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Evidence of Problem-Solving in Lizards Using a Citizen Science Approach

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Abstract

Problem-solving has been widely documented in mammals and birds, but comparatively few studies have investigated it in reptiles. Positive findings have been reported in some species, but the abilities of many others remain unexplored. Citizen science approaches may be particularly useful for the study of reptile problem-solving (and cognition more broadly) as they could allow access to a range of previously untested species without straining resources. Here, we investigated the problem-solving capabilities of 18 pet lizards of five previously untested species via video calls with their owners in their home environment. Six of the lizards (3 bearded dragons, 2 starred agamas and 1 leopard gecko) progressed from training to a problem-solving test wherein they needed to remove a lid from a dish to obtain a food reward. One starred agama and one bearded dragon successfully removed the lid at test, although it was unclear whether the bearded dragon did so to obtain the food reward. The other subjects were unsuccessful: they either did not pass the training or did not make any attempts to solve the test. The clear success of the starred agama calls for further research into this species' cognitive capabilities. The advantages and limitations of using this novel approach to testing are discussed with the aim of guiding future citizen science-based studies with reptiles.

Keywords: cognition, reptiles, pet lizards, citizen science, starred agama, bearded dragon

Introduction

Traditionally, the field of comparative cognition has placed particular emphasis on studying the mental capabilities of mammals and birds (Healy, 2019). However, non-avian reptiles (henceforth reptiles) have been found to possess surprisingly

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complex cognitive abilities (Szabo et al., 2019). In the first review of reptilian behaviour and cognition, Burghardt (1977) described processes such as habituation, visual discrimination, and maze and detour learning in over 70 species. In recent years, the use of reptiles as models in cognitive research has rapidly increased due to the interesting questions raised by their phylogenetic position, and physiological and ecological diversity (Szabo et al., 2019). Mounting evidence suggests that reptiles possess a wide range of cognitive capabilities that are similar to those of mammals and birds (e.g., long-term memory, flexible learning, and quality and quantity discrimination; see Szabo et al., 2019, for a comprehensive review).

In reptiles, problem-solving has received comparatively less attention than other cognitive capabilities (e.g., social learning; Szabo et al., 2019). However, recent work has demonstrated that several reptile species (mainly lizards from the *Varanidae* and *Scincidae* families) are capable of problem-solving. Four species from the *Varanidae* family and three species from the *Scincidae* family have been shown to possess such capabilities: black-throated monitors (*Varanus albigularis albigularis*; Manrod et al., 2008); emerald tree monitors (*Varanus prasinus*; Cooper et al., 2019); Mertens' water monitors (*Varanus mertensi*; Cooper et al., 2019); lace monitors (*Varanus varius*; Rowell & Rymer, 2023); Australian tree skinks (*Egernia striolata*; Riley et al., 2018); Australian eastern water skinks (*Eulamprus quoyii;* Qi et al., 2018); and hatchling three-lined skinks (*Bassiana duperreyi*; Clark et al., 2014). Although studies focussing on species outside of these two families are scarce, positive findings have been reported in Guatemalan beaded lizards (*Heloderma charlesbogerti*; Cooper et al., 2019), Italian wall lizards (*Podarcis siculus*; Damas-Moreira et al., 2018), and anoles (*Anolis evermanni*; Leal & Powell, 2012; *Anolis sagrei*; Storks & Leal, 2020).

Whilst the study of problem-solving in lizards is clearly promising, evidence remains limited to only a few families. As such, the capabilities of many species – including those commonly kept as pets – remain unexplored. Thus, we aimed to investigate problem-solving in a range of previously untested species. Whilst previous work has largely focussed on wild or captive zoo populations, we instead adopted a citizen science approach in which pet lizards were tested remotely in collaboration with their owners.

In recent years, citizen science approaches to animal behaviour and cognition research have increased in popularity (Griffin et al., 2024). Perhaps the most notable example is the website *Dognition.com* (Stewart et al., 2015), which enables dog owners to test their dogs' cognitive capabilities in their own homes, with data being collected via questionnaires and owner-submitted video recordings of behavioural tests. More recent examples include: the assessment of looking behaviours in dogs using the video-calling platform Zoom (Pelgrim et al., 2024); the use of the mobile phone application 'Wingtags' to build cockatoo social networks based on observations made by the general public (Aplin et al., 2021); and the use of video recordings to explore pet cats' susceptibility to visual illusions (Smith et al., 2021).

