturae* model and the search for human traits hinder rigorous neurobiological and ethical assessment. Drawing on the non-linear “space of possible minds” and embodied intelligence (exemplified by studies on bumblebees and octopuses), the text introduces a new “research toolbox” including signature testing and failure points. This framework shifts the focus from demonstrating success to systematically mapping cognitive limits. Replacing anthropocentric measures with a species-adequate approach facilitates a reliable understanding of the unique ways animals navigate their own worlds.

**Keywords:** comparative cognitive science, anthropocentrism, embodied intelligence, species-adequate approach, space of possible minds

**Ключевые слова:** сравнительная когнитивистика, антропоцентризм, воплощенный интеллект, видо-адекватный подход, странство возможных разумов

“Regarding humans as ‘higher’ can be a scientifically unjustified and anthropocentric prejudice”<sup>1</sup>

Daniel Dennett

## The Hall of Mirrors: Anthropocentric Biases in Zoopsychology

Contemporary zoopsychology, despite its dynamic development and daily reports of the extraordinary capabilities of various species, still resembles a metaphorical hall of mirrors. Instead of perceiving other species through the prism of their own *Umwelt*, the researcher often seeks only a reflection of their own cognitive capacities. This drive to identify a “human element” within the natural world results in a situation where the limits of animal cognition, which researchers so frequently discuss, are in fact the limits of our own research methods. The cause of this state of affairs lies deep within human cognitive architecture. To function rapidly and effectively in such a complex world, the human brain constantly processes vast amounts of information, thereby generating implicit biases and heuristics. These are unconscious attitudes, stereotypes, and beliefs that shape human perceptions, judgments, and behaviours toward other beings, operating below the threshold of conscious perception.<sup>2</sup>

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<sup>1</sup> Daniel Dennett, cited in Sherman Xie, “Are Humans (Higher) Animals? On the Rational Awakening and Life Transcendence of Death Cognition,” *Acta Psychologica* 257 (2025): 105090, <https://doi.org/10.1016/j.actpsy.2025.105090>.

<sup>2</sup> Holly G. Molinaro and Clive D. L. Wynne, “Barking Up the Wrong Tree: Human Perception of Dog Emotions Is Influenced by Extraneous Factors,” *Anthrozoös* 38, no. 2 (2025), <https://doi.org/10.1080/08927936.2025.2469400>.

## The Similarity Heuristic and the “Phenotypic Fallacy”: Why the Mirror Test Fails

The similarity principle leads humans to empathize more and rate intelligence higher in species phylogenetically, cognitively, or behaviourally similar to themselves.<sup>3</sup> This bias is reinforced by a sensory communication barrier: human senses evolved to solve human environmental problems, not to decode non-human signals.<sup>4</sup> Consequently, humans demonstrate a natural tendency to appreciate only those communication strategies that they are able to recognize and interpret within their own semantic system. This automatically favours species closely related to us; meanwhile, the absence of recognizable expression (e.g., facial expressions in cuttlefish or insects) is prematurely interpreted as evidence of cognitive inferiority,<sup>5</sup> rather than a limitation of our own perception. These phenomena exemplify anthropocentrism, the biased use of human standards as a universal “meter stick” for all life.

Methodological anthropocentrism permeates scientific practice by adopting humans as a universal model, restricting the search for animal abilities to those familiar to human experience. This results in the researcher being enclosed within their own perceptual sphere (Jakob von Uexküll’s *Umwelt*) isolated from alternative cognitive perspectives. Unaware of these boundaries, they often misinterpret divergent strategies as cognitive deficits rather than perceptual differences. Behavioural interpretation oscillates between two extremes: anthropomorphism and anthropodenial. While anthropomorphism, driven by the similarity principle, may seem empathetic, it risks welfare errors by misattributing human motivations while ignoring actual animal needs. Conversely, anthropodenial poses a greater threat to scientific integrity. It is the unwarranted, a priori denial of animal intelligence or self-awareness,<sup>6</sup> stemming from a conviction of human uniqueness that disregards evidence challenging human transcendence over nature.

<sup>3</sup> Agnese Crisante, Oliver H. P. Burman, and Anna Wilkinson, “All Is Not Equal: Public Perception of Cognitive Abilities, Suffering and Emotional Attachment in Different Pet Species,” *Applied Animal Behaviour Science* 280 (2024): 106434, <https://doi.org/10.1016/j.applanim.2024.106434>.

