Systematic iterative design of interactive devices for animals

Guidance and reflections

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The numerous systems designed to facilitate animals' use of computers often are specific to the animals involved, their unique context, and the applications – enrichment among them. Hence, several development methods have arisen in parallel, largely transposed from the human-computer interaction (HCI) domain. In light of that prior work, the paper presents a step-by-step guide for iteratively designing and constructing interactive computers for animals, informed by the rich history of HCI yet applying animal-centred principles, to enrich animal-computer interaction. For each stage in the iterative design (requirements, ideation, prototyping, and testing), the author reflects on real-world experience of building interactive devices for various animals. The paper concludes with overarching considerations vital for future practice of developing interactive computers for animals. Thus, it serves as a valuable reference and information source for researchers designing novel computer systems for animals.

Keywords: iterative design, interactive devices for animals, animal-computer interaction

1. Introduction

Animals have been using digital electronic devices broadly characterised as computers for many decades (Mancini, 2011). The traditional aim behind the design has been insight into their cognition and behaviour, most recently for awareness of animals' mood, personality, food and resource-use preferences, and social skills (Hirskyj-Douglas & Kankaanpää, 2022). The systems thus cultivate understanding of the species that facilitates broader care efforts in *ex-situ* (conservation) and *in-situ* (native) environments (Webber, Carter, Smith, & Vetere, 2017).

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The emerging discipline of animal-computer interaction (ACI), focusing on how animals and computers work together (Mancini, 2011), examines how animals can use computer interfaces to perform tasks safely, effectively, and efficiently and what animals can achieve via computers (Hirskyj-Douglas, Pons, Read, & Jaen, 2018; Mancini, 2011). To this end, ACI researchers shift the focus from traditional methods wherein the animals must use generic computers to bespoke technology developed especially for animals' use. Such systems – designed for contexts that extend from meeting zoo residents' needs (French, Mancini, & Sharp, 2015; Webber, Carter, Sherwen, et al., 2017) to those of domesticated (Hirskyj-Douglas & Lucero, 2021; Robinson, Mancini, van der Linden, Guest, & Harris, 2014) and farm animals (Makinde, Islam, & Scott, 2019), to even wild animals' (Kobayashi et al., 2015) – address the animal as a technology-user by considering the animals' requirements and needs, the computer functionality necessary, and relevant constraints (Mancini, 2011). In their efforts concentrating on the animal as a user, termed 'animal-centred design', the animal drives the design process as a key stakeholder throughout the technology-building process (Paci, Mancini, & Price, 2017; Ruge, Cox, Mancini, & Luca, 2018). This involvement frequently entails a collaborative process probing the human stakeholders (farmers, animals' carers, zoo personnel, etc.) but also the animals themselves, to reveal the animal's needs (Noz & An, 2011; Ruge et al., 2018; Siguín, Blanco, Rossano, & Casas, 2021). Continuous testing as the technology is developed ensures the animal users' part in the design process for the computer system (Grillaert & Camenzind, 2016), typically by means of an iterative approach (Mancini, 2013; Westerlaken & Gualeni, 2014).

A well-established method in the HCI domain, iterative design is a cyclical process of testing aspects of the technology with the user as its development progresses through its various stages, to improve the finished product's overall quality and functionality (Ishii, Kobayashi, & Arita, 1994). Exploiting iterative design's rich history to inform design for animals has grown increasingly commonplace in ACI developers' implementation of novel technologies (French, Mancini, & Sharp, 2016). The practice of gradually distilling requirements and system specifications via several iterations with the animals (Noz & An, 2011) has legitimated animals' position as users and design contributors (Mancini, 2013). The iterative process directly tackles the challenge of design and evaluation for users unable to provide verbal or written feedback, by enabling the animals to evaluate the technology either directly or via a human proxy along the journey. Research attests that iterative design improves the ultimate design and functionality, thereby producing more animal-friendly products and systems for animals (Paci, Mancini, & Price, 2019) via better-tuned building and evaluation of technologies (Westerlaken & Gualeni, 2014). A thorny challenge remains, however, related to subjective interpretation by human researchers (Weilenmann & Juhlin, 2011) when they engage animals in the iterative design process (Westerlaken & Gualeni, 2016) and evaluate it.

To address how best to address that issue bundled with iterative design for animals, this paper presents a method for creating new interactive computer devices for animals. The framework articulates four stages (requirements, ideation, prototyping, and testing and analysis), each featuring specific tasks. After presenting the step-by-step method, informed by lessons from applying traditional HCI methods of iterative design to animals, I reflect on considerations central to the process as a whole.

While iterative design is not an entirely new approach in developing computers for animal users, let alone humans, the paper draws together lessons across diverse species. This synthesis should facilitate interactive systems' creators purposeful attention to the activities conducted, their assumptions, and the choices made.

2. Iterative design

The iterative design developed for HCI comprises multiple stages in which user-inclusive testing or solicitation of input (e.g., on requirements or meeting of them) informs evaluation of the current output. These stages, each typically an amalgamation of requirement-gathering, analysis and design, implementation, testing, and evaluation (Ishii et al., 1994), together continually refine and adjust the final product. Informed through tight cycles of trial and error, the designers learn throughout the process from real end users (Preece, Sharp, & Rogers, 2015).

Under this model, the designer need not proceed between the stages in strictly the order presented here. Project context and the findings from each stage determine the level of adherence to the typical sequence. Progress may be non-linear also because researchers seldom know all the problems when they start creating a solution (Fallman, 2003). Returning to earlier stages or changing the overall order of doing things is not uncommon.

2.1 Iterative design with animals

Most ACI researchers developing novel computers for animals focus on how iterative design benefits reflection and development in the design process (French, Mancini, & Sharp, 2017). Much of their work toward a fuller picture of the design's various angles and dimensions has focused on holistic iteration for one particular aspect of the computer system at a time rather than on developing the whole system at once (French, Mancini, & Sharp, 2020; C. Robinson & Torjussen, 2020).

Iterative design demonstrates numerous benefits for ACI, related primarily to addressing animals' inability to provide direct feedback in spoken or written words. The method supports their involvement in exploring from early prototypes onward, across all of the stages (French et al., 2017), in a species-appropriate manner (Kankaanpää & Hirskyj-Douglas, 2023). Feedback on the experience of the technology can be gathered from observing how the animals behave (French et al., 2017; Webber, Carter, Smith, & Vetere, 2020; Wirman & Zamansky, 2016), measuring their behaviour (Piitulainen & Hirskyj-Douglas, 2020), or examining information revealed via human-carer relations (French et al., 2017; Hirskyj-Douglas & Lucero, 2021; Webber et al., 2020). This process shows designers how the animal tests out and uses the solution before they have to commit to any set principle or finished product (Webber, Cobb, & Coe, 2022). Scholars suggest that continual user feedback for progressively shaping the computer helps technology-creators challenge their underlying assumptions by forcing them to make more informed and conscious decisions (Hirskyj-Douglas & Lucero, 2019).

