

RESEARCH ARTICLE

The Use of Technology to Enhance Zoological Parks

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Technology can be used in a zoological setting to improve visitor experience, increase research opportunities, and enhance animal welfare. Evaluating the quality of these technological innovations and their use by nonhuman and human counterparts is a critical part of extending the uses of technology to enhance animal welfare and visitor experience at zoological parks. Survey data from a small sample of institutions housing primates suggest that computers, television, radio, and sprinklers are the most prevalent types of technological enrichment currently used. Survey respondents were positive about the technology implemented, stating a desire to increase its use. *Zoo Biol* 30:487–497, 2011. © 2010 Wiley Periodicals, Inc.

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INTRODUCTION

In zoological parks, a variety of technological applications are currently being used to improve visitor experience and enhance animal welfare. This review discusses a number of the current and potential applications of technology. For example, technology has been used to enhance visitor experience by promoting conservation education, increasing opportunities for human–animal interaction, and using the internet to reach a broader audience. Technology has been used to facilitate captive

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animal research by allowing noninvasive testing of nonhuman animals' cognition, behavior, and perceptual abilities. Finally, technology has been used to improve animal welfare by promoting behavioral diversity, increasing control and choice, and creating more cognitively complex environments.

In all of these areas, we advocate an intensified approach to the scientific evaluation of the use of technology in zoological institutions. There is clearly potential for technology to improve visitor experience, research, and animal welfare in the zoo. However, careful application and evaluation is necessary to realize this potential and ensure that the implementation of technology is worth the cost. Therefore, it is important to evaluate the success of existing applications and carefully monitor future developments.

A brief survey of five institutions which house great apes, reported here, provides insight into some types of technology that are currently being used and whether these technological devices are being evaluated by staff. Technological innovations in conjunction with an effective quantitative evaluation program will enable zoological parks to incorporate positive changes into the management of captive animals and to enhance animal welfare, zoo visitor experiences, and programs of research in zoological institutions.

THE ZOO VISITOR EXPERIENCE

Technological innovations to zoo animal exhibits may enhance the education of zoo visitors by influencing their attitudes, knowledge, and behavior as well as improving their conservation efforts. Zoos are in a special position to educate the public [Maple et al., 1995], and thus continuously improving methods for doing so is a necessity. A variety of techniques have already been used to improve visitor experience and education at exhibits, including interactive elements, touch tables, training demonstrations, and oral interpretations [Anderson et al., 2003; Derwin and Piper, 1988; Lindemann-Matthies and Kamer, 2005; Swanagan, 2000]. Improved technology in conjunction with quantitative evaluation can be used to expand and potentially to improve on these existing practices. We will briefly focus on some of the ways in which zoos are currently using technology to enhance visitor experience and education. Additionally, areas of research evaluating these applications are proposed.

Educational graphics are commonly used to convey information to zoo visitors. Graphics in zoos have progressed from presenting basic animal identification information (species name, country/region of origin, range, diet, etc.) to more detailed information incorporating conservation messages [Serrell, 1988]. Electronic graphics at exhibits provide up-to-date, accurate information about the conservation status of a species [Swanagan, 2000]. Educational graphics that are interactive have been shown to improve cognitive recall of information presented at an exhibit [Derwin and Piper, 1988]. Touchscreen monitors allow for interaction with information while videos can be used to provide dynamic information, replacing static signs. For example, a video message at Zoo Atlanta's orangutan exhibit educates visitors about orangutan conservation issues and research. A nearby touch screen kiosk allows visitors to browse information about the individual orangutans (personal observation, 2008). Although low-tech methods of educating zoo visitors, such as traditional signage, interpretive graphics, and staff presentations, have been

shown to stimulate interest, greater interactivity has been shown to have the potential to increase visitor interest [Andersen, 2003].

