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SHORT COMMUNICATION

Bridging pure cognitive research and cognitive enrichment

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Abstract
Cognitive enrichment is a growing subset of environmental enrichment for captive animals. However, it has been difficult for practitioners to design, implement, and evaluate relevant and appropriate cognitive challenges. Even though pure comparative cognition researchers focus on fundamental evolutionary questions, their knowledge and expertise can also shape the future of cognitive enrichment. This paper describes the motive, means, and opportunity to do so. Taxon-specific summaries of animal cognition (including inter-individual variation in skill and effects of motivation), and experimental designs (including the task itself, training, and reward) need to be accessible to practitioners in applied settings, such as farms, zoos, and sanctuaries. Furthermore, I invite pure researchers to directly evaluate their cognitive research program as enrichment and thus bridge the disciplines of animal cognition and welfare.

Keywords Affective state · Animal welfare · Cognitive task · Emotion · Research impact

Introduction

The comparative study of animal cognition increases our fundamental understanding of evolution (Shettleworth 2010; Zentall and Wasserman 2012; Wynne and Udell 2021). Yet it is increasingly recognized pure research can also have applied, real-world impacts for society or animals (Penfield et al. 2014; Russell and Sluckin 2016). Knowledge of animal cognition can be applied to their care in captivity, but while relationships between animal affective state and the cognitive processes of perception, attention, memory, learning, and problem-solving have been addressed (Duncan and Petherick 1991; Mendl et al. 2009; Paul et al. 2005; Crump et al. 2018), leveraging these connections in practice is still lacking (Clark 2017). Cognitive enrichment (CE) is a relatively small but growing subset of environmental enrichment which can be split into two types according to the desired outcome (Clark 2017): CE_{skill} and $CE_{welfare}$. In both CE types, an animal's cognitive skills are challenged by a new activity or environment (Clark 2011). CE_{skill} is primarily studied in laboratory settings and aims to slow the rate of cognitive decline and/or enhance future cognitive skills (Milgram et al. 2005, 2006; Frick and Benoit 2010). For example, Milgram et al. (2006) found that aged, laboratory-housed beagle dogs with prior experience of neuropsychological testing performed better on a new cognitive task (size discrimination and reversal) than dogs with no prior experience of neuropsychological testing. CE_{skill} has also been proposed as a way to develop the survival skills of threatened wildlife species before they are reintroduced to the wild (Riley 2018) but this application of CE currently lacks explicit evaluation. $CE_{welfare}$ is the most common type of CE used in applied settings and aims to enhance animal welfare; $CE_{welfare}$ may target immediate emotions (Zebunke et al. 2013; Gourkow and Philips 2016), longer term mood or affect (Manteuffel et al. 2009; Krebs and Watters 2017), or physiological indicators of stress (Oesterwind et al. 2016). For example, Puppe et al. (2007) found that domestic pigs undergoing sustained exposure to discrimination learning tasks had reduced abnormal behavior and fear responses compared to control pigs. Regardless of type, a solid understanding of animal cognition is needed to design, implement, and evaluate CE.

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The motive

CE has already benefitted from a cross-over of animal cognition and welfare disciplines (reviewed by Clark 2017). For example, Yamanashi et al. (2016) provided cognitively challenging feeders to zoo-housed chimpanzees (*Pan troglodytes*) that were inspired by studies of wild chimpanzee foraging cognition (e.g., Yamakoshi and Sugiyama 1995; Matsuzawa et al. 2011). Matrai et al. (2020) evaluated whether a task originally designed to test cooperative problem-solving in Indo-Pacific bottlenose dolphins (*Tursiops aduncus*; Kuczaj et al. 2015) was enriching for the genus, and this was followed by another enrichment evaluation of modified tasks with more complex shapes and cooperative partners (Matrai et al. 2022). In farms, operant conditioning has been used as a form of cognitive challenge for pigs and goats (e.g., Ernst et al. 2005; Kalbe and Puppe 2010; Zebunke et al. 2013). Therefore, pure cognition researchers may wonder what else they can contribute to this field. There are two salient problems with the current state of CE that will hopefully incentivize pure researchers to begin or increase their participation.