While this approach presents clear advantages, how to involve animals directly in building novel computers for them is far from straightforward. Several factors complicate this. For instance, one must balance contradictory information when working with the various human and animal stakeholders (Hirskyj-Douglas & Piitulainen, 2021), ascertain the correct choices in each stage (French et al., 2017), consider ethics and legal factors (Mancini, 2017), address a lack of preexisting theories and guidelines (Hirskyj-Douglas et al., 2018; Westerlaken & Gualeni, 2014), and wrestle with fundamental differences between how humans and other animals give feedback on technologies (Webber et al., 2020). Furthermore, many animals' choice not to engage with technological interventions when given a choice (Ritvo & Allison, 2014) makes the considerable time and financial commitment required for the technologies' development and maintenance (French et al., 2015; Webber et al., 2022) even more risky. A useful end product is anything but guaranteed.

Identifying another problem in animal-inclusive design, some scholars state that iterative design in this arena is generally slower than traditional methods wherein one commits to designs without gathering feedback / iterating over ideas (Myers, 1994). Nonetheless, it is crucial for animal computing that the human technology-creators come to greater understanding of the animal users' real-world problems via testing that, through a steady stream of feedback, precludes costly mistakes (Webber et al., 2022). Such testing affords understanding how animals experience computer systems in the actual use settings rather than reflecting humans' perceptions/expectations. By reducing the space of unknowns, this testing helps computer designers home in on what works with animals and quickly abandon concepts incompatible with that (Kankaanpää & Hirskyj-Douglas, 2023).

2.2 Iterative design with animals, from theory to practice

Quantifying animals' input for purposes of iteratively evaluating technologies is complicated by the issue of intersub jectivity, the possibility of a shared mental state between designer and user (Mancini, 2013). In the absence of a shared language, how can one obtain feedback such that it can inform changes and refinements to the system (North & Mancini, 2016)? Building on Wittgenstein's (2018) argument that we as humans cannot understand what is being communicated by any animal that could supply feedback and that reaching a point where an animal could provide feedback compressible to us would render the animal no longer animal, North (2015) has posited that we can never truly understand or judge an animal's experience.

One approach to the dilemma of understanding animals' user experience of computer devices is 'becoming with': giving the animals items and judging their engagement by observing the responses manifested in their relationships and their play (French et al., 2017; Westerlaken & Gualeni, 2016; Wirman & Zamansky, 2016). In that play is regarded as intrinsically motivating and innate to all animals, it is valued for affording anthropocentrism-free insight as to what animals might want. Feedback from playful interactions is often grouped into device-triggered behaviours (such responses to the technology as smelling and touching items) and stimulus-triggered ones (changes in emotions, phys-iological/behavioural responses, etc.) (Wirman & Zamansky, 2016). Researchers can quantify both through media recordings, notes, and journals.

However, with such feedback-gathering tools, the human still retains general control, so some anthropocentrism is unavoidable (Westerlaken & Gualeni, 2016). With humans maintaining an overarching role in the process, the challenge of how to create a shared mental state and judge the animal's feedback and experience remains (Mancini, 2013; Westerlaken & Gualeni, 2016; Wirman & Zamansky, 2016). To bridge this gap in understanding from a human vantage point, researchers often strive for unmediated testing of prototypes with animals (French et al., 2020; Hirskyj-Douglas & Lucero, 2021; Piitulainen & Hirskyj-Douglas, 2020; Webber et al., 2020). The input from their voluntary engagement with prototype computer systems is assessed in relation to aesthetics, form, and quantitative measurements (French et al., 2020; Hirskyj-Douglas & Lucero, 2021; Piitulainen & Hirskyj-Douglas, 2020), which get considered alongside the human carers' feedback (French et al., 2020; C. Robinson & Torjussen, 2020; Webber et al., 2020). Scholars regard iteratively testing prototypes with animals as a window to what gives animals joy and, thereby, to fuller understanding generally (French et al., 2020). Observing engagement with prototypes indeed aids in comprehending the animals' context (Webber et al., 2020), so researchers have been encouraged to deploy multiple prototypes for evaluation against the requirements elicited (Hirskyj-Douglas & Piitulainen, 2021; Kankaanpää & Hirskyj-Douglas, 2023). Here, quantitative data obtained directly from the animal are deemed integral to success measurement that minimises human bias, preconceptions, and expressions of vested interest (Piitulainen & Hirskyj-Douglas, 2020), especially because humans make most of the design choices (French et al., 2017). Still, these data alone cannot illuminate why animals use the technology, the meaning behind their behaviours, or whether more use indicates preferences and the design's success (Ritvo & Allison, 2014).

No consensus exists on methods for verifiability-conferring iterative design with animals. Even designers who work purely with humans have struggled for decades to interpret individuals' experiences with computers (North & Mancini, 2016). Many researchers have concluded that perfect understanding is impossible; however, it might not be necessary – with iterative design, the process itself is what truly matters, through incremental learning and working toward success (Fallman, 2003; North & Mancini, 2016). The method described here builds on precisely such a reflection process.

2.3 An iterative design model for developing technology for animals

While HCI's iterative design methods vary in the terms employed for the various stages, all models focus on creation, testing, and analysis of the technologies for deployment. My ACI-oriented model articulates the phases of iterative design as **requirements, ideation, prototypes**, and **testing and analysis**. These stages, outlined in Figure 1, can be summarised thus:

- *Requirements:* Ascertain what is to be accomplished by the technology for the animal users
- *Ideation:* Formulate ideas for meeting these requirements (via digital or physical media)
- *Prototypes:* Experiment on physical forms, with animals and human proxies, to evaluate aspects of the technology and enhance design early on
- *Testing and analysis:* Test the product with the animal species to examine findings and draw conclusions

While developers can work through them in the manner presented, as is typical for iterative design, steps within each stage might equally well be followed in another, pro ject-specific order. The designer might opt to move between stages and tasks in an alternative manner so as to refine the results from previous stages/ steps. Looping back to earlier stages in light of insight emerging later on is commonplace in iterative design.