Interaction with animals is another influential tool for educating the public. With the exception of petting zoos, which allow interaction with domesticated species such as goats and sheep, it is not realistic to permit contact interaction with most wild species due to welfare and safety concerns for both the animals and zoo visitors. Technology bridges this gap, allowing noncontact interaction to occur. For instance, Yanofsky and Markowitz [1978] created an interactive game that allowed mandrills and zoo visitors to compete in a speed race. The mandrills could initiate a game with a visitor by pushing a lighted circle. At Zoo Atlanta, when orangutans choose to interact with an on-exhibit computer, a monitor for visitors displays a replication of the image on the orangutans' monitor (personal observation, 2008). Thus, the public is able to watch the animals engage in cognitive tasks and other activities such as virtual painting. A planned expansion of Zoo Atlanta's current program will eventually allow visitors to "play" computer games with the orangutans, taking inspiration from Yanofsky and Markowitz's [1978] earlier design.

Technologically enabled free-ranging programs for captive animals also allow visitors to experience the animals more directly and may increase visitor interest in the species as well as in its conservation. Several zoos, such as the Smithsonian National Zoological Park, have free-ranging golden lion tamarins that are able to leave an enclosed space and range freely in the trees. These programs are possible because of radio collars, which allow the tamarins to be monitored even when out of sight. In this case, technology provides a more interactive experience than traditional exhibits because visitors are immersed in the same environment as the animal.

Finally, technology can also be used to influence zoo visitors' awareness of conservation issues and conservation-related behavior. Interactive computers at exhibits allow visitors to take immediate conservation action such as on-ground emailing of their views [Swanagan, 2000]. At the Bronx Zoo, kiosks set up around the gorilla enclosure allow visitors to watch a short movie about gorilla conservation and then take a tour of the gorilla exhibit. They are then invited to contribute money directly to a conservation issue of their choice [Chin, 2002]. Technology has also created opportunities for educating the public that expand beyond zoo boundaries. Many zoos operate web cameras that display videos of the animals at the zoo on websites which are available to the general public. For example, the San Diego Zoo has live "webcams" of polar bears, orangutans, siamangs, elephants, and giant pandas [Zoological Society of San Diego, 2007]. Visitors to these websites can then access information about the different species' natural histories and their status in the wild.

An important consideration is that non-natural technology and enrichment could negatively influence the zoo visitor. Naturalistic enclosure design has traditionally been used to foster appropriate visitor knowledge and attitudes [Finlay et al., 1988], and it is important to ensure that technological innovations do not interfere with this goal. Computer and television monitors, for example, are clearly not part of the natural landscape. However, one study found that non-naturalistic enrichment, such as colorful balls or barrels, did not affect visitors' perceived naturalism of the exhibit [McPhee et al., 1998]. This finding may generalize to technological enrichment, but research is necessary to evaluate whether these types of technological additions deter from the visitor's experience in any way.

As more technology is implemented in zoos, there is a need for a quantitative assessment of the impact of technology on visitor experience and education, as well as on visitor interest in conservation. Visitor surveys and observation of visitor-preferred locations and devices can also be used in zoos to assess zoo visitor behavior and preferences, much as they are used for other facilities such as museums [Goulding, 2000; Jansen-Verbeke and Rekom, 1996]. We recommend research that evaluates and compares technological innovations in exhibits to other less expensive, low-tech methods such as traditional signage, oral interpretations and training demonstrations. Also, the possibility that the technology at exhibits negatively impacts visitors should be thoroughly examined by measuring visitor satisfaction before and after the implementation of technological devices at exhibits. Finally, the impact of internet based webcams and zoo websites on the viewers should be assessed. Although this final suggestion may be the most challenging to implement, one option would be to have website visitors submit an online survey before and after viewing the website, enabling researchers to investigate the websites' effects on knowledge and conservation-oriented attitudes.