The first problem relates to how enrichment practitioners (i.e., those practically caring for animals in farm, zoo, sanctuary, and shelter settings) view animal cognition, and how the putative goals of CE are represented in the literature. While hybrid cognition and welfare research take place as illustrated above (also see Hopper 2017), it is imperative to acknowledge this is the exception and not the rule. The majority of animal housing facilities across the globe do not have staff with specialist cognitive knowledge. CE is the least common subset of enrichment used by zoos (de Azevedo et al. 2007; Brereton and Rose 2022) and other settings may show the same trend although reviews are lacking. A recent survey of zoo personnel revealed that "limited knowledge" is a salient barrier to CE development, and respondents were uncertain about how to define and operationalize both animal cognition and cognitive enrichment (Hall et al. 2021). Nawroth et al. (2019) highlighted similar problems in farms, with a lack of integration of cognition and welfare knowledge. In the most recently published review of zoo-based enrichment, Brereton and Rose (2022) found that CE design was unlikely to be informed by prior empirical research and/or biological information on the target species (note, the authors used the term "occupational" rather than "cognitive" enrichment, but their definition is broadly in line with CE). It is not clear from Brereton and Rose's (2022) analysis whether scientific evidence is deemed unimportant or is difficult to access by enrichment practitioners. It is clear from the existing literature and industry vernacular that CE is equated with providing 'games' or 'puzzles' to animals (de Azevedo et al. 2007; Young 2013; Brereton and Rose 2022). This is convenient shorthand but introduces the risk of anthropomorphism by assuming animals find human tasks challenging, or have the same affective experiences as task-using humans. Many studies referring to puzzles or more specifically CE have failed to demonstrate task design was based on known animal cognitive skills (e.g., puzzle boxes: Gilloux et al. 1992; Dantas-Divers et al. 2011; great ape touchscreen CE reviewed by Scheer et al. 2019).

The second problem refers to a criticism of CE I hear (and that possibly underlies a reluctance by some to use CE as a bona fide enrichment category) that "all enrichment is cognitive", meaning all responses to a new object or environment require animal cognition. My counter-argument is that CE challenges cognition beyond baseline levels and exercises skills that would not normally be used (Clark and Smith 2013). Therefore, to produce effective CE we must be prepared to test animal cognitive skill and confirm the challenge. CE_{skill} requires a further testing step, to confirm whether cognitive skill was *enhanced* compared to baseline levels. Testing animal cognition outside specialist research laboratories or centers is knowingly difficult because of restricted access to animals, a lack of experimental control, problems accommodating experimental trials and animal training alongside routine husbandry, and some negative human stakeholder perceptions of cognitive research (Garcia-Pelegrin et al. 2022). However, farms, zoos, and sanctuaries have literally hundreds of species that can be studied for taxonomic comparisons (Garcia-Pelegrin et al. 2022). In doing so, there is a chance to make a contribution to the ex-situ conservation of highly endangered species (Garcia-Pelegrin et al. 2022). In addition, as a final incentive, pure researchers are understandably driven to produce scientific articles to communicate their findings to peers. However, it is also important to engage with clearly defined stakeholder groups (such as zoo visitors) about specific findings (such as animal conservation and welfare implications) to have a rounded scientific impact (Weingart et al. 2021). Working in zoos allows science to be communicated to up to 700 million visitors per year (Gusset and Dick 2011).

The means

Pure researchers have the means to shape the future of CE because of their (1) animal cognition knowledge and (2) experimental expertise (Fig. 1). In the remainder of this paper, I will focus on pure researchers who undertake formal animal cognitive testing using task apparatuses, rather than researchers who undertake naturalistic animal observations (Shettleworth 2010; Bueno-Guerra and Amici 2018).