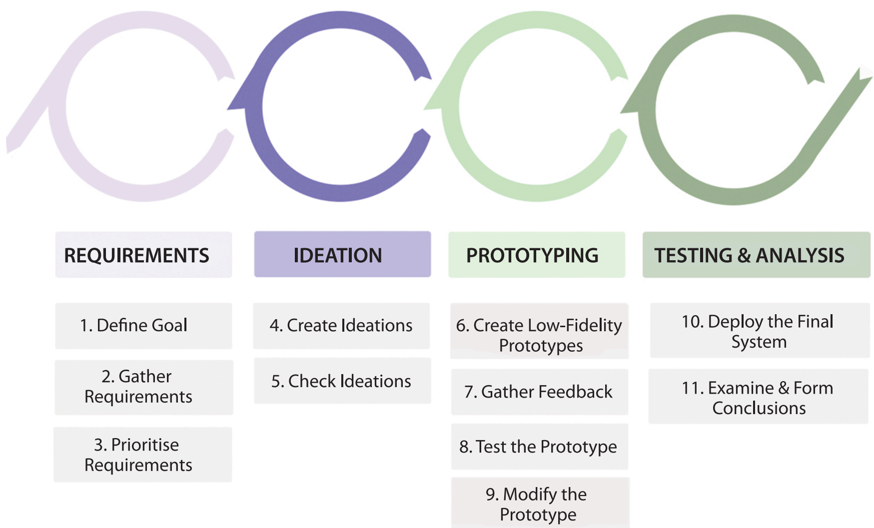

Figure 1. A diagram of the process for iterative design with animals

While an ethical manner of working with animals is inherent to the method, the framework does not formally feature explicit ethics components, because of contextual elements' unique demands. For example, generalisations related to appropriate timing of formal ethics-committee applications are rendered impossible by some locales and situations requiring specific methods and data-gathering applications. Since such procedures' rigidity may comprise the flexibility so vital to iterative design, it is best to address ethics matters continuously as the design process unfolds rather than in any single step.

3. Requirements

The first stage comprises steps 1–3 of iterative design: specifying, compiling, and prioritising the things that the final system must achieve/do. Given the involvement of both animals and humans, this can be challenging: the boundaries differ from those in traditional HCI-aligned capturing and sorting of requirements.

Many researchers adjust HCI frameworks and methods for examining the requirements (Zamansky, van der Linden, & Baskin, 2017).

Step 1: **Formulate the system's goal**

Step 1 in building novel systems is specifying the goals for the system in light of user needs, clearly and in a manner ensuring that the system suits their unique context (Zamansky, van der Linden, & Baskin, 2017). The goal articulates the aim behind the system and its desired effect on the animal and human parties. At the goal-setting stage, it is important to consider any limitations and issues existing in the technology's deployment location (Webber et al., 2020).

The goals may express a synthesis of human and animal objectives, and a combination of sources can inform them. They may be drawn from opinions of domain experts or of human proxies for the animals (Webber et al., 2020; Zamansky, Roshier, et al., 2017), the literature or case studies (Hirskyj-Douglas & Piitulainen, 2021), first-hand experience (Hirskyj-Douglas & Lucero, 2021), and direct observation of relevant animals (Webber, et al., 2017). One structure applied for this step is the Welfare Through Competence model, which expresses ob jectives via a matrix of questions about how computers can support an animal's mental well-being (nutrition, environment, health, and behaviour) and competence (choice, control, variety, and complexity) (Webber et al., 2022). Goals run the gamut from improving monkeys' welfare by conferring control over some aspect of their enclosure (Piitulainen & Hirskyj-Douglas, 2020) and enriching domestic dogs' time alone by letting them control screens in the home (Hirskyj-Douglas, Read, & Cassidy, 2017).

One problematic aspect of goal definition is distinguishing between human and animal goals, alongside the drivers and influences behind those goals. Without direct awareness of what animals want, understand, or are motivated by when using computer technologies, we cannot confidently state the benefits a computer may bring or why they might want to use computers. The objectives set for ACI systems should be rooted in the animal's genuine needs, not solely in what the technology enables (Rault, Webber, & Carter, 2015). Goal-setting based on real needs – e.g., helping animals gain abilities that they would not otherwise have (Ritvo & Allison, 2014) – reduces the risk of the system harming the animals (Lawson, et al., 2015) and that of humans pro jecting their own goals and design priorities onto animals (Zamansky, van der Linden, & Baskin, 2017). That said, the most reasonable balance between animal- and human-focused goals depends on the ultimate requirements for the technology. For instance, a system for veterinary work has to meet human and animal goals if it is to function effectively.

Step 2: **Compile animal-computer systems requirements**

Once goals have been set, requirements can be built from them. Step 2 may be defined as 'the process of seeking, uncovering, acquiring, and elaborating requirements for computer-based systems' (Zamansky, van der Linden, & Baskin, 2017). This covers a combination of functionality requirements (related to what the system does), non-functionality-related requirements (related to **how** it performs a certain function), and constraints (what it must, must not, or cannot do). Similarly to goals, requirements may arise from multiple sources. Literature is especially useful in this respect, as much is known about key challenges connected with how to support animals well (Webber et al., 2022), encourage behaviour equivalent to that in natural habitats (Martin & Shumaker, 2018), etc.

Observing animals is an important part of gathering requirements: the researcher monitors them in their normal habitat, typically over an extended time, and takes notes on behaviour, locomotion, physiological factors, and interactions (Webber et al., 2020, 2022). Scholars have characterised this technique as learning from animals as 'experts of their own experience' (Webber et al., 2020) and as a way of recognising agency in animals (Aspling & Juhlin, 2017). Experts encourage observing animals in 'natural' ways and in ordinary contexts of their existence (Aspling & Juhlin, 2017; Webber et al., 2020).

When undertaking observation, one ought to remember that animals are complex entities, with behaviours that often vary with the species, individual, and context and with groups motivated by both individual- and collective-level goals and signals (Cabrera, Nilsson, & Griffen, 2021; Sumpter, 2006). A researcher who studies animals' behaviours is attempting to understand not only what is going on but why, along with how these specific actions contribute to psychological well-being (Webber et al., 2020). The behaviours should be examined in relation to location- and housing-linked factors (physical structures, the space, climate, humans' presence, etc.) and circumstances in the space – the number of individuals in the habitat, demographics, and relationships among group members (Webber et al., 2022; Yamanashi et al., 2022).

Humans acting as proxies for the animals flesh out the picture of requirements for animal technology by drawing on their experiences and expertise (Farrell, McCarthy, & Chua, 2019; van der Linden & Zamansky, 2017). Designers consult an animal's keepers and others who work closely with the animal (its owner, professionals in various related industries, experts in animal behaviour and cognition, etc.) with regard to its needs/desires and how technology can support fulfilling them. Using questionnaires (Hirskyj-Douglas & Piitulainen, 2021), interviews (Webber et al., 2020), focus groups, design fiction (Hirskyj-Douglas & Lucero, 2019), and various combination of these (Farrell et al., 2019), the researchers often ask about the animals' and the respondents' day-to-day life, activities, and experience with technology, along with the humans' experience with other animals, the animals' preferences, objects the animals typically use, and any practicality-based constraints or requests (Kaygan & Yargin, 2019; Hirskyj-Douglas & Piitulainen, 2021; Webber et al., 2020). For mitigating humans' tendency to anthropomorphise and to over-represent their own needs and experiences when characterising those of animals, I strongly recommend involving a wide range of stakeholders and consulting the literature, to afford a comprehensive picture of what is required, from several perspectives.