RESEARCH USING TECHNOLOGY

Technology can also be used to enhance another goal of zoological institutions: research. Animal cognition research, which can be challenging to undertake, could benefit greatly from the use of technology. For example, at the Primate Institute in Kyoto, chimpanzees are outfitted with microchips in their wrists which enable a computer to record individual-specific data on various tasks. In addition, the microchips allow the computer to activate tasks appropriate for that animal. Animals can work whenever they like, rather than having to comply with researcher schedules, and can also remain in their social groups. It has been shown that some socially housed animals will actually work more (thus providing researchers with more data) than animals that are isolated [Preilowski et al., 1988]; thus, technological devices such as the microchips just described can enhance not only animal welfare, but also the quality and quantity of data collected.

Finally, microchip implantation allows for computer programs to be individualized in a multitude of ways. For example, microchip implantation allows for control of the level of difficulty of various tasks according to the individual animal, as well as controlling the amount of food-rewarded trials a given animal can perform per day, which could mitigate the challenge of animals that overeat or otherwise dominate the computer platform. Similar technology has been employed at multiple institutions [Andrews, 1994] and can be used with other complex feeding devices and enrichment strategies [Hoy et al., 2006].

Computers have revolutionized the breadth of cognitive research questions which can be addressed noninvasively. In a recent study, virtually simulated environments were presented to four captive chimpanzees at the Language Research Center at Georgia State University to test their spatial cognitive abilities in comparison with those of children and adults [Dolins et al., in preparation]. Studies using virtual reality have shown that humans will navigate in three-dimensional space, despite the two-dimensional presentation, and that their cognitive and even neural processing reflects navigation in a real world situation [Maguire et al., 1996, 1997]. The four chimpanzees and sixteen humans tested in the virtual environments

displayed comparable navigational patterns and problem-solving, moving from the start position to localize the goal by attending to directional landmarks. Analyses of actual to optimally generated path lengths suggest no significant difference between the chimpanzees and human counterparts; the chimpanzees' path lengths were not significantly sub-optimal. Moreover, as environmental complexity increased, the chimpanzees' performance did not significantly differ from that of the humans in terms of decision-making at choice points or backtracking, indicating that they were not making more spatial errors than their human counterparts.

However, computer testing is not easy to implement for some species, such as those that are large, or that lack visual acuity or manual dexterity. Continued technological advancement could lead to better methods for conducting cognitive research in these animals. For example, one study has examined spatial recall ability in giant pandas using a matrix of lights [Perdue et al., 2009]. Technology was critical in developing the apparatus to test this ability in a species with little manual dexterity, and the results broadened our knowledge of spatial recall ability in giant pandas. Technological innovations are rapidly improving our ability to test a wider diversity of species.

It is imperative that the development of these technological devices for research is continuously monitored. The costs of such devices can be high, and maintaining them requires expertise and funding. Therefore, evaluating the utility of new innovations and sharing that information with others should be a part of any technological improvement undertaken by a zoo or laboratory facility. Furthermore, zoos should ensure that the use of technology for research purposes does not endanger the welfare of animals in any way.

ANIMAL WELFARE

Finally, and perhaps most importantly, technology can be used to directly influence an animal's welfare. This can be done in a variety of ways such as promoting behavioral diversity, increasing control and choice, and creating a cognitively complex environment. We should not overlook the fact that many demonstrably effective forms of enrichment are extremely low tech and less expensive (e.g. straw bedding for chimpanzees) [Baker, 1997], but technology provides many new and effective ways to enrich captive animals.

A major principle of conservation in zoos is that captive animals should be maintained in conditions that closely approximate their natural habitats and maintain behavioral diversity. Markowitz [1979] was the first to attempt to use computerized and mechanized technologies to encourage captive animals to engage in problem-solving and other natural behaviors such as working for food or, for predatory species, hunting behaviors. For example, a computer-controlled acoustic device encouraged African leopards to "hunt" based on the playback of bird sounds, resulting in increased activity and other behavioral indicators of well-being [Markowitz et al., 1995]. Another example was the installation of grip detectors in certain vines in a siamang exhibit which was accompanied by a program to reinforce a varying number of vine contacts. Once the appropriate number of vine contacts was reached, an audible tone signaled to the siamang that food would be delivered at a certain location in the exhibit [Markowitz, 1979, 1982]. This system succeeded in

increasing the siamangs' activity to more species-typical levels without detracting from the aesthetic naturalism of the enclosure.