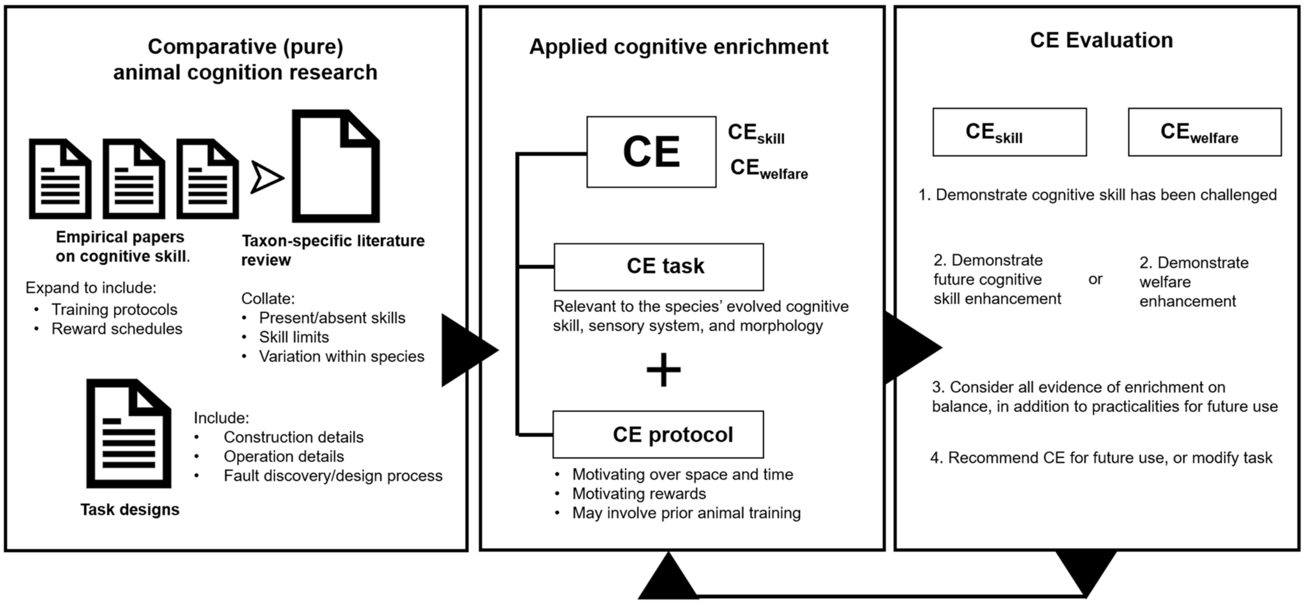

Fig. 1 Bridging comparative cognition and cognitive enrichment

Animal cognition knowledge

In most published cases, CE practitioners design novel CE tasks for animals (e.g., Millar 2013; Krebs and Watters 2017; Schmelz and Krause 2021) rather than taking designs from pure research and, therefore, need access to information on taxon-specific cognitive skills. From personal experience as an academic embedded in the zoological industry, it can be intimidating for practitioners to locate and extract relevant findings from empirical animal cognition literature. Practitioners would benefit from concise and comprehensive taxon-specific summaries of cognition, written by experts (Fig. 1). Like all enrichment, CE is currently overwhelmingly mammal-focused (Clark 2017; Hall et al. 2021; Brereton and Rose 2022) but this can change going forwards as pure research expands to explore the capacities of lesser-studied taxa (e.g., cephalopods: Schnell et al. 2021; testudines: Bridgeman and Tattersall 2019).

It may sound obvious to state CE should suit a species' cognitive skills, but it has proven difficult to provide the correct type and level of challenge ("task relevance": Meehan and Mench 2007). If animals are faced with an unsolvable challenge, either because they do not possess the necessary skill or the task does not accommodate their sensory and morphological adaptations, this can induce frustration or anxiety (Myers and Diener 1995). Conversely, a challenge that is too easy can induce boredom or apathy (Myers and Diener 1995). Therefore, in addition to information on the presence/absence of animal cognitive abilities, practitioners need to know the level of cognitive skill and variation between individuals they should expect to accommodate.

Pure researchers should also be transparent about their subjects' training and testing histories (Webster and Rutz 2020). Unfortunately, for well-studied taxa-like great apes and corvids, highly trained or enculturated research subjects are representative of the species at large and this limits the generalizability of results (Call and Tomasello 1996; Bering 2004).