Step 3: **Categorise and prioritise the requirements for the system**

The requirement list is then arranged by theme/code. For example, requirements can be grouped into species-specific psychological and welfare requirements (Veasey, 2019); population- and individuallevel needs (Webber et al., 2020); physical, sensory, and cognitive requirements (French et al., 2017); and needs of keepers and visitors (Hirskyj-Douglas & Piitulainen, 2021).

Next, ordered lists are synthesised by prioritising the requirements in line with what the technology **must** do and discarding those requirements that it cannot meet. One technique for this is dubbed 'MoSCoW', for its ranked lists of 'Must Have', 'Should Have', 'Could Have', and 'Won't Have' traits (Khan, et al., 2015). Farrell et al. (2019) adjusted this slightly by applying a SWOT model to identify requirements as opportunities, blocks, needs for changes, and values.

The prioritisation typically puts the animal's needs first in light of the goal, though the financial, space, and technological constraints of the implementation context are important too (Veasey, 2019). Researchers can make sure the animal's needs are properly accounted for by involving the project stakeholders, who can act on the animal's behalf, in setting the order. Their engagement also supports more accurate lists (Hirskyj-Douglas & Piitulainen, 2021; Webber et al., 2020). For pinpointing what is necessary for solid welfare practices, Veasey (2019) recommends multiple panels of species experts, representing diverse backgrounds, to supply a non-biased perspective. Reliance on experts' prioritisation among requirements entails its own risks, though: by focusing narrowly on what is currently required, this approach may overlook opportunities to shed new light on what animals prefer and how they engage with technologies (Webber et al., 2020). Therefore, I recommend priming users to be open to future contexts also. Discussing requirement prioritisation with stakeholders represents an opportunity to raise awareness of the problem, document it, and discuss the technology open-endedly (Robbins & Margulis, 2014).

Requirement-gathering grows even more complex when the human proxy and the designer are the same person(s), as in the case of researchers building technologies for animals cared for in a home where they are also users and the data analysts (Hirskyj-Douglas & Lucero, 2021; Lawson, Kirman, & Linehan, 2016; Westerlaken & Gualeni, 2016). Negotiating boundaries between human and animal requirements, needs, and goals becomes challenging in such conditions, so one should take care to consider the animal fully as a user and the human as the technology-builder, coder, designer, and interpreter, coupled with the part these roles play in choosing prototypes (Hirskyj-Douglas & Lucero, 2021).

The process of forming requirements is unique to each use case, and every iteration may bring changes in the requirements and entail new relations among them as further factors come to light. The requirement listing formed in the beginning develops throughout the project as a living document.

3.1 Compiling the requirements: Lessons learned

- Human stakeholders may express mutually contradictory perspectives
- Requirements often start off abstract and grow more precise as the iteration process progresses
- All projects should be safe/robust and the system/data remotely accessible

The multiplicity of humans involved as proxies complicates the first step in developing new animal technology. Differences of opinion often emerge: what the researcher wishes to explore might not mesh with what the other human stakeholders bring from their particular organisational contexts. This tension was highlighted when I worked with monkeys at Helsinki Zoo, where the facility's visitors (who view and learn from the technology) and its staff (who looked after the animals daily) expressed very different requirements (Hirskyj-Douglas & Piitulainen, 2021). For example, the latter favoured technologies that, by weighing the monkeys or monitoring individuals, aid in caring for the monkeys, while visitors wanted systems to help them learn about or directly interact with the monkeys. Likewise, the concerns expressed by the two groups diverged, with zoo-keepers desiring reliable, well-monitored technology and zoo visitors not wanting an addictive- or unnatural-seeming system in place. As these examples demonstrate, humans bring their own particular narratives to the requirement-gathering process. Furthermore, I found that the individual humans involved often expressed unique sets of requirements: a synthesis of complex motivations, user narratives, vantage points, and past experiences of technology and animals. The requirement-gathering process pulls in all of these (Hirskyj-Douglas & Piitulainen, 2021). It is, therefore, essential to validate and synthesise the requirements with reference to prior work, experts' input, and such requirement-gathering methods as observation.

Secondly, the requirements' granularity can grow much finer as the process progresses, with some needs getting revisited in later iterations. Initially, our highest-priority requirements for the Helsinki Zoo project were that the technology be enriching for the monkeys, improve their health, lack adverse effects, not require training, and let humans observe the animals' interactions with the technology (Hirskyj-Douglas & Piitulainen, 2021). Later, as we began the prototyping, we made these requirements more concrete. For example, we defined safety as entailing inaccessible wiring (so that the monkeys could not gnaw on the system's wires, thus incurring injury), and specifying a see-through roof addressed keepers' worries about the monkeys possibly feeling enclosed (Piitulainen & Hirskyj-Douglas, 2020).

Finally, my experience of designing and building technologies for several particular species in several particular contexts has revealed certain fundamental requirements for any technology built for animals. Among the requirements applicable across all animals from a technology-building standpoint are that the system be safe and rugged enough to withstand exploring with the mouth and fingers, being urinated upon and jumped on, etc. and be remotely accessible (e.g., for verifying the data and checking use by the animals). Meeting these basic requirements minimises disruption for the animal and supports high standards of ethical care, and it guarantees constant collection of data, thereby permitting swift response to any adverse reactions.

4. Ideation

Step 4: **Map the design ideas back to the system requirements**

Once the requirements have been gathered, the iterative process enters its second stage: the ideation phase. The aim here is to generate a large pool of ideas in a creative and innovative manner without initial restriction by technological or practical constraints. Through a broad scope, the designer is not confined to standard features or typical methods so can focus squarely on the requirements and on the realm of possible solutions. A multidisciplinary team that represents numerous motives for involvement can aid in combining multiple perspectives and strengths, thereby leading to more innovation. Numerous techniques can develop low-fidelity ideation, among them sketching (Hirskyj-Douglas & Lucero, 2019), cardboard or paper prototyping (Gray et al., 2018), storyboarding (French, Hirskyj-Douglas, & Väätäjä, 2021), crowdstorming (collaborative brainstorming with a large community of people) (Gray et al., 2018), and co-creation workshops (Webber et al., 2020). This step's output connects the initial requirements' appropriate scope with technology concepts.

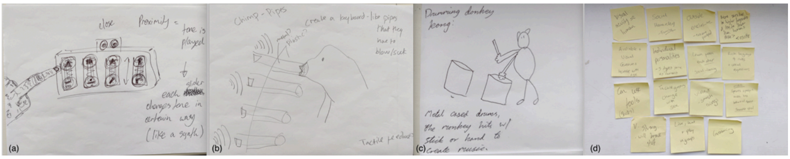

Figure 2. Three sketches for a music-player for chimpanzees, presenting proximity buttons whereby chimpanzees can synthesise music (a), pipes akin to a keyboard that give tactile feedback when blown upon (b), and drums for chimpanzees (c). The process's sticky notes captured key elements of chimpanzee-relevant literature (d)

Figure 3. Sketches from the process for a giraffe music-player (including a hanging ball, a keyboard, a slider, and a neck-rubbing device) and sticky notes referring to important giraffe-specific literature

One fruitful approach to developing ideas utilises a workshop for joint ideation with stakeholders. Workshops of this nature present the requirements through such media as sticky notes, and they ground the ideation via such resources as vital information about the species (see Figure 2's pane d and Figure 3), videos of earlier solutions, key information from stakeholders, and items used by the animal (toys etc.). For further inspiration, stakeholders may benefit from visiting the animals and seeing them in their lived circumstances (Hirskyj-Douglas, Gray, & Piitulainen, 2021).