A recent study investigated stereotypic pacing in tigers by placing magnetically locked feeding boxes, each containing meat, in different locations around the tigers' exhibit [Jenny and Schmid, 2002]. During random time periods an electronic timer turned the magnets off, making the food accessible. Regular investigation of the feeding boxes resulted in food delivery. This feeding method was compared with the conventional situation in which food is delivered by animal care staff once per day irrespective of the animals' behavior. The mechanized enrichment created a situation more similar to wild foraging conditions, and also allowed the tigers more control over the delivery of food. A significant reduction in stereotypic pacing occurred [Jenny and Schmid, 2002].

Other studies have evaluated the effects of different forms of auditory stimuli on captive exotic animal behavior and zoo visitor behavior. A study conducted at Zoo Atlanta used auditory playback of lion roars to enrich captive lion habitats. The results showed that the lions roared significantly more while not exhibiting an increase in any behaviors that would indicate compromised welfare [Kelling et al., 2007]. Similar studies have investigated the effect of ecologically and nonecologically relevant auditory enrichment in gorillas: infant stress-related behavior decreased during ecologically relevant auditory enrichment [Ogden et al., 1994], and adult abnormal behavior decreased although only marginally ($P = 0.07$) in the presence of ecologically and nonecologically relevant auditory enrichment [Wells et al., 2006]. Studies such as these demonstrate a continued interest in "naturalizing" mechanized enrichment devices and, importantly, in evaluating the devices' effects on behavior.

Another application of technology in captive environments is to increase the amount of control an animal has over its surroundings. Choice and control are important features of an enriched environment for captive animals. A substantial body of research supports the idea that control over the environment is important for animal welfare [Carlstead and Sheperdson, 2000]. In state-of-the-art facilities, control over elements such as room temperature, access to outdoor areas, access to social partners or to privacy, for example, permits animals to make choices about their physical and social environments.

Many institutions have implemented technological means to provide captive animals with more control of environmental features. At the Lincoln Park Zoo, apes can activate food dispensers by tapping artificial tree trunks or direct air blasts at zoo visitors. Los Angeles Zoo created devices that allowed their apes to pull ropes to ring bells located in visitor areas or to spray water on their viewers [Schencker, 2005]. At Zoo Atlanta and Miami Zoo, apes can activate a water sprayer that shoots jets of water at the public (personal observation, 2008). Apes at the Great Ape Trust in Iowa can choose foods from a food dispenser, choose whether or not to open doors for visitors, choose food items or other "gifts" for humans, or communicate to humans in the area using lexigram. However, it should be noted that not all forms of enrichment seem to be affected by the degree of control they afford [Bloomsmith et al., 2000]. This again points to the need for consistent evaluation of technological additions to zoological parks.

Although control of the environment may have implications for captive animals' psychological welfare, opportunities for increased physical activity are also important. Failing to provide these opportunities can lead to obesity problems

[Hosey, 2005; Schwitzer and Kaumanns, 2001]. Although their wild counterparts devote a high percentage of time to foraging, captive animals provided with nutritionally balanced diets are not required to “work” for their food. Activity has been increased for some animals by using technology, such as Markowitz’s previously discussed design for siamangs [Markowitz, 1979, 1982], and these applications can be used to improve physical health in captive environments.