<sup>4</sup> Crisante et al., “All Is Not Equal,” 2.

<sup>5</sup> Helen Lambert, Gemma Carder, and Neil D’Cruze, “Given the Cold Shoulder: A Review of the Scientific Literature for Evidence of Reptile Sentience,” *Animals* 9, no. 10 (2019): 821, <https://doi.org/10.3390/ani9100821>.

<sup>6</sup> Sherman Xie, “Are Humans (Higher) Animals? On the Rational Awakening and Life Transcendence of Death Cognition,” *Acta Psychologica* 257 (2025): 105090, <https://doi.org/10.1016/j.actpsy.2025.105090>. For foundational debates on cognitive ethology, anthropomorphism, and the philosophical attribution of mental states to non-human animals, see also Donald Griffin, *Animal Minds: Beyond Cognition to Consciousness* (University of Chicago Press, 2001); Colin Allen and Marc Bekoff, *Species of Mind: The Philosophy and Biology of Cognitive Ethology* (MIT Press, 1997); and Kristin Andrews, *The Animal Mind: An Introduction to the Philosophy of Animal Cognition* (Routledge, 2020).

The Mirror Self-Recognition (MSR) test (Gallup 1970) exemplifies methodological enclosure. Long considered the “gold standard” for self-awareness, it primarily measures sensory convergence with the human visual apparatus.<sup>7</sup> This is confirmed by recent studies on species evolutionarily distant from mammals, such as insects or cephalopods.

Shishimi's (2025) study on honeybees (*Apis mellifera*) deconstructs the MSR paradigm. While insects showed increased mirror activity, a reliable analysis must focus on the bee's unique *Umwelt*. Evolutionarily, bees detect bilateral symmetry to localize flowers. The mirror reflection presents the bee with exactly such a highly attractive symmetrical pattern,<sup>8</sup> explaining stimulus interest as an attentional artifact rather than self-reflection.<sup>9</sup>

Shishimi (2025) attributes mirror-grooming and duration to social agitation rather than self-recognition. Bees likely perceive reflections as conspecific intruders, triggering grooming as a form of generalized agitation rather than self-recognition.<sup>10</sup> Consequently, according to Morgan's Canon, these behaviours reflect parsimonious non-cognitive mechanisms, such as novelty responses or social arousal, rather than self-awareness. This case illustrates how ignoring species-specific traits leads to systematic data misinterpretation.

While bee research suffers from overinterpretation, cephalopod studies often overlook the physical limitations of research tools. Standard mirrors fail to reflect light polarization, a “concealed communication channel” cuttlefish use for intra-specific signalling.<sup>11</sup> Because mirrors may distort these patterns, the animal might perceive its reflection as a foreign stimulus rather than “self,” rendering the test fundamentally inadequate for the species' sensory reality. Evidence from *Sepia officinalis* suggests that mirrors act as social stimuli; females display the “Splotch” body pattern almost exclusively to other females or to their reflections.<sup>12</sup> This perception of the image as a same-sex conspecific explains their “failure” in classic mark tests. MSR failure does not prove a lack of cephalopod self-awareness. Howard and Baron (2024) emphasize their 500 million neurons and decentralized nervous system,

<sup>7</sup> Gentaro Shishimi, Rena Akaishi, and Mana Matsukami, “Investigating the Potential for Mirror Self-Recognition in Honeybees (a): A Preliminary Study Using the Mark Test,” bioRxiv preprint, (2025): 1, <https://doi.org/10.1101/2025.10.14.682345>.

<sup>8</sup> Martin Giurfa et al., “Bilateral Symmetry as an Information-Processing Strategy in Honeybees,” *Nature* 382, no. 6590 (1996): 458, cited in Shishimi et al., “Investigating the Potential,” 1.

<sup>9</sup> Shishimi et al., “Investigating the Potential,” 25.

<sup>10</sup> Shishimi et al., “Investigating the Potential,” 25.

<sup>11</sup> Nadav Shashar et al., “Polarization Vision in Cuttlefish: A Concealed Communication Channel?” *Science* 273, no 5279 (1996): 1150, cited in Shishimi et al., “Investigating the Potential,” 1.