To support the variety of human expression in ideation processes, the workshop can utilise not only writing but also various drawing media and also physical objects, such as Lego, toys, and modelling clay (Hirskyj-Douglas et al., 2021). Typically, individuals, all participants together, or smaller groups engage in rapid cycles of brief iterations wherein they use these materials to note, sketch, or build either a new idea or elaboration on another participant's idea. Figures 2 and 3 present examples from ideation work on a new audio system for chimpanzees and generation of music-player ideas for giraffes, respectively.

Grounding the generation of ideas in the requirements and goals from stage 1 is critical, all the more so when the stakeholders are unfamiliar with the process or have limited experience of providing feedback in such a manner. Collaborating with stakeholders in this task can prove especially challenging when children or other individuals with limited understanding are involved (Hirskyj-Douglas et al., 2021; Pons & Jaen, 2017). Care must be taken to address any power disparities between the systemcreator and other stakeholders, lest they end up less deeply involved and with poorly represented views (Pons & Jaen, 2017). Templates, board games, toys, and card decks (French, Mancini, & Sharp, 2021; Hirskyj-Douglas et al., 2021) are additional tools that can help bridge the gap. Ideation and concept cards have been a prominent method for collaborative ACI work. These gamify the process by means of cards intended to spark stakeholder reflection on certain questions (French, Mancini, & Sharp, 2021). For instance, French et al.'s (2021) deck uses sets of concept cards that focus on key values, characteristics of the species, aesthetics, interaction, experience design, and crafting/tinkering, and the cards developed with my colleagues (Hirskyj-Douglas et al., 2021) coheres around certain types of animals and enrichment in a manner geared toward children (see Figure 4).

Before the next step, participants map the ideas back to the initial requirements. This ensures that the ideas developed are consistent with what the animal user needs. At this point, any design that does not mesh with the requirements is removed from consideration.

Figure 4. How children can use animal- and enrichment-specific ideation cards and ideation sheets to form ideas for technologies used at zoos

Step 5: **Validate the ideas with human stakeholders**

If the human stakeholders have not yet been brought into the process, the researchers should present the surviving designs for their feedback, to avoid pitfalls. Developing interfaces may entail many iterations between ideas and meetings with human stakeholders (Gray et al., 2018). The feedback should be examined in conjunction with the non-functionality-related constraints. This input to shaping the design and selecting a single design to pursue is part of a delicate balancing act of ensuring that the system honours the animals' needs as articulated in the original requirements while also meeting the humans' requirements (inclusive of relevant organisational ones) and reaching the goals specified at the outset.

Typically, the developers advance one design or a few designs emerging from the ideation session that mesh with the overall goal, most of the requirements, and what can be implemented. The choice of idea can be made in any of various ways. One idea may stand out as fitting the goals and requirements best. Voting works well if the stakeholders and designers can achieve critical mass, and conversations among the participating stakeholders offer an alternative way forward.

If an ideal design does not emerge after the collection of feedback, the team can hold an additional ideation session, building on the knowledge cultivated since the first one, or conduct convergence work or clustering of the top ideas connected with the new system or promising themes. Careful narrowing to a small number of avenues or a single idea guides shaping of the technology to suit the animals and human proxies well. It ensures not only meeting their needs but also fitting the implementation context.

4.1 Key lessons from ideation experience

- Carry one idea forward, but keep the feature space and look of the technology open
- A list of nascent ideas can give structure to conversations in which human stakeholders accept/reject ideas, merge them, and create new ones

My typical experience of ideation involves singling out one idea for further work while remaining open to multiple alternatives for the aesthetics, functionality, interaction method, and many other undefined aspects of the system. While these facets often coalesce as prototyping progresses, the core idea remains constant and aligned with the main goal – for example, a music-player that activates upon detecting an approaching monkey (Piitulainen & Hirskyj-Douglas, 2020) or a video-call device for dogs composed of their toys (Hirskyj-Douglas & Lucero, 2021). The features at the ideas' heart often are integral to the nature of the system envisioned (while also meshing with the central goal, most requirements set, and the needs of the humans involved). The soft and flexible 'flesh' on this idea skeleton brings in the look and form of the technologies, such as which specific dog toy to use for the calling device (Hirskyj-Douglas & Lucero, 2021) or how monkeys might trigger the audio (Piitulainen & Hirskyj-Douglas, 2020). I found that keeping many elements flexible provides more room for vital features of the technology to coalesce around concrete results from prototyping with the animals themselves in the real-world deployment context. This helps to avoid falling prey to human bias, and I have found that the centrality of direct exploration of features with the animal supports arriving at a better system sooner.

I have drawn lessons also from the challenges of the dialogue with human stakeholders. Zoo staff and other organisations' professionals seldom have copious time, and consumers often stay fixated on current technologies (for pets etc.). Therefore, drawing human stakeholders deeply into the ideation process might demand extensive preparation. To support ideation among humans who are not ideally oriented toward exploring possible system ideas, one can supply an initial set of ideas. After providing this starting point for conversation, I invite the stakeholder to reject aspects of my proposals and identify favourite ideas. By arranging the ideas in terms of concerns and preferred features, stakeholders contribute to collaborative articulation of the final concept. Concrete ideas with a clear connection to the requirements render the process smoother. Also, by supporting simple paths to providing feedback, this approach reduces the time required of busy organisations.

5. Prototyping

Step 6: **Create one or more low-fidelity prototypes for the system**

After the design-selection stage, the process moves on to prototyping, generally defined as transforming ideas (with various fidelity levels) into example systems to test. In our case, this turns rough sketches, 'mind maps', cardboard models, etc. into more robust physical objects, for tests with animal and human users in animal computing contexts.

While scholars have described prototyping with animals as forming the realised specific artefact necessary for scientific purposes (French et al., 2017), prototypes' uniqueness renders the evaluation of success problematic; the choice of metrics/criteria is not self-evident (French et al., 2017). The issue of what constitutes success is an especially pertinent question in the ACI field. Animal-computing researchers have defined success in terms of play or other behaviour changes (Hirskyj-Douglas & Kankaanpää, 2021; French, Hirskyj-Douglas, & Väätäjä, 2021), the actions completed (Gray et al., 2018; C. Robinson & Torjussen, 2020) – especially as measured over time (Yamanashi et al., 2022) -and human carers' assessment of successful use (French, Mancini, & Sharp, 2018). I would encourage designers to develop success metrics based on the case-specific requirements and goals, metrics that may constitute conceptually rich output in their own right (Gaver, 2012).