Another challenge in housing captive species is to create more problem-solving opportunities. One method that has been used to increase problem-solving opportunities is to provide access to computerized tasks such as match-to-sample tasks, mazes, or number recognition tasks. Computer-task availability has been shown to have many positive effects such as the reduction of abnormal behavior in rhesus macaques [Washburn and Rumbaugh, 1992]. In studies of captive animals given a choice of either food presented or having to work to obtain food systematically it has been found that these animals choose to work for their food, a behavioral phenomena called “contrafreeloading” [Neuringer, 1969; Young, 1999]. Even in social environments, monkeys will continue to work on computerized tasks at a high rate for food rewards despite being given access to normal daily rations [Washburn et al., 1994].

Computers may provide an effective way to encourage captive animals to solve complex problems, and because task difficulty can be altered to suit different species or even individuals, computers may provide an easy method to accommodate individual differences in problem-solving ability. Such cognitive challenges are important for maintaining psychological health and behavioral diversity in captive species. For example, the neuroprotective value of challenging problem-solving tasks has been demonstrated in rodents, humans, and nonhuman primates [Milgram et al., 2006].

Computer-created virtual environments may also provide additional problem-solving opportunities for captive animals. As previously discussed, Dolins et al. [in preparation] found that chimpanzees and humans respond similarly to a computer-based virtual environment. One benefit of providing virtually real landscapes to captive primates and possibly other captive animals is that this could allow us to extend space-limited captive environments to perceptually larger and more complex space than may be possible in their immediate physical world. Other possibilities include creating social stimuli by presenting virtual environments in which animals can navigate to a virtual room where real-time footage of otherwise nonviewable conspecifics could be provided.

The use of computers as enrichment, however, particularly necessitates continuous evaluation. This is chiefly because of the cost involved in acquiring, setting up, and maintaining computers for animal use. In addition, computerized testing has in some cases induced behaviors typical of stress and frustration in great apes, as indicated by vigorous scratching in orangutans [Elder and Menzel, 2001; Tarou et al., 2004]. Some studies have reported increased stress due to increasingly difficult tasks [Honest and Marin, 2006; Leavens et al., 2001]. Computer-task availability has also increased aggression in conditions where the number of animals outweighs the number of available computers [Tarou et al., 2004]. However, providing multiple systems as well as providing systems in different locations of the enclosure has been shown to increase the overall use of computers by groups of pigtail macaques [Lincoln et al., 1994] and to decrease aggression in orangutans [Mallavarapu and Kuhar, 2005], as individual animals can then access computers without any one animal being able to monopolize all the available systems.

In addition to critically evaluating computers, other types of technological enrichment need to be considered. Implementing any kind of technological device can be expensive, and providing the animals with different options (such as air blast activators, temperature gradients and foraging devices) should be evaluated to determine the most practical, effective, and inexpensive ways to increase species-typical behavior in captive animals. Post-Occupancy Evaluations can be used to assess the effectiveness of new exhibit designs or new additions to old exhibits by comparing use of a space before and after changes have been implemented [Chang et al., 1999; Ross and Lukas, 2006]. It is also important to evaluate individual differences in response to different forms of enrichment and different types of technology. For example, in a captive chimpanzee colony allowed access to puzzle feeders, though group levels of aggressive and abnormal behavior did not change, individual levels often did change significantly; in some cases these undesirable behaviors increased, and in others they decreased [Bloomstrand et al., 1986].

One benefit of consistently evaluating new methods of using technology to enrich animal environments is that it allows for the development of more cost-effective and time-efficient methods for achieving behavioral diversity, for example, using enrichment devices that provide variable, noncontinuous reinforcement by providing unpredictable food resources [Jenny and Schmid, 2002; Tarou and Bashaw, 2007]. For example, programmable timers could be wired into puzzle boxes that only allow reinforcement to be obtained at certain times. Researchers could then test different schedules of reinforcement to see which resulted in more species-typical behavior and which resulted in longer-term beneficial effects for the animals using the device. Long-term evaluations need to be applied to ensure sustained effects of enrichment, such as have been demonstrated with some forms of feeding enrichment [Bashaw et al., 2003].