<sup>12</sup> Mark R. Palmer et al., “Agonistic and Socio-sexual Signaling in the Cuttlefish *Sepia officinalis* in Response to Mirror Images and Intruders,” *Animal Cognition* 9, no. 1 (2006): 1, cited in Shishimi et al., “Investigating the Potential,” 1.

radically different from vertebrates. Through the rubber arm illusion, octopuses demonstrate sophisticated body ownership, integrating visual, tactile, and proprioceptive data beyond the mirror modality. This “many-to-one mapping” problem implies that visual test failure may reflect non-primate sensory mechanisms rather than a lack of consciousness.<sup>13</sup> Consequently, researchers must develop species-appropriate tests respecting the subject’s unique *Umwelt*.

Reliable cognitive assessment requires positive controls, tasks the animal can successfully perform within the study. These validate results by ensuring that negative outcomes do not stem from confounding factors, such as environmental stress, lack of motivation, or inappropriate rewards.

Positive controls distinguish genuine cognitive limits from what Howard and Barron term “bad experiments”: methodological artifacts where animals fail due to design errors rather than incapacity.<sup>14</sup> By ensuring that subjects understand task instructions, these controls shift research from merely reporting failures to accurately mapping cognitive boundaries. Here, ecological validity plays a defining role, representing one of the most persistent challenges in test design for decades. To prevent errors stemming from an unnatural experimental context, research paradigms must be systematically planned around an animal’s unique sensorium. Common strategies include:

- Tasks of increasing difficulty: Starting with a variant the animal performs flawlessly and gradually increasing stimulus complexity until reaching the cognitive limit.
- Spatial example: Using short-distance nest returns as a baseline to ensure comprehension before increasing distances to determine true spatial boundaries.
- Memory example: Employing minimal delays in match-to-sample tasks (e.g., in honeybees) to confirm task comprehension before testing longer intervals to identify real memory limits.<sup>15</sup>

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<sup>13</sup> Alexander H. Taylor et al., “The Signature-Testing Approach to Animal Cognition,” *Trends in Cognitive Sciences* 26, no. 3 (2022): 215, cited in Scarlett R. Howard and Andrew B. Barron, “Understanding the Limits to Animal Cognition,” *Current Biology* 34, no. 7 (2024): R294, <https://doi.org/10.1016/j.cub.2024.02.043>.

<sup>14</sup> Howard and Barron, “Understanding the Limits,” R295.

<sup>15</sup> Shaowu Zhang et al., “Delayed Match-to-Sample Task in Honeybees,” *Proceedings of the National Academy of Sciences* 102, no. 35 (2005): 12606, cited in Howard and Barron, “Understanding the Limits,” R295.

## From the Mythical Ladder to Multidimensional Space: Evolution of the Model of Mind

Dennett's opening quote challenges the "single ladder" myth, or *scala naturae*. This anachronistic belief views evolution and mental development as a linear hierarchy with humans at the summit.<sup>16</sup> In practice, this logic assesses animal intelligence solely by its similarity to the human model, favouring mammals while marginalizing phylogenetically distant organisms. Modern science rejects the "higher" versus "lower" dichotomy as groundless anthropocentrism. As Dennett argues, "higher" status is a subjective prejudice: each species evolves unique abilities optimized for its ecological niche.<sup>17</sup> Maintaining this myth distorts biological reality and devalues animal subjectivity, leading to poor treatment and insufficient legal protection.

The "phenotypic gambit" poses a significant trap in cognitive research: the risky assumption that behavioural correlations faithfully reflect an organism's genetic structure.<sup>18</sup> This leads researchers to treat intelligence as a monolithic "processor," ignoring complex mechanisms such as pleiotropy or genotype-environment interactions.

"General intelligence" is often a statistical resultant of specific adaptations to particular challenges. Lashley's error occurs when a single task dominates the entire measurement. Sauce et al. (2018) calculated a general cognitive ability (GCA) index for mice using five tests, including the Lashley maze.<sup>19</sup> However, reanalysis showed the GCA index correlated almost perfectly ( $r = 0.99$ ) with Lashley maze results alone. The alleged "g factor" thus reflected specific task proficiency rather than universal mental ability. Reducing mental complexity to a single score creates a misleading "single measure" illusion, masking unique evolutionary strategies that defy anthropocentric IQ schemes.