Citizen science-based approaches have even been used to identify and confirm new behaviours. For instance, Bokermann and Natálio (2024) analysed text and image data from the platforms 'Birds of the World' and 'WikiAves' to confirm that there was no prior record of palm tanagers (*Thraupis palmarum*) manipulating and eating snails.

In reptiles, citizen science approaches have, thus far, primarily focussed on ecology (e.g., via iNaturalist observation data; Haney et al., 2022). This is surprising, as citizen science-based approaches are particularly well-suited to research on reptile cognition for the following reasons:

i) Testing animals that are housed remotely reduces strain on resources: reptiles are typically housed alone in specialised enclosures that are expensive to set up and maintain, and take up significant laboratory space.
ii) Testing pets eliminates the need to capture wild animals (but at the cost of not being able to test genetically wild populations).
iii) Testing pets can increase our sample sizes, as zoos typically only keep a few individuals from any given species, and wild individuals are often difficult to locate.
iv) With this approach, we can access both conventional pet species (e.g., bearded dragons, *Pogona vitticeps*) and rarer ones (e.g., starred agamas, *Laudakia stellio*) by tapping into the large and international hobbyist reptile-keeping community.
v) This approach can provide insight into potential cognitive similarities and differences between genetically 'wild' individuals (either from previous studies, or from studying wild-caught pet lizards) and those that have been bred in captivity for the pet trade.
vi) This approach has the added benefit of increasing reptile owners' engagement with science through directly interacting with researchers and actively participating in ongoing research.

Given these benefits, we utilised a citizen science approach to test the problem-solving capabilities of a range of previously untested lizard species. Pet owners were recruited using online advertisements posted on social media platforms and forums. As this was an opportunity sample, we did not decide on any focal species prior to recruitment. Instead, we aimed to recruit as many different species as possible given the limited time frame of the study. Given its success and simplicity, we adopted a similar test to that of Leal and Powell (2012), wherein the subjects needed to dislodge an opaque disc from an opaque feeding well to obtain a food reward inside. We adapted this design slightly to suit a citizen science approach, for example, by using a single dish and lid that could easily be sourced online and sent to the owners' homes. Our study consisted of three phases: two training phases and the problem-solving test. To pass training phase 1, subjects had to obtain a food reward from an open feeding dish. To pass training phase 2, they had to obtain a food reward from a dish that was partially (75%) covered by an opaque lid. To pass the problem-solving test, they had to obtain a food reward from a dish that was fully covered by an opaque lid. All trials were conducted in the animals' home enclosures, and owners were guided through the procedure by the researcher via a live video call. All trials were video recorded. To our knowledge, none of the species we tested have, to date, been tested using this type of paradigm.

Method

Owners and Subjects

Owners were recruited via an advertisement posted on Twitter, several Facebook reptile groups, and Reptile Forums UK (see the Supplementary Material for the advertisement and an exhaustive list of platforms). When they emailed the researcher (the first author, who will henceforth be referred to as "E") to express interest in participating, E replied with written information about the study and arranged an initial video call (using the video-calling platform Skype) to discuss the project. If owners agreed to participate, they were sent a consent form to complete and return by email.

Eighteen subjects (from 6 different pet owners) took part in this study. They ranged from approximately 1.5-8.5 years old and varied in their sex and rearing background (Table 1). Six subjects completed the entire procedure (training phases 1 and 2, and the problem-solving test): 3 bearded dragons (*Pogona vitticeps*), 2 starred agamas (*Stellagama stellio vulgaris*) and 1 leopard gecko (*Eublepharis macularius*). The remaining subjects (7 bearded dragons, 1 starred agama, *Stellagama stellio daani*, 1 leopard gecko, 2 Yemen chameleons, *Chamaeleo calyptratus*, and 1 blue-tongued skink, *Tiliqua gigas evanescens*) began testing, but failed to reach the problem-solving test as they did not pass both of the training phases. The research was approved in advance by the university ethics committee.