Experimental expertise

As discussed previously, a ready-made pure cognitive task apparatus can be used as a form of CE (e.g., dolphins; Matrai et al. 2020, 2022). This approach is appealing, because the laborious task design was already taken care of in the course of pure research. However, most cognitive task apparatuses are not designed for immediate and spontaneous animal use and, therefore, cannot simply be transplanted from pure to applied settings. Behind the scenes, many pure researchers spend weeks or months training animals for cognitive testing, yet this intensive process is rarely acknowledged. Tasks with touchscreens or other computer interfaces (buttons, joysticks, etc.) are increasingly popular for CE because of the detail, speed, and reactivity they provide (Egelkamp and Ross 2019; Schmitt 2019), but they rely on prior training, making them a major roadblock for zoos (Garcia-Pelegrin et al. 2022). This means more training-free CE tasks need development (e.g., Clark et al. 2013, 2019), and pure researchers need to be very transparent about the training requirements of their cognitive tasks. It is also important to remember that animal motivational state can strongly influence cognitive task performance (Kangas et al. 2016;

van Horik and Madden 2016; Rössler et al. 2020), so CE will rely on matching an animal's current motivations (task appropriateness: Meehan and Mench 2007). Therefore, pure researchers should share information on how exactly their animals were pre-trained to use a task, how task rewards were selected, and how the schedule of testing or reward was determined. There is a concern about publishing negative or supplementary results in the field of animal cognition (Scheel et al. 2021; Farrar et al. 2021, 2022), but they can have high applied value.

Pure researchers are experts in designing cognitive tasks from scratch, or modifying pre-existing designs to suit the sensory and morphological adaptations of new species (e.g., Shaw and Schmelz 2017; Many Primates 2019; Schubiger et al. 2020). A good example is a cognitive test adapted for sun bears *Helarctos malayanus* to use with their tongues in place of a fingertip; Perdue 2016). Clear technical drawings, reproducible building instructions, and accounts of how different construction materials perform during animal use and wear-and-tear (e.g., Arce and Stevens 2022) would help charity zoos and sanctuaries recreate tasks in a cost-effective manner. Such information could be published in journals' open access supplementary material, industry-specific newsletters, blogs, or conference proceedings.

The opportunity

Finally, is an opportunity for pure researchers to evaluate whether their own cognitive research program is enriching (Fig. 1). The approach will depend on whether they are evaluating CE_{skills} or $CE_{welfare}$.

Assessing cognitive challenge

Pure researchers already have the experimental setup to observe if/how animals solve a task and by deduction whether they possess a particular cognitive skill; the task can be sequentially modified to explore the 'tipping point' between pass and failure and, therefore, limits of skill (Shettleworth 2010; Bueno-Guerra and Amici 2018). An animal who spectates rather than uses a task is more a complicated case; they could theoretically be challenged, but this has proven difficult to quantify in applied settings (e.g., zoo-housed bottlenose dolphins *Tursiops truncatus* spectating a cognitive enrichment task; Alexander et al. 2021). Pure research settings typically have much higher experimental control than applied settings, so pure researchers may have better opportunities to determine whether task spectating could be enriching (for example by recording gaze in social learning research, see Lonsdorf and Bonnie 2010 for methodological approaches).

Assessing cognitive skill enhancement

To fit the criterion of CE_{skill}, task-use should enhance an animal's cognitive skill (or at least maintain it relative to baseline). The effect of task-use on future performance on the same task, as well as new tasks, has been well-studied in laboratory animals (Milgram et al. 2006) and humans (Owen et al. 2010). It should hopefully be fairly straightforward for pure cognition researchers to evaluate skill enhancement in animal subjects with longitudinal study designs, and keeping good records of previous testing histories. It would also be interesting to examine whether 'high performer' individuals, i.e., those known to perform with more readiness and competence in cognitive tests, have higher welfare.