For prototyping aligned with iterative design, this stage usually involves low-fidelity prototypes and 'Wizard of Oz' techniques (Kankaanpää & Hirskyj-Douglas, 2023). Low fidelity readily supports testing for numerous aspects of the technology: various shapes, possible interaction mechanisms, and other system features. My prototyping work has included testing several device shapes, in plastic and wood both, to shed light on the interaction experience of monkeys (Piitulainen & Hirskyj-Douglas, 2020) and giraffes (see Figure 6); trying out different sensors worn by dogs against their fur (Hirskyj-Douglas & Read, 2018), to check technology constraints (see Figure 5); and testing how white-faced saki monkeys touch buttons (Kankaanpää & Hirskyj-Douglas, 2023), for interaction-mechanism development. Off-the-shelf devices sometimes are suitable (Robinson & Torjussen, 2020; Zeagler et al., 2016), while other ACI research has worked with foam board, cardboard, knitted wool, plastic pipes, ropes, buttons, and wood to explore shapes and sizes of prototypes (French et al., 2017; Gray et al., 2018). Whatever the material, the prototypes should be safe and durable enough for the necessary testing with animals.

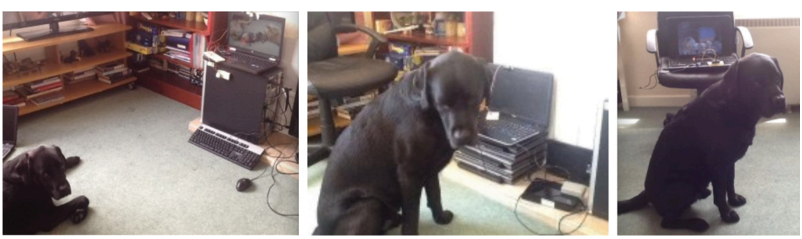

Figure 5. An example presenting prototyping to test technology for an interaction method under development for dogs: A canine-controlled television device. The figure shows an animal tester with passive infrared sensors (left), ultrasound sensors (middle), and standard infrared sensors (right)

To enable 'lightweight' changes to the design in light of how the animal behaves with the system, this stage begins with low-fidelity objects that are not technically sophisticated (as Figures 5 and 6 demonstrate). Restricting the prototyping to low fidelity in the beginning allows quick iteration for honing of partic-

Figure 6. An example from prototyping of aesthetics for the physical interface of our giraffe-controlled music device, including (from left to right) a barrel, Tupperware boxes, a cage containing a ball, and a Boomer Ball

ular elements and for testing design decisions with animals in a way that facilitates swiftly reducing human bias and supports understanding how the system **could** function. Since animals see the world and computers differently than humans, uncovering how they access and use computers in practice is crucial for success.

The Wizard of Oz approach can be valuable in early testing. This experimentation technique has a human 'behind the curtain' of the technology who controls various of the functions such that the technology can be assessed before fuller development. The technique has shown utility for exploring more abstractly articulated designs with animals, since it can greatly reduce expenditure on prototypes that might well provoke largely unknown responses (Webber et al., 2020). The prototypes created serve to demonstrate the proposed interactivity of the system nicely. Still, one should bear in mind the attendant ethics concerns: this method may deceive the user and, in scenario-based settings, works only for a clearly identifiable task such as pressing a screen or biting a stick (Riek, 2012).

Step 7: **Gather feedback on the prototype from human stakeholders**

All prototypes created must be evaluated solidly. This should be done as early as possible, with both the animal user and the relevant humans, to allow for multiple iterations informed by user feedback (Alcaidinho et al., 2017). When evaluating prototypes, researchers assess how well they match user needs and the requirements and goals set for the system (in steps 1–2). The first activity is to show the prototype to the humans involved in the animal's care. Stakeholders should note any obvious flaws at this point. For instance, zoo personnel noted that one of our prototype devices intended for giraffes was too heavy for keepers to move into the chosen location. This filtering with humans decreases the time needed for testing with animals and reduces the burden that novel computer devices' development imposes on animals. In these and other respects, it follows the principles of the three 'R's for animal ethics: replacement, reduction, and refinement (Fenwick, Griffin, & Gauthier, 2009).

Step 8: **Test the prototype with animal stakeholders**

After human stakeholders have validated the prototype, testing for longer-term stability can catch additional errors. This further reduces the burden on the animals. Before testing with them, researchers run the system for some time, interacting with and triggering it periodically in the expected manner. Testing with the animal can begin once the system is stable enough – it has to be safe and robust at this point since repeatedly replacing components or constructing them *in situ* can prove costly and time-consuming (French et al., 2015), also posing dangers (Webber et al., 2022).

The testing period for ACI systems should be appropriate for the context and might extend to several days (Piitulainen & Hirskyj-Douglas, 2020). There may be several iterations, with brief tests of various prototypes (sometimes taking mere minutes), to concentrate on smaller pieces of the design for purposes of validating specific core elements of the concept. For instance, it may take only five minutes to discover whether buttons are an appropriate interaction mechanism for the animal (Kankaanpää & Hirskyj-Douglas, 2023). In other situations, wherein the prototyping is oriented more toward comparison between alternative concepts, testing requires significantly more time, such as a day or two. In fact, each iteration in our initial testing of interface mechanisms with monkeys took several days (Piitulainen & Hirskyj-Douglas, 2020). The time hinges partly on whether the prototyping focuses on a single feature of the device or encompasses all of its functionality.

Analogously to the capturing of requirements, testing of the prototype with animals can entail both quantitative and qualitative mechanisms. One might observe the animal with the prototype, measure the interactions, and consult carers and/or other human stakeholders about the animal's interactions. For the initial prototyping and earliest interactions especially, designers seldom want to leave the animal unattended with the system. The practices should follow sound ethics. For instance, to guard against unintended consequences and safeguard the animals' welfare, developers should ensure that the system can be quickly removed if it causes the animal distress. This stage should include guidance from carers on the animals' well-being.

Critics have stressed that ACI prototyping can rely on behaviour assumptions derived from animals' initial responses to new stimuli, which may include exploratory behaviour or novelty effects (Hirskyj-Douglas & Webber, 2021; Webber et al., 2022). To ameliorate this factor, exposure to the prototypes can be lengthened such that observation extends beyond the initial responses. Adjusting the testing times to the context enables addressing factors such as how long it takes for the novelty to wear off. For instance, in our development of buttons for monkeys, we gradually reduced the prototypes' testing time from an hour to 15 minutes after finding that most, if not all, relevant interactions occurred within the latter time (Kankaanpää & Hirskyj-Douglas, 2023). Such scaling requires care, though. When animals experience a prototype with incomplete functions, the incomplete feedback loop might lead to misunderstanding how the device functions.