Table 1

Individual Characteristics of Each Animal

ID	Species	Sex	Age (years)	Origin	Reward Species
BD1	**Bearded dragon**	**Male**	**2.5**	**Captive**	***Blaptica dubia***
BD2	Bearded dragon	Male	3	Captive	*Pachnoda marginata* (larvae)
BD3	Bearded dragon	Male	1.5	Captive	*Zophobas morio* (larvae)
BD4	Bearded dragon	Male	5	Captive	*Hermetia illucens* (larvae)
BD5	Bearded dragon	Female	3	Captive	*Zophobas morio* (larvae)
BD6	Bearded dragon	Female	5	Captive	*Zophobas morio* (larvae)
BD7	Bearded dragon	Male	6	Captive	*Zophobas morio* (larvae)
BD8	Bearded dragon	Female	5	Captive	*Zophobas morio* (larvae)

ID	Species	Sex	Age (years)	Origin	Reward Species
BD9	**Bearded dragon**	**Male**	**7**	**Captive**	***Zophobas morio* (larvae)**
BD10	**Bearded dragon**	**Male**	**8.5**	**Captive**	***Zophobas morio* (larvae)**
SA1	**Starred agama**	**Male**	**1.5+**	**Wild**	***Zophobas morio* (larvae)**
SA2	**Starred agama**	**Male**	**1.5+**	**Wild**	***Zophobas morio* (larvae)**
SA3	Starred agama	Female	1.5+	Wild	*Zophobas morio* (larvae)
YC1	Yemen chameleon	Male	4	Captive	*Tenebrio molitor* (larvae)
YC2	Yemen chameleon	Male	1.5	Captive	*Tenebrio molitor* (larvae)
SK1	Blue-tongued skink	Male	2.5	Captive	*Zophobas morio* (larvae)
LG1	Leopard gecko	Male	Unknown	Captive	*Blaptica dubia*
LG2			**1.5**	**Captive**	***Schistocerca gregaria***

Note. ID codes refer to bearded dragons (BD), starred agamas (SA), Yemen chameleons (YC), blue-tongued skinks (SK), and leopard geckos (LG). Individuals who progressed to the problem-solving test are highlighted in bold.

Materials

Opaque, reptile-safe plastic feeding dishes of two different sizes (small = 66mm diameter, 25mm high; medium = 90mm diameter, 33mm high) were used to create feeding wells. Circular medium-density fibreboard (MDF) discs were used as lids (small = 75mm diameter, 3mm thick, weight = 10g; medium = 100mm diameter, 3mm thick, weight = 17g). The dishes and lids were size-matched to each species: the starred agamas, leopard geckos, and Yemen chameleons were tested using the small dishes and lids; the bearded dragons and blue-tongued skink were tested using the medium dishes and lids. All materials were ordered via Amazon.co.uk and were sent directly to the owners' homes.

Prior to testing, owners were asked to decide upon an appropriate live food reward for each of their animals. To reduce variation in motivation, the species of reward used for each individual (Table 1) was kept constant throughout the experiment.

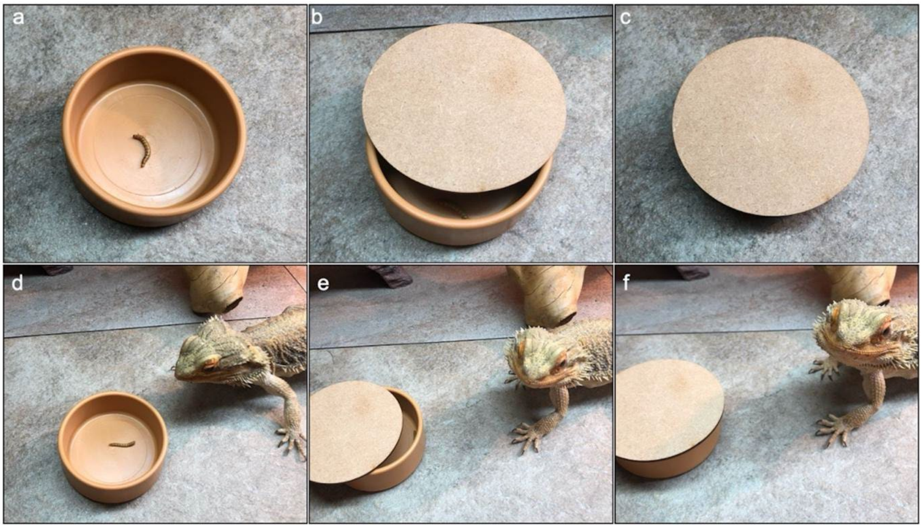
All animals were tested in their home enclosures. Hides and other safe areas were left in-situ to ensure that the animals could move away from the apparatus at any time. All animals were deemed to have been kept in safe, species-appropriate conditions by E, an experienced reptile owner.

