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Research article

The impact of immersive exhibit design on visitor behaviour and learning at Chester Zoo, UK

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Abstract

As extinction rates accelerate, zoos have evolved from places for public entertainment to centres of conservation, education and research. Zoo-based learning is inherently 'free-choice', meaning it is subject to visitors' personal experiences, knowledge and agendas. Naturalistic, 'immersive' exhibits are commonplace in modern zoos and should provide the sense of discovery that maximises free-choice learning. Chester Zoo is developing 'Grasslands', a multi-species, immersive exhibit based on African savannahs, due to open in 2023. To assess the educational potential of Grasslands, this study uses a mixed-methods approach combining quantitative visitor observation data with Personal Meaning Mindmaps (PMMs) and qualitative surveys to compare visitor learning at three Chester Zoo exhibits housing charismatic grassland megafauna. 'The Giraffe House' is a traditional, 'second-generation' exhibit lacking naturalistic features, whereas 'Mkomazi Painted Dog Reserve' is an immersive, 'third-generation' exhibit. 'Tsavo Black Rhino Reserve' is a functional but aesthetically pleasing exhibit, treated as an intermediate. While visitor 'dwell time' was almost five times higher at The Giraffe House than Mkomazi, visitors were more than twice as likely to engage with interpretation at Mkomazi than The Giraffe House and spent significantly more time doing so at Mkomazi than any other exhibit. Survey data revealed occasional, modest increases in knowledge at Mkomazi and Tsavo, while there was no evidence of increased knowledge at The Giraffe House. A tentative link between engagement with interpretation and learning outcomes can therefore be drawn. Providing attractive and engaging interpretive elements should therefore be central to the design of new exhibits.

Introduction

Species extinction rates may be 100 times the background average, and continue to increase (Nakamura et al. 2013; Urban 2015). In this context, zoos have evolved from places for public entertainment to centres of conservation, education and research (Roe et al. 2014). Modern zoos place great importance on their role in improving the 'biodiversity literacy' of the general public (Moss et al. 2014), and references to education are near-ubiquitous in zoo mission statements, particularly in the English-speaking western world (Moss and Esson 2013). For example, Patrick et al. (2007) found that 131 of 136 mission statements in North American zoos mentioned education in 2004, which was more frequent even than references to conservation (118 out of 136). Furthermore, a follow-up study found that by 2014 the prevalence of references to conservation-specific education in zoo mission statements had increased from 16% (n=22) to 80% (n=108; Patrick and Caplow 2018).

Worldwide, zoos receive approximately 700 million visits annually (Gusset and Dick 2010), representing diverse socioeconomic backgrounds, baseline knowledge and visit agendas (Davey 2007; Falk et al. 2007; Roe and McConney 2015). Therefore, zoos have considerable potential as centres of conservation education. However, quantifying the educational impact of zoos is complicated by the 'free-choice' nature of learning in these settings (Falk and Dierking 2002; Falk 2005; Kola-Olusanya 2005). That is, learning in zoos is visitor-driven and subject to the diverse learning styles, life experiences and motivations of individual visitors (Packer and Ballantyne 2002; Ballantyne et al. 2007). Zoo visits can be highly conducive to free-choice learning because the duration, content, and pacing of zoo visits are primarily determined by the visitor (Clayton et al. 2009; Moss and Esson 2013). Exhibits themselves form part of the 'educational landscape' of zoos and should be designed with free-choice learning in mind (Moss et al. 2010). Packer (2006) identified four conditions that facilitate free-choice learning, including a sense of discovery, an appeal to multiple senses, the appearance of effortlessness, and the availability of choice. Modern, 'third-generation' zoo exhibits typically attempt to create these conditions through what is termed immersive design, in which exhibits replicate the natural habitat of species while minimising visible barriers between visitors and animals (Moss et al. 2010). This contrasts with more traditional, 'second generation' exhibits, which are generally functional in design and lack naturalistic materials or features. Free-choice learning theory suggests that immersive third-generation exhibits should therefore be more effective in educating zoo visitors.