Assessing welfare enhancement

Welfare assessment should be well integrated into cognitive testing programs, rather than being an afterthought. Several studies have assessed the effect of cognitive testing on zoo primate welfare (e.g., Herrelko et al. 2012; Whitehouse et al. 2013; Jacobson et al. 2019) and an integrated approach allows data collection before, during, between, and after periods of cognitive testing in many other taxa. Other aspects of cognitive research should be measured as potentially contributing to the enrichment effect, such as the change to dietary rewards, human contact, and perhaps physical location (see Gazes et al. 2013; Gaillard et al. 2014; Cronin et al. 2017). Note that assessing the welfare impact of cognitive testing does not replace institutional animal welfare assessments; these have a standalone role by considering the animals' entire captive milieu beyond research participation (e.g., Wolfensohn et al. 2018; Sherwen et al. 2018; Ryan et al. 2021).

The duration, frequency, type, and outcome of CE task-use can all correlate with welfare indicators. One cognitive testing trial may last only a few seconds (Bueno-Guerra and Amici 2018) but it is still possible to assess welfare within one testing session. In great apes undergoing cognitive testing, behaviors directed 'off-task' (i.e., towards themselves, conspecifics, or the wider environment) such as rough-scratching and aggression have been positively correlated with task difficulty and failure (Elder and Menzel 2001; Leavens et al. 2001; Yamanashi and Matsuzawa 2010) and, therefore, appear to be predictive of short-term emotional response to challenge. The existence of the 'Eureka moment' in cattle and domestic dogs highlights the welfare value of spontaneous problem-solving (Hagen and Broom 2004; McGowan et al. 2014) but is yet to be studied in other taxa (e.g., recently no evidence was found in bottlenose dolphins; Alexander et al. 2021). Pure researchers who study animal problem-solving and innovation, particularly in primates and birds (Griffin and

Guez 2014) have a unique opportunity to formally capture and quantify animals' emotional responses at the point of innovation.

Pure researchers may, dependent on their experimental design, be able to use the duration of voluntary task-use as an indicator of its value to the animal. This assumes the animal can voluntarily choose the task versus other resources and is not severely deprived of the reward for doing so (Dawkins 1990; Fraser and Nicol 2018). As a point of caution, it can be difficult to determine if an animal perceives an experience (such as working on a difficult task) as positive just because they invest time in doing so (Dawkins 1990; Fraser and Nicol 2018), whereas positive anticipation of an upcoming task may be a good indication of positive experience (Boissy et al. 2007; Clegg et al. 2018). Animal welfare indicators are species-specific and require knowledge from the animal welfare literature; animal welfare researchers should reflect on how accessible their knowledge and experimental designs are to cognitive scientists. For $CE_{welfare}$, the concept of affective balance is powerful, because it considers the overall ratio of positive and negative experiences and, therefore, an animals' overall welfare state (Webb et al. 2019). According to affective balance, a task that initially caused aversion or periodic frustration could ultimately be enriching if solvable and controllable (Meehan and Mench 2007).

Bridging pure researchers and practitioners

It is important to re-emphasize the success of future CE will rely on bridging pure researchers and practitioners. I have focused on calling pure researchers to arms (for more practitioner-focused considerations see Garcia-Pelegrin et al. 2022), but want to spend the remainder of this paper considering how to foster a positive, two-way relationship for active collaborations.

i. If a pure researcher plans to work with an external animal facility (e.g., a zoo), a memorandum of understanding/agreement should lay out the expectations of both parties. This may include commitments to building additional research infrastructure, realistic availability of practitioner and researcher time, expected welfare implications, data ownership/protection, and ethical review procedures.
ii. Job shadowing may highlight fundamental differences between research in pure and applied settings. 'How we do things' is not always clear to an outsider from another discipline or setting.
iii. Regular and transparent feedback is vital to ensure a successful research endeavor and relationship.

Conclusions

1. When we take a snapshot of the current state of CE, many practitioners lack knowledge of animal cognition, 'puzzle/game' tasks lack design justification in the literature, and there are prevailing difficulties with testing animal cognition in most captive settings which makes it difficult to validate new forms of CE.
2. Pure researchers can contribute to CE by more directly targeting their research findings at practitioners, collaborating with practitioners on CE projects, and evaluating their own cognitive research as a form of CE.
3. In future, positive collaboration between pure researchers and practitioners relies on memorandums of agreement/understanding, job shadowing, and regular feedback.

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Consent for publication The author affirms that the research described here has not been submitted or published in another venue.

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