Procedure

The general procedure was the same across all three phases (training phase 1, training phase 2, and the problem-solving test). First, E video-called owners at an appointed time and asked them to position their device (mobile phone, tablet, or computer with a camera and internet connection) so that the animal and apparatus would be in view throughout the procedure. Whilst most owners were able to mount their device on a stand for stable recording, this was not always possible. Thus, one owner stood in front of their animals' enclosures and held their device instead. For multiple subjects, light reflecting on the glass enclosure doors impeded E's view of the animals. In these instances, the owners were either asked to place the device inside the enclosure (as far from the animal as possible) or to leave the doors open during the trials (which was then kept consistent across all trials). For each owner, video calls were pre-arranged to keep testing times as consistent across trials as possible. The video call screen recording functionality was used to record each trial. For video-coding purposes, E began recording 30 seconds before the apparatus was introduced. This allowed the animal's behaviour both immediately before and after the apparatus was introduced to be assessed for signs of stress. Thirty seconds of acclimation was considered sufficient as the subjects were pets, and thus were used to their owners approaching their enclosures. After 30 seconds, the apparatus was introduced (with the food reward having already been put inside) and placed at a distance of approximately one body length (the length of the animal excluding its tail) in front of the animal so that the animal was facing it. The dishes and lids were set up for each phase as shown in Figure 1.

Figure 1

The Positioning of the Apparatus for Each Phase of the Study



Note. The configuration of the apparatus in each phase of the study: Panels a and d correspond to training phase 1, b and e to training phase 2, and c and f to the problem-solving test. The medium dish and lid are pictured next to a bearded dragon.

The animal was given 30 minutes to attempt to complete each phase of the task. If the animal completed the task, the trial ended, and the apparatus was removed from the enclosure. If the animal did not succeed, the trial ended after 30 minutes, and the apparatus was removed. If an animal retreated to its hide and did not emerge again within 10 minutes, the trial was terminated, and no further trials were conducted with that animal on that day. To advance through each of the training stages and pass the problem-solving test, the animals were required to pass 2 out of 3 consecutive trials in each phase. Due to time constraints for the study, and to avoid placing too much of a burden on owners, an upper limit of 20 trials across all phases (a maximum of 5 for each training phase, and 10 for the problem-solving test) was set in advance for each animal. Animals that did not pass a particular stage within the set number of trials were considered to have failed and did not progress to the next stage. Whenever possible, each animal undertook one trial per day on consecutive days. However, for most owners there were several occasions on which they could not participate on consecutive days due to personal commitments.

Three of the animals – BD1, BD2, and LG1 – were E's own pets. As such, E set up the apparatus at home, and recorded the animals directly using a mobile phone. All other aspects of the procedure were the same.

Training

In line with the method used by Qi et al. (2018), subjects were given the opportunity to habituate to and eat from the apparatus prior to attempting the problem-solving test. This training occurred in two sequential stages:

Training Phase 1

Individuals were presented with the feeding dish open (without the lid) with a food reward placed in the centre (see Figure 1a & d). To pass this phase, the animal was required to obtain and consume the reward within the allocated time (30 minutes) in 2 out of 3 consecutive trials.

Training Phase 2

The lid was placed on top of the feeding dish, covering 75% of the opening (Figure 1b & e). Owners were instructed to position the apparatus so that the open 25% was nearest to the animal, and to place the reward in the open portion of the dish. To pass this phase, the animal was required to obtain and consume the reward within 30 minutes in 2 out of 3 consecutive trials.

Problem-Solving Test

The problem-solving test was conducted in a similar manner to both of the training phases. However, the lid was now placed on top of the dish so that it completely covered the food reward inside (Figure 1c & f). To pass, the animals were required to obtain and consume the food reward by removing the lid from the dish (either by pushing it off with their snout and/or claws or by biting it and pulling it off) within the allocated time in 2 out of 3 consecutive trials.