Cognitive evolution is inherently non-linear, refuting the "single ladder" myth. Aaron Sloman's "space of possible minds" offers an alternative model: species occupy unique niches within a multidimensional landscape rather than points on a linear progress vector.<sup>20</sup> According to this view, ecological pressures and adaptive

<sup>16</sup> Howard and Barron, "Understanding the Limits," R294; see also Crisante et al., "All Is Not Equal," 106434.

<sup>17</sup> Daniel Dennett, cited in Xie, "Are Humans (Higher) Animals?," 105090.

<sup>18</sup> Marc-Antoine Poirier et al., "How General Is Cognitive Ability in Non-Human Animals? A Meta-Analytical and Multi-Level Reanalysis Approach," *Proceedings of the Royal Society B* 287 (2020): 20201853, <https://doi.org/10.1098/rspb.2020.1853>.

<sup>19</sup> Poirier et al., "How General Is Cognitive Ability?," 6.

<sup>20</sup> Aaron Sloman, "The Structure of the Space of Possible Minds," in *The Mind and the Machine: Philosophical Aspects of Artificial Intelligence*, ed. Steve Torrance (Ellis Horwood, 1984), 127–142, cited in Howard and Barron, "Understanding the Limits," R294.

demands dictate how cognitive capacities are distributed across the evolutionary landscape. Such a perspective facilitates interpreting the convergent evolution of complex psychological functions across phylogenetically distant taxa. An example is episodic-like memory (what-where-when) evolved independently across cephalopods, insects, fish, rodents, and birds.<sup>21</sup> Despite radical neural differences, these taxa achieve similar functional goals, as evidenced by self-recognition in bees, cleaner wrasses, and magpies. This supports the social intelligence hypothesis: group-living demands, rather than mammalian lineage, constitute the primary driver of advanced cognition and self-awareness.<sup>22</sup>

## Mind in the Body, Body in the World: Embodied Intelligence and the Limits of Self-Awareness

Cognitive abilities are inseparable from morphology and an animal's Umwelt.<sup>23</sup> This decentralized view emphasizes embodied intelligence: the use of body geometry and physical capabilities to solve problems. Grounded in the broader framework of 4E cognition (Embodied, Embedded, Enacted, Extended), this paradigm posits that cognitive processes are fundamentally shaped by the organism's physical body and its active engagement with the environment.<sup>24</sup> Embedded cognition highlights how organisms operate within their specific ecological niche, where ecological validity becomes crucial for experimental design.<sup>25</sup> Furthermore, cognition is enacted (emerging dynamically through movement, such as the head-scanning movements in bees used to estimate distance) and extended (as seen in tool use and nest construction where external structures become functional parts of the cognitive system). In this gradualist model, consciousness exists on a continuum ranging from basic bodily self-perception to sophisticated, conceptual body ownership.<sup>26</sup> This allows animals to distinguish their actions from the environment without requiring an abstract "concept of Self."<sup>27</sup> Ravi et al. (2020) demonstrated in their

<sup>21</sup> Howard and Barron, "Understanding the Limits," R295.

<sup>22</sup> Shishimi et al., "Investigating the Potential," 25.

<sup>23</sup> Howard and Barron, "Understanding the Limits," R295.

<sup>24</sup> Joanna Brebner and Lars Chittka, "Animal Cognition: The Self-Image of a Bumblebee," *Current Biology* 31, no. 4 (2021): R207–R212, <https://doi.org/10.1016/j.cub.2020.12.027>; see also Shishimi et al., "Investigating the Potential," 1.

<sup>25</sup> Brebner and Chittka, "Animal Cognition," R207.

<sup>26</sup> Frans de Waal, *Mama's Last Hug: Animal Emotions and What They Tell Us about Ourselves* (W. W. Norton & Company, 2019), cited in Shishimi et al., "Investigating the Potential," 1.

<sup>27</sup> Shishimi et al., "Investigating the Potential," 25.

breakthrough research on bumblebees (*Bombus terrestris*) that these insects possess a form of bodily self-awareness.<sup>28</sup> Bumblebees precisely assess the width of a gap in relation to their own wingspan, performing a body-roll manoeuvre in flight to avoid collision.<sup>29</sup> As Brebner and Chittka (2020) note, this testifies to the perception of spatial structure in strict reference to one's own form.