Findings from this stage could well run counter to the original requirements or the human stakeholders' assumptions. In a study involving tunnels for monkeys (Piitulainen & Hirskyj-Douglas, 2020), we initially designed the tunnel system to be dish-shaped because keepers suspected that white-faced sakis would not want it enclosed in a tunnel. However, testing of various distinct shapes with the monkeys prompted us to abandon the dish after a few days whereas the 'enclosed' space became a regular congregation spot for the monkeys. Thus, the testing allowed us to check against the requirements and also validate the zoo-keepers' feedback, which turned out to be misaligned with the monkeys' actual behaviour. This example attests to the value of willingness to revisit the previous stage in the design process (ideation) as new aspects emerge. It is essential for researchers to reflect on what the animal is expressing and on the behaviours' motivations, in light of observations and experts' input both.

Step 9: **Modify the system in light of the animal stakeholders' contribution**

Once the case-specific metrics (which, naturally, depend on the goal) have identified a prototype as successful, it can be modified and scaled to higher fidelity. This scaling over the course of multiple iterations builds on the lessons learnt as the process continues, and the researchers can revise the requirements as necessary. A reflexive and flexible method facilitates technology cohering around the findings from testing alongside the animals while always feeding back to the system's requirements.

5.1 Insight related to prototyping

- Ascertaining when to start testing with animals can be challenging
- Animals' behaviour in response to technology can vary with individual-specific and environmental factors
- Standardising prototyping to some extent (within and across species) can facilitate methods' and systems' development/exploration
- For comprehensive awareness of various (human/animal) goals' and motivations' influence, developers must document the factors influencing the design decisions and clarify the rationale

Many of the most pivotal lessons come from the prototyping stage – animals often behave in unexpected ways. For this reason, the sooner testing begins, the sooner the design's flaws are found. Hence, a question arises about when a prototype should move from the ideation stage to being tested with animals. For this timing, one must be cognisant of the risks of imposing undue stress on animals, sensitive to the need for balance between novelty and habituation effects, and ready to check that no unwarranted assumptions are made about how animals behave/interact. Prototyping that sets these concerns in good mutual balance is an ongoing effort. While encouraging designers to negotiate this balance for themselves, I would recommend testing one's devices with animals sooner rather than later to ground the prototypes in the animals' feedback before the design could end up excessively reliant on human assumptions.

Another important lesson is that animals display widely divergent behaviours when interacting with technology, owing to an array of uncontrollable factors (personality traits, group housing conditions and interpersonal dynamics, time of day, mood, prior experience, etc.). Therefore, engaging numerous members of the relevant species (particularly when they live together) for long enough is imperative if one desires reliable data. Finding the optimal duration for testing of prototype technologies with animals is tricky, however. Novelty and habituation effects vary with the species, for instance. Some require gradual introduction in which the computer device is inactive or 'muted' in its functioning at first, then activated once the animals have grown accustomed to its presence (Kleinberger, Cunha, Vemuri, & Hirskyj-Douglas, 2023; Yamanashi et al., 2022). Such techniques are suitable for species whose neophobic tendencies necessitate more time and support in conditions of exposure to a novel system. For example, when developing a parrot-to-parrot interface, we implemented lower-intensity feedback (reduced volume for sounds, the screen's placement further away, etc.) prior to the final implementation (Kleinberger et al., 2023). Alongside leaving the technology in the animals' everyday environment, albeit turned off or at a lower setting, for the animals to explore at their own pace, another way to support gradual introduction is to encourage the carer to explore the technology in front of or with the animal, demonstrating its features. Keepers at Blair Drummond Safari Park who were collaboratively developing technologies with chimpanzees advocated this method highlighted by prior work (Yamanashi et al., 2022) in hopes of reducing negative reactions to the system's screens and projectors. In any case, timing and test modality are contingent on the animal's unique requirements and must be adapted also to the context under investigation.

Reflecting on prototyping, I conclude that there is merit both in implementing prototyping practices across diverse species and in testing continuously with the same animals. As ACI, inspired by HCI methods/theories, adapts these for animal use, novel techniques emerge, with innovative approaches to soliciting animal feedback, measuring animals' behaviour, and facilitating human-animal interaction while balancing the power dynamics. Cross-cutting work across species boundaries offers opportunities to expand the knowledge base accordingly and uncover fresh avenues for exploiting prototyping methods.

Simultaneously, continuous prototyping efforts with the same animals could mould them into expert feedback-providers – in humans, prolonged prototyping with a consistent group has been demonstrated to significantly enhance the quantity and authenticity of observed behaviours (Summers et al., 2003). Similarly, animals could develop proficiency in testing and in offering feedback; this and better researcher attunement to their input can enrich inter-species comprehension. That said, the sharing of experience compromises ability to distinguish between decisions rooted in feedback on the interface and those grounded in prior knowledge. The choices made during prototyping reflect both animals' and humans' experiences (Gaver, 2012). Hence the final lesson: documentation is crucial. The reasoning and motivation behind the choices, their alignment with the requirements, and other factors all may influence the data gathered and the final outcome (Gaver, 2012).

6. Testing and analysis

Step 10: **Deploy the final system for animal stakeholders**

Once prototyping has confirmed its functionality, the next step is to deploy the system created. Various methods and theories from HCI, ACI, and other animal-studies fields can inform deployment and subsequent measurement of how well the the animal's use of the system meets the success criteria articulated (Hirskyj-Douglas et al., 2018; Zamansky, Roshier, et al., 2017). While these methods' great variety and their strong dependence on the objective, context, and animals involved preclude addressing the metrics and later data analysis in any depth here, several of my previous publications delve into how we devise novel device-testing methods sensitive to the uniqueness of developing interactive interfaces for animals (Hirskyj-Douglas & Kankaanpää, 2022; Hirskyj-Douglas & Read, 2016; Hirskyj-Douglas et al., 2017). Reflecting on testing methods generally, researchers have cited a need for animal-computing work to remain receptive to the vast array of methods available via literature from neighbouring fields, for formulating a well-structured, systematic approach (Zamansky, Roshier, et al., 2017). Many have adopted or adapted HCI methods and principles for animals accordingly.

Whenever deploying a computer system with animals, one ought to consider several factors. For instance, the sequence of presentation to animals can produce an order effect, and the duration of testing influences how much the animal interacts with the system – overly brief testing may capture merely novelty-exploration behaviours, but protracted testing may over-represent habituation-linked ones (Hirskyj-Douglas & Webber, 2021). Again, sensitivity to species' specifics is necessary. For instance, monkeys typically display intense interaction at first, which wanes after several weeks (Kankaanpää, 2021), while chimpanzees normally show heightened use of the technology only after a few weeks of becoming comfortable with it (Yamanashi et al., 2022). For scientific measurement of these changes, it is advisable to track the overall usage curve over time, for the whole group and each individual, then analyse the data produced. A third potential influence on the results is the time of day, weather, etc., on account of the animals' biological rhythm, alertness and attention levels, and related effects on use of space (Yamanashi et al., 2022). Fourthly, humans' presence can profoundly affect the results. For instance, white-faced sakis are more likely to explore technology held in a human's hands than items hung in their enclosure (Kankaanpaäaä & Hirskyj-Douglas, 2023).