Debrief With Owners

At the end of the study, E debriefed the owners and thanked them for their participation. They were later sent a £10 Amazon gift voucher as recompense for their participation.

Coding

All trials were live-coded, with the animal's performance in each trial recorded as either "pass" (obtained and consumed the food reward) or "fail" (did not obtain the food reward). The latency (in seconds) to pass each phase was also recorded for all trials. To assess inter-rater reliability for the coding of pass/fail responses in the problem-solving test, 50% of the trials undertaken by each animal were randomly selected and coded by an independent observer. Perfect inter-rater agreement was achieved: $\kappa = 1.00$. All analyses were carried out using SPSS (IBM SPSS Statistics, version 26, MacOS).

Results

Due to the small sample sizes obtained, statistical tests were not possible. Therefore, results are reported descriptively for each phase.

Training Phase 1

Eighteen animals participated in this phase. Of these, 12 reached criterion (7 bearded dragons, 2 starred agamas, 2 leopard geckos, and 1 Yemen chameleon; Table 2).

Training Phase 2

Ten animals participated in training phase 2 (6 bearded dragons, 2 starred agamas, and 2 leopard geckos). Two of the subjects that had been successful in training phase 1 (YC2 and BD8) did not complete training phase 2: YC2 was dropped partway through due to an injury (not sustained due to the study), and BD8 was unable to participate due to time constraints. Of the 10 who completed training phase 2, 6 reached criterion (3 bearded dragons, 2 starred agamas, and 1 leopard gecko; Table 2).

Problem-Solving Test

Six animals participated in the problem-solving test (3 bearded dragons, 2 starred agamas, and 1 leopard gecko). Only 1 bearded dragon (BD9) and 1 starred agama (SA2) were successful. The other subjects failed to approach the apparatus, thus failing the test. Neither the successful bearded dragon nor the successful starred agama failed any trials in the problem-solving test: they were each successful in three consecutive trials, thus reaching criterion in the lowest number of trials possible (Table 2).

Table 2

Number of Trials Taken to Reach Criterion in Each Stage for Each Subject

Species/ID	Training Phase 1	Training Phase 2	Test	Total Trials
BD1	3	3	n.a. (4)	10
BD2	3	n.a. (4)	-	7
BD3	3	n.a. (4)	-	7
BD4	n.a. (4)	-	-	4
BD5	3	n.a. (4)	-	7
BD6	n.a. (5)	-	-	5
BD7	n.a. (4)	-	-	4
BD8	n.a. (5)	-	-	5
BD9	3	4	3	10
BD10	3	3	n.a. (4)	10
SA1	3	3	n.a. (4)	10
SA2	3	3	3	9
SA3	n.a. (5)	-	-	5
YC1	n.a. (4)	-	-	4
YC2	3	n.a. (1)	-	4
SK1	n.a. (4)	-	-	4
LG1	3	n.a. (4)	-	7
LG2	3	3	n.a. (4)	10

Note. ID codes refer to the bearded dragons (BD), starred agamas (SA), Yemen chameleons (YC), blue-tongued skink (SK), and leopard geckos (LG). Failure to pass a phase is denoted by 'n.a.', and the number of trials undertaken in these failed phases is given in brackets. 'Total trials' refers to the total number of trials each individual animal undertook across all phases they participated in.

For both animals, the latency to remove the lid decreased with each successive presentation of the apparatus (see Table 3). In each of the test trials, the starred agama solved the test faster, descriptively, than the bearded dragon. Overall, the starred agama (mean latency = 201s) solved the test three times faster than the bearded dragon (mean latency = 607s). Both used the same method to remove the lid: they bit the lid and pulled it off with their mouth.

Table 3

Latency (in Seconds) to Complete Each Problem-Solving Trial for Each Successful Subject

Species/ID	Trial 1	Trial 2	Trial 3	Mean
BD9	978	506	337	607
SA2	504	89	9	201

Note. BD9 and SA2 refer to the bearded dragon and starred agama, respectively, that successfully solved the problem-solving test.