In cognitive and philosophical literature, the concepts of consciousness, awareness, and self-awareness are defined within a gradualist perspective, positing that these states are not "all-or-nothing" phenomena but rather form a continuum of varying complexity. Consciousness is frequently equated with sentience, which is the organism's capacity to possess subjective experiences and directly feel sensory and affective states. It is characterized by the presence of mental functions such as emotion, memory, recognition, and decision-making, thereby distinguishing sentient organisms from non-sentient matter.<sup>30</sup> Conversely, awareness (or operational awareness) in animal studies most commonly refers to bodily awareness. This is the organism's capacity to account for its own physical dimensions, reach, and anatomical limitations during environmental interactions. For example, bumblebees evaluating aperture width relative to their wingspan demonstrate a functional awareness of their body in relation to the external world. Finally, self-awareness is defined as the ability to identify oneself as a distinct entity, separated from the environment and conspecifics. Recognized as a higher-order cognitive function, it ranges from basic bodily self-perception to the abstract concept of the "Self," classically indicated by a successful MSR test. The neurocognitive and neurobehavioural conditions for these states define the boundaries at which specific levels of consciousness can be attributed to animals. In mammals, complex capacities like mirror self-recognition depend on multimodal integration, such as the formation of hippocampal neuronal ensembles through visuotactile integration. However, in invertebrates like octopuses, a sophisticated sense of body ownership is achieved by integrating visual, tactile, and proprioceptive information within a radically decentralized nervous system.<sup>31</sup> Furthermore, modern research on "miniature brains" demonstrates that insect neural architectures (comprising approximately one million neurons) possess the functional organization necessary to support basic consciousness and abstract concept learning, proving that complex cognition does not strictly require a neocortex. Behaviourally, these boundaries are evidenced by affordance-based responses such as lateral flight reorientation in bumblebees indicating an operational body schema

<sup>28</sup> Sridhar Ravi et al., "Bumblebees Perceive Their Own Body Size," *Proceedings of the National Academy of Sciences* 117, no. 49 (2020): 31294, cited in Brebner and Chittka, "Animal Cognition," R207.

<sup>29</sup> Brebner and Chittka, "Animal Cognition," R207; see also Shishimi et al., "Investigating the Potential," 1.

<sup>30</sup> Crisante et al., "All Is Not Equal," 2.

<sup>31</sup> Crisante et al., "All Is Not Equal," 2.

and by the intentional use of a mirror to inspect unseen body parts, distinguishing genuine self-awareness from mere social agitation. Evolutionarily, these capacities are heavily driven by the Social Intelligence Hypothesis, wherein the demands of complex group living compel an organism to distinguish its own internal states from those of others.<sup>32</sup> Kawashima and Ikeda (2025) push these findings further by adapting the rubber arm illusion for octopuses.<sup>33</sup> Their research demonstrates that these cephalopods possess an advanced sense of body ownership, integrating visual, tactile, and proprioceptive signals.<sup>34</sup> This offers a vital, non-linear alternative to the mirror test: it proves that invertebrate self-awareness can manifest through body schema integration rather than purely visual reflection.

## A New Toolbox: From Reporting Successes to Mapping Limits

The future of animal research relies on a new toolbox, marking a transition in comparative cognitive science from demonstrating successes to systematically investigating cognitive limits and underlying behavioural mechanisms.<sup>35</sup> Howard and Barron (2024) identify its key elements:

- Signature Testing: Analyses error structures and specific behavioural biases,<sup>36</sup> resolving the “many-to-one mapping” problem where identical behaviours stem from divergent cognitive processes.<sup>37</sup> For example, in a sequence-learning task, signature analysis allows researchers to determine whether errors are random or form a consistent pattern indicating a specific strategy, such as a “win-stay, lose-shift” heuristic.<sup>38</sup>

<sup>32</sup> Crisante et al., “All Is Not Equal,” 2.

<sup>33</sup> Shunsuke Kawashima and Yuzuru Ikeda, “Rubber Arm Illusion in Octopus,” *Current Biology* 35, no. 14 (2025): R702, <https://doi.org/10.1016/j.cub.2025.05.017>, cited in Shishimi et al., “Investigating the Potential,” 1.