SURVEY: USE OF AND ISSUES WITH TECHNOLOGY IN CAPTIVE ANIMAL FACILITIES

In a preliminary effort to assess the issues involved in using technology in captive animal facilities, five institutions housing ape species were surveyed. The surveys were intended to measure the diversity of technology currently in use at these institutions, to gather information about staff's feelings about the technology, to identify problems inherent in using this technology, and to delineate possible limiting factors in the adoption of additional technology. Although this is a preliminary survey of a small set of institutions, the results were illustrative as several common trends in responses emerged.

A large variety of technology was in use at these facilities with the most commonly used technology (reported used by at least four of the five institutes) being televisions, sprinklers/water blasters, radios/other audio, and computers as used for data collection. The use of televisions and radios was reported to be least problematic for staff. Respondents were also asked whether the use of technological enrichment was being empirically investigated (Table 1). Responses about empirical investigation varied but indicated that some evaluation is taking place, especially with regard to computer use.

TABLE 1. Survey Results

Type of enrichment	Enrichment provided to animals?	Enrichment used by animals?	Reported problems with enrichment	Evaluation?	Allow for interaction with humans?
TV	5	4	1	1	2
Sprinklers	4	3	3	2	1
Temperature	0	—	—	—	—
Animal controlled doors	1	1	1	1	0
Audio/radio	4	3	1	1	1
Foraging	1	1	1	1	0
Air blasters	0	—	—	—	—
Communication	2	2	1	2	0
Radio collars	0	—	—	—	—
Computer as enrichment	2	2	1	1	2
Computer for data collection	4	4	2	4	4
Other	1	1	1	1	1

Number of institutions (out of five) reporting whether different types of technological enrichment are provided to animals, actually used by the animals, cause problems, are empirically investigated, and whether it allows for interactions with humans.

Unanimously, staff reported favorable attitudes toward the use of technology, with all reporting institutions responding that, if possible, they would increase the availability of the technology to the animals. However, the use of technology does present problems. The most common problem reported is that the technological devices being used are designed for people, not apes. This leads to various issues such as equipment breaking due to use by apes or “animal frustrations” due to animals using equipment designed for more dexterous (and less physically strong) humans. To mitigate problems due to the strength and destructive capacity of apes, for example, touch screen computers for orangutans at Zoo Atlanta required extensive modification of caging and of the computers themselves. Specifically, the screen mesh around animals’ indoor cages had to be modified, protective barriers had to be designed to protect the computer screen, and a network of PVC pipes had to be arranged to protect computer cords (personal observation, 2008). Other issues reported by surveyed institutions included equipment breaking down with no one available and/or capable of making repairs; software incompatibility; microchips migrating under the skin of animals; equipment being difficult or time-consuming to set up; and equipment being difficult to integrate with existing facility structures.

Respondents were also asked to describe limiting factors for implementing new technology. Most respondents indicated that cost is the primary limiting factor. Other limitations reported included lack of animal care staff time, technological assistance, expertise in building devices, ape-proof hardware, and appropriate space and structure in animal areas. However, staff members at the surveyed facilities generally stated that technology-based enrichment is worth the associated costs.

Our survey of several institutions reveals that despite some problems, technology is frequently used to enrich captive animals. Future research should address a wider variety of species and include zoos outside of North America.

Advances in technology have the potential to greatly improve visitor education, animal welfare, and research programs in zoological parks. Continued evaluation can increase shared knowledge regarding how technology is currently used and expand possibilities for extending this use in zoos.

CONCLUSIONS

- Technology has been used in a variety of ways in zoos, including: to improve visitor experiences; to increase research opportunities; and to enhance animal welfare.
- Systematic and quantitative evaluation is needed to monitor the effectiveness and efficiency of each new innovation, especially as compared with lower cost, low-tech methods.
- Of a small number of institutions surveyed, all reported they currently use technology to improve the lives of their ape species and would increase technology use if possible; however, few reported engaging in systematic evaluation of enrichment devices.

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