Methodological Issues

However, perhaps unsurprisingly given the citizen science approach, there were some minor methodological issues with some trials. During the starred agama's first problem-solving test trial, SA2 accidentally opened the lid very slightly with his back claw whilst facing away from the apparatus. The opening was only approximately 5mm large, and it was unclear from E's perspective whether the lizard could see the food inside. When SA2 turned around, he looked at the apparatus for a few seconds and poked it with his snout several times, then touched the edge of the lid with his claw before moving away. He returned to the apparatus several minutes later, examining it for several more minutes before pulling off the lid to obtain the food in one attempt. In SA2's second trial, there were no methodological problems: he examined the apparatus briefly before pulling the lid off and obtaining the food in a single attempt. However, in his final trial, SA2 lunged towards the apparatus as the owner was placing it into the enclosure, removing the lid and obtaining the food before the apparatus was placed in the cage.

Another issue was that it was unclear whether the other successful subject, the bearded dragon, BD9, removed the lid with the aim of obtaining the food. Instead, it seemed that BD9 was more interested in the lid itself: in the final trial of training phase 2, BD9 removed the lid with his mouth but did not eat the food. The owner repositioned the lid twice, and BD9 pulled it off with his mouth again both times, but only ate the food once the owner had removed the lid from the enclosure. To avoid giving BD9 any additional experience with the lid, he was moved to the test phase for subsequent trials. Again, in each test trial, BD9 pulled off the lid but did not immediately consume the food, only doing so when the lid was eventually removed. Instead, BD9 remained fixated on the lid, often holding it in his mouth and thrashing it around by shaking his head.

Discussion

These results provide evidence of problem-solving ability in a previously untested species: a starred agama. SA2 solved the test quickly, with his performance improving over subsequent trials. A bearded dragon – BD9 – also showed some relevant exploratory behaviour. None of the other animals tested were able to solve the problem-solving task. However, their lack of success does not necessarily indicate a lack of problem-solving ability, or cognitive ability more generally. Several methodological factors (discussed below), such as the limited number of trials, motivational differences, and environmental distractions may have affected their performance.

Problem-Solving Mechanisms

The success of SA2 is impressive given the difficulty of our test, and the cognitive abilities required to solve it. For instance, subjects needed to rapidly acquire the relation between the apparatus (an arbitrary cue) and the food reward inside – which SA2 demonstrated after just seven interactions with the apparatus. Moreover, success also relied on the subjects understanding object permanence (i.e., knowing that objects continue to exist even when they are no longer visible; Singer & Henderson, 2015), as the food reward was always hidden from view during the problem-solving test. Finally, subjects were required to retain this information in long-term memory over multiple days – an ability that SA2's improved performance over subsequent trials clearly demonstrates.

Whilst impressive, SA2's success was not necessarily unexpected: recent findings indicate that at least some other reptile species possess the cognitive abilities required to succeed in such tests. For instance, rapid and flexible learning has been observed in several lizard species (e.g., Font, 2019), and long-term memory retention of information for at least 18 months has been demonstrated by lizards (Cooper et al., 2020) and tortoises (Soldati et al., 2017). Whilst object permanence has not yet (to our knowledge) been explicitly tested in reptiles, evidence is widespread in other vertebrates (see Schaffer et al., 2024 for an overview), suggesting that it could be a widespread ability. Furthermore, the successful anoles in Leal and Powell's (2012) problem-solving task were also able to dislodge an opaque disc to obtain a hidden food reward. Whilst the authors did not explicitly discuss object permanence, the successful subjects needed to understand that the reward still existed inside the well even when it was no longer visible.

The full success of only one individual in this study limits our ability to draw conclusions about the cognitive capabilities of starred agamas (and reptiles more broadly), and this result would need to be confirmed by future research with a larger sample. However, the success of SA2 clearly calls for more behavioural and cognitive research both in this species, and in other reptiles.

Citizen Science Approach: Advantages and Limitations

To our knowledge, this study is the first to investigate reptile cognition using a citizen science approach. As such, we provide an in-depth discussion of the advantages and limitations of our approach, accompanied by actionable suggestions for future studies. We hope that this will stimulate future work on reptile cognition using such methods, as we believe they have the potential to positively contribute to the field.

Although many of the subjects did not ultimately progress to the problem-solving test, we were still able to recruit from a range of different species without incurring the high costs associated with housing multiple species in a lab. None of these species (to our knowledge) had previously been tested in problem-solving tasks, which highlights the potential such approaches have for recruiting scientifically interesting species via the hobbyist reptile-keeping community. Our approach was also fruitful from a science communication perspective. The pet owners involved in the study – and members of the public who had seen the advertisements – were excited about our work. Multiple people reached out to ask questions about studying reptiles (some asking on behalf of their children), and one individual even contacted us to enquire about a potential PhD project on reptile cognition. Whilst anecdotal, these experiences highlight the potential for citizen science to inspire the public to engage with science in ways that they would not have had the opportunity to do otherwise.