At this juncture, I must note that the iterative design method, while letting the designer readily return to previous stages and revise the requirements if changes are needed (e.g., some component of the system might not function as intended upon deployment), does not 'rewind the clock': deploying the technology for the same animals may affect the findings, since experiences from its earlier deployment could influence their behaviour.

Step 11: **Examine the findings, and draw conclusions**

It is crucial to conduct the data analysis with care and develop conclusions that account for the animal both as an individual and relative to the species (and other relevant taxa). Furthermore, collection of data should not end when the technology is withdrawn from the animals' environment. For instance, enriching one's insight via interviews or questionnaires for human stakeholders is recommended. These may ask about memorable moments; the method's impact, if visible to the participant; the animals' experiences, reactions, and preferences; factors that might have influenced the study; potential tweaks; interest in the technology's future use; and general feedback. Also, to evaluate longer-term impacts, I keep measuring the animals' space use after removal of the device (Hirskyj-Douglas & Kankaanpäaaä, 2022). This is especially vital when the artefact has modified the habitat and where space is at a premium (i.e., a valued resource). Analysis encompassing all these elements can promote deeper understanding of the experiences of the animals and humans alike and, thereby, promote positive long-term effects while minimising negative ones.

Analysis from multiple perspectives, including the animals', human proxies', and designers', not only supports rich, multifaceted insight but also enables the iterative design process to keep improving the technology produced and yielding insight for other devices and for interaction more broadly. Further iteration cycles can support the development of computer systems that support animals' lives better and better.

6.1 Lessons for testing and analysis

- Continue the monitoring, retain the timestamped data, and configure the system for regular status checks
- Even lack of interest in the artefact is a useful result: it can prompt further investigation and alternative approaches

Through my experience of extensive testing with several animals, I have come to recognise the importance of implementing real-time status checks. These entail the system updating a remotely accessible location with details of its current condition (e.g., online, offline, or some other relevant state). I make sure the data are stored in a secure online repository too, to enable troubleshooting and provide precise real-time data for usage-monitoring. In addition, I recommend complementing this material by means of multiple cameras, set at various angles, that record the animals' interactions. Such recordings support verification of the other data and retrospective analysis of the animals' behaviour.

Even with the most sensitive and well-executed iterative design process, some animals may not find the output interesting, irrespective of how well it dovetails with the requirements and goals specified and refined over the course of the process. I have come to regard such instances not as reflecting design 'dead ends' but as representing starting points for finding what works for the animals and context. Any seeming failure also constitutes a reminder of why ACI should proceed to prototyping quickly. Rapidly building something functional to evaluate with the animal permits identifying problems with the system, parts of it, or certain features before things progress very far. For instance, having completed project work wherein we devoted considerable time to building a button-based system for monkeys (Kankaanpää, 2021), we found that the monkeys quickly abandoned the button system: after initial exploration, they never used it again, even when several weeks' exposure was followed by reintroduction. Picking up the process again, we finally iterated the device into a proximity-based one, which successfully elicited interaction.

7. Key considerations in iterative design for animals

Reflecting on the iterative design process in the ACI realm highlights how little is known about what animals want and need, their way of experiencing the world, and how computer systems can support them accordingly. Though this paper offers some answers, ample room remains for developing a solid platform for creating novel computers that meet those needs. While abundant caution and ethics considerations are paramount, as is anchoring the technology in support for the animal's wellbeing, ACI scholarship should cultivate imaginative and expansive exploration of ways to develop novel computers and of means for animals to access and use those computers.

My experience of transposing design methods from human to animal settings reflects a fundamentally non-linear, iterative learning process with many stumbling blocks and unexpected complications along the way. The numerous regrettable incidents I have encountered, from monkeys eating the wires and crickets getting into the devices to humans neglecting to switch the system on or coercing their pets to use it, have offered valuable lessons – most importantly, underscoring the ongoing learning inherent to the process of developing technologies for animals and exploring what animals need and how computers can benefit them. Issues with hardware failing, device enclosures breaking, and software malfunctioning are inevitable. By embracing the process's natural uncertainties and complexities, designers can create systems that are more effective and responsive to the animals' needs. The resulting deeper understanding helps designers reflect on their preconceptions and approach their work on both animal and human technologies with greater curiosity and a more open mind.

Clearly, designing computer systems for animals is a multifaceted task. One substantial part of this complex undertaking is the unavoidable need for involving human carers in creating the systems and gathering feedback on them. Feedback from humans has conferred some stability on my efforts to develop animal computing systems, by driving the project forward and highlighting fundamental problems early. However, all iterative design in ACI contexts requires balancing the needs/perspectives of humans and other animals. We need to remember that humans are biased, and we must constantly strive for ways to focus on the animals' feedback instead of humans'. While the humans considering animals' experiences and needs typically have the best interests of the animal in mind, misconceptions, anthropomorphism, and self-interest are part of the mix; therefore, it is important to acknowledge the significant gaps in our understanding of animals' desires, needs, unique experiences, and perspectives on the world. One aspect of tackling this challenge is attempting to set the human feedback against the backdrop of scientific knowledge, which in itself can be challenging, in that much remains unclear. The frontiers of our knowledge about animals are advancing rapidly.

Even what constitutes an animal-centred system is subject to debate. This is a matter of perspective, with some scholars having defined animal-centredness as giving animals the best possible life (Webber et al., 2022) and others having foresworn the notion of animal-centredness altogether in favour of the species-neutral 'designing for dignity' (van der Linden, 2022). Were we able to agree on what an animal-focused system is, we would still have to wrestle with how to ascertain what is best for the animals in computing contexts. The issue of possible misalignment between humans' perceptions of a good life, welfare, or dignity with what animals need and want rears its head once more. As system designers strive to avoid imposing their own values and preferences on the process, they must embrace continuous evaluation/assessment of the ACI technology in pursuit of an evidence-based approach and continuous refinement. One route is that presented here: engaging in iterative design to obtain better understanding of what works and what does not. The development cycles should improve and refine systems for technology applied to support animals' living, whatever these may look like.

8. Conclusions

While more and more systems, of numerous sorts, are being developed that grant animals means of accessing computers, academic literature is largely silent on systematic support for consistent, well-grounded design and development of the novel interfaces. This paper, by introducing a framework for employing iterative design in four stages to create animal-computer interfaces, contributes to filling the gap. The reflections on lessons from each stage of developing devices for various animal users and contexts serve as a resource for important overarching considerations. As iterative processes gain popularity with the ACI field's maturation, these reflections can guide developers of novel computerised devices for animals such that their design efforts yield more robust and useful systems.

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