<sup>34</sup> Shishimi et al., “Investigating the Potential,” 25.

<sup>35</sup> Howard and Barron, “Understanding the Limits,” R295.

<sup>36</sup> Alexander H. Taylor et al., “The Signature-Testing Approach to Animal Cognition,” *Trends in Cognitive Sciences* 26, no. 3 (2022): 215, cited in Scarlett R. Howard and Andrew B. Barron, “Understanding the Limits to Animal Cognition,” *Current Biology* 34, no. 7 (2024): R294, <https://doi.org/10.1016/j.cub.2024.02.043>.

<sup>37</sup> Taylor et al., “The Signature-Testing Approach,” 215, cited in Howard and Barron, “Understanding the Limits,” R294.

<sup>38</sup> Howard and Barron, “Understanding the Limits,” R295.

- Identifying Failure Points: Utilizes tasks of incremental difficulty to pinpoint when an animal's cognitive system reaches its limit.<sup>39</sup> Within this framework, failure provides positive evidence of a specific cognitive limit rather than a "lack of result." Honeybee working memory studies exemplify this by gradually extending match-to-sample intervals until response accuracy drops to chance.<sup>40</sup>
- Applying Positive Controls: Introduces reference tasks (simplified test versions the animal can perform) to ensure main test failures reflect genuine cognitive limits,<sup>41</sup> rather than external factors like stress, lack of motivation, inappropriate reward, or illness. A bee failing a long-delay memory test, for example, must first pass a minimal-delay version to confirm task comprehension.
- Multilevel Mixed Models (MMMs): Advanced statistical tools that partition variance at inter- and intra-individual levels, shifting focus from a mythical "g" factor toward mapping correlations between specific cognitive modules.<sup>42</sup> MMMs reanalysis of mouse studies revealed hidden trade-offs between abilities previously misclassified as a single intelligence factor dominated by the Lashley maze.<sup>43</sup>
- Computational Modelling: Uses artificial neural networks to test hypotheses on a nervous system's objective processing limits.<sup>44</sup> "Miniature brain" models prove that complex abstract learning (e.g., "above/below" relations) does not require vast neuronal mass, challenging the dogma of large vertebrate brain superiority.

Modern tools guarantee success only within an appropriate theoretical framework. Integrating these methods into a species-adequate approach provides the ethical and methodological compass for modern cognitive science.

<sup>39</sup> Howard and Barron, "Understanding the Limits," R295.

<sup>40</sup> Shaowu Zhang et al., "Delayed Match-to-Sample Task in Honeybees," *Proceedings of the National Academy of Sciences* 102, no. 35 (2005): 12606, cited in Scarlett R. Howard and Andrew B. Barron, "Understanding the Limits to Animal Cognition," *Current Biology* 34, no. 7 (2024): R294, <https://doi.org/10.1016/j.cub.2024.02.043>.

<sup>41</sup> Howard and Barron, "Understanding the Limits," R295.

<sup>42</sup> Poirier et al., "How General Is Cognitive Ability," 6.

<sup>43</sup> Poirier et al., "How General Is Cognitive Ability," 6.

<sup>44</sup> Vera Vasas and Lars Chittka, "Insect-Inspired Sequential Inspection Strategy Enables an Artificial Network of Modern Integrated Circuits to Count," *iScience* 11 (2019): 140, cited in Gentaro Shishimi, Rena Akaishi, and Mana Matsukami, "Investigating the Potential for Mirror Self-Recognition in Honeybees (*Apis mellifera*): A Preliminary Study Using the Mark Test," bioRxiv preprint, 2025, 1, <https://doi.org/10.1101/2025.10.14.682345>.