Whilst it is likely that citizen science approaches will be able to generate larger sample sizes than those reported in traditional experiments, our study did not demonstrate this due to time and resource constraints. Of the 18 subjects recruited, only six reached the test and only one demonstrated clear evidence of problem-solving. For practical reasons (i.e., the purchase and distribution of the test apparatuses), we limited our sample to UK-based owners. However, we received many responses to our recruitment advertisements from owners all over the world (particularly the US). Had we had the time and resources to expand the study, we would have had access to a much larger and more varied sample of lizards. As such, we recommend that future studies recruit internationally where possible.

The limited success observed in our study may have been due to the maximum number of training trials being capped at 10 for each subject (five in each training phase, with only a further 10 allocated for the test). This cap was again implemented for practical reasons: time constraints on the duration of the study, and also consideration of the burden placed on owners to participate in multiple sessions. Typically, the upper limits set in traditional experiments are much higher. For instance, Damas-Moreira et al. (2018) gave subjects 40 trials to reach criterion. In our study, many of the subjects failed to reach the test phase because they did not readily approach the apparatus. For example, of the ten bearded dragons tested, only three engaged with the apparatus often enough to pass both training phases. One of the starred agamas (SA3) was also very skittish, only approaching the open dish once before being dropped from the study, whereas the blue-tongued skink did not approach the apparatus at all. This neophobia might have been reduced by giving the subjects more training trials. Furthermore, the low number of training trials may have impeded the subjects' understanding of the problem-solving test itself. In order to pass the test, the subjects needed to understand that the dishes contained a food reward even when the reward was not visible. This would have been especially challenging given that the food was visible during the training phases. Whilst SA2 appears to have learned this quickly, the other subjects may have required additional trials to do so. Thus, we recommend that future studies increase the maximum number of trials given to subjects (increasing the number of training trials, in particular) to increase task understanding. This might require increasing the recompense provided to owners for their participation.

It is also possible that differences in motivation to engage with the apparatus arose between subjects due to differences in the species of prey used as rewards. Because we were only able to use food items that the owners already had to hand, we were unable to keep the rewards constant for all subjects. Overall, asking owners to select a single type of food reward that their pet enjoyed worked well, and most subjects were given morio worms (*Zophobas morio* larvae; Table 1). However, there were differences across the leopard geckos and bearded dragons that may have influenced performance. For example, one of the leopard geckos was rewarded with locusts (*Schistocerca gregaria*) whereas the other was rewarded with small dubia roaches (*Blaptica dubia*). The locusts were larger and more active than the dubia roaches, and subsequently may have been easier to locate both visually and auditorily. Additionally, the olfactory cues given off by the prey differed across prey species, which may have led to differing levels of motivation between subjects. Future studies should control for differing visual, olfactory, and auditory cues across prey species by using the same species across subjects and species whenever possible. This could be achieved by sending the chosen food rewards to the owners directly, and habituating the subjects to the food prior to testing.

Finally, some trials were conducted with the enclosure doors open and/or with the owner standing directly in front of the enclosure, and some were conducted with the recording device inside the enclosure. Although both SA2 and BD9 were successful despite being tested with their enclosure doors open and their owner standing in view, it is still possible that these factors may have distracted them, or the other subjects tested in this way. Thus, we recommend ensuring that the owners always mount their devices on tripods in front of closed enclosures. If the owners do not have access to tripods (or other objects that would function as tripods such as phone holders or tablet stands) then, if financially feasible, these should also be provided by the researchers.

In summary, using a novel citizen science approach, we successfully demonstrated problem-solving ability in a starred agama – a previously untested species. As such, we encourage future work to further investigate the problem-solving and general cognitive abilities of starred agamas and other untested reptile species. Whilst there were some limitations to our approach and findings, this study highlights that such methods have the potential to contribute positively to the field.

We hope that the insights and actionable recommendations generated by the study can be used to guide future citizen science approaches to the study of comparative cognition.

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