## The Species-Adequate Paradigm: Pillars of a Biologically Relevant Experiment

Howard and Barron (2024) diagnose that neurobiology often sacrifices real animal behaviour on the “rigidly standardized laboratory protocols.”<sup>45</sup> This paradigmatic error ignores that cognition represents an evolutionary adaptation to specific environmental challenges rather than existing in a vacuum. Consequently, the new “research toolbox” redefines reliable design, understood here not merely as statistical repeatability, but as the methodological capacity of an experiment to accurately isolate genuine cognitive limits from procedural artifacts, by requiring a species-adequate approach across four dimensions:

- **Motivation and Reinforcement:** Positive controls ensure that animals fail due to genuine cognitive limits rather than reward disinterest, stress, or anxiety. This distinguishes true incapacity from motivational or emotional deficits.
- **Ecological and Social Context:** Following the social intelligence hypothesis, many cognitive processes evolved to navigate group relationships. Research on Japanese macaques shows that simulating natural interactions reveals decision-making strategies that remain hidden in sterile, isolated cages.<sup>46</sup>
- **Species-Specific “Natural Genius”:** Design tasks referencing evolutionary challenges rather than abstract human constructs. Bumblebee bodily self-awareness, for example, emerged only through gap-squeezing tests, a behaviour directly embedded in their foraging strategy.<sup>47</sup>
- **Rejecting *Scala Naturae* Valuation (*scala naturae*):** Abandon “higher” versus “lower” categorizations. Operations humans view as complex (e.g., counting) may represent simple computational procedures optimized for another animal’s specific niche.<sup>48</sup>

Only experiments “tailor-made” to a species’ sensory world (*Umwelt*) and ecology reliably map cognitive potential. Replacing forced “human” behaviours in sterile cages with tests that highlight an animal’s “natural genius” provides the only path

<sup>45</sup> Howard and Barron, “Understanding the Limits,” R295.

<sup>46</sup> Rúni Sigmundson et al., “Exploring the Cognitive Capacities of Japanese Macaques in a Cooperation Game,” *Animals* 11, no. 6 (2021): 1497, cited in Lucia Regolin and Maria Loconsole, “Behavioural Methods to Study Cognitive Capacities of Animals,” *Animals* 13, no. 22 (2023): 3445, <https://doi.org/10.3390/ani13223445>.

<sup>47</sup> Sridhar Ravi et al., “Bumblebees Perceive Their Own Body Size,” *Proceedings of the National Academy of Sciences* 117, no. 49 (2020): 31294, cited in Joanna Brebner and Lars Chittka, “Animal Cognition: The Self-Image of a Bumblebee,” *Current Biology* 31, no. 4 (2021): R207, <https://doi.org/10.1016/j.cub.2020.12.027>.

<sup>48</sup> Howard and Barron, “Understanding the Limits,” R295.

to credible understanding. This shifts negative results from testaments of failure to valuable evidence of genuine cognitive limits.

## Conclusions: Toward Understanding Subjective Worlds

This review synthesizes historically fragmented frameworks spanning Sloman's space of possible minds, 4E cognition, signature analysis, and empirical breakthroughs in invertebrates into an integrative model for evaluating animal cognitive limits. The value of this approach lies in bridging evolutionary biology, ethology, cognitive science, and psychology, encouraging researchers to move beyond anthropocentric assumptions. However, adopting a species-adequate methodology faces a fundamental epistemological limit: human researchers can never fully experience an animal's *Umwelt*. We can model the physics of polarized light or echolocation, but we cannot subjectively experience the sensory world of another species, which introduces significant challenges regarding cross-species standardization, higher resource demands, and complex experimental controls. To navigate these boundaries, future research must prioritize interdisciplinary collaboration by combining ethologists, cognitive psychologists, neuroscientists, and engineers to design hardware tailored to non-human sensory modalities. Furthermore, researchers should reject anthropocentric benchmarks in favour of ecologically embedded tasks that test cognition through the species' natural motor repertoire, while mandating positive and motivational controls to systematically rule out stress or perceptual mismatches before attributing negative results to true cognitive ceilings. In this paradigm, we cease to ask whether animals are "intelligent" by our standards; instead, we begin to understand how effectively and uniquely they operate within their own cognitive capacities.<sup>49</sup> Such an approach opens new dimensions of the animal world, which our anthropocentric lens often obscures.<sup>50</sup> Thus, rather than asking if they are "as smart as we are," let us ask: "in what way do they understand their own world?"<sup>51</sup>

<sup>49</sup> Howard and Barron, "Understanding the Limits," R295.

<sup>50</sup> Xie, "Are Humans (Higher) Animals?," 105090; Crisante et al., "All Is Not Equal," 106434.

<sup>51</sup> Regolin and Loconsole, "Behavioural Methods," 3445; see also Howard and Barron, "Understanding the Limits," R294.

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