Comparative studies of second- and third-generation zoo exhibits to date suggest that there may be an educational benefit to immersive exhibit design, although these have generally focused on visitors' self-reported attitudes towards exhibits (Wilson et al. 2003; Nakamichi 2007), or on visitor time budgets and behaviour rather than by directly quantifying visitor learning (Moss et al. 2010). These studies rarely combine quantitative data from visitor observations with qualitative and/or quantitative assessments of what, if anything, visitors are learning. Qualitative assessments of visitor knowledge can provide rich datasets that can account for differences in visitors' baseline knowledge and experiences that are central to free-choice learning (Falk 2005). One such method is Personal Meaning Mindmaps (PMMs; Falk et al. 1998). PMMs were originally devised to assess visitor education in museums and have been somewhat overlooked in zoo studies in favour of traditional methods such as visitor observations. One notable exception was a small-scale study at the immersive 'BUGS' exhibit at London Zoo (Chalmin-Pui and Perkins 2017), which found that this third-generation exhibit improved visitor knowledge and understanding of biodiversity, and that the open-ended nature of PMMs allowed visitors to freely express their impressions of the exhibit and of their own learning experience. Therefore, PMMs can be an effective method of assessing free-choice learning, particularly when complemented with quantitative methods, such as covert observations.

We use a mixed-methods approach, combining covert observations with PMMs and questionnaires designed to quantitatively and qualitatively assess visitor knowledge at three exhibits at Chester Zoo, UK. Chester Zoo is developing 'Grasslands', an immersive, multi-taxa exhibit based on East African savannahs that will open in 2023. To provide insight into the educational potential of Grasslands, exhibits displaying charismatic East African megafauna that will be featured in Grasslands were selected for this study. These include a traditional second-generation exhibit housing giraffe *Giraffa camelopardalis*, an immersive third-generation exhibit displaying painted dogs *Lycaon pictus*, and a modern yet functional exhibit housing black rhinoceros *Diceros bicornis*, treated as an intermediate. Visitor behavioural responses may be influenced by species preferences (Carr 2016), and this study does not make generalised claims about the educational impact of all immersive exhibits across multiple institutions. However, the hypothesis for this study was that improvements in visitor knowledge and understanding of displayed species, assessed by pre- and post-visit surveys, would be greatest at the immersive painted dogs exhibit and lowest at the second-generation giraffe exhibit. Attraction power (percentage of visitors who stop to view animals or engage with exhibit interpretation), hold time (time visitors spend viewing animals or engaging with interpretation) and dwell time (time visitors spend in an exhibit overall) were also predicted to be highest at the painted dogs exhibit and lowest at the giraffe exhibit, after correcting for visitor capacity (indoor floor space).

Methods

Study site

Data were collected between May and July 2019 at three Chester Zoo exhibits: The Giraffe House (TGH), Tsavo Black Rhino Reserve (TBRR), and Mkomazi Painted Dog Reserve (MPDR) (Figure 1).

TGH is a second-generation exhibit with brick walls, concrete flooring and metal fencing separating animals from visitors. A large outdoor area of grass and sand is encircled by a shallow moat. Indoor interpretation consists of five large signs covering basic giraffe biology, husbandry and conservation. All indoor signage in TGH is mounted on the back wall, behind visitors as they view giraffes (Figure 2a). At the time of the study, TGH housed 10 giraffes, including two babies.

TBRR housed three mother-infant pairs and one adult male rhino in four large outdoor paddocks. Two mother-infant pairs shared the indoor area open to the public, with sections separated by wooden fencing. The indoor area is functional, but the wooden fencing, curved walls and thatched roof are aesthetically pleasing and evocative of East Africa. Interpretation comprises of a small species information card, a board with hand-drawn sketches and notes on individual rhinos, and a large 'book of field notes' and binoculars embedded into the wooden fence (Figure 2b-c).

MPDR is named after Mkomazi National Park in Tanzania, where Chester Zoo and partners conduct research and conservation to re-establish viable painted dog populations. This immersive third-generation exhibit housed a breeding pair and six offspring. Artificial boulders evocative of East African landscapes surround the exhibit, with large glass windows offering unobstructed views into the enclosure. The indoor section imitates an East African field station, with wooden walls, corrugated iron roofing and windows into an artificial 'burrow' where the pack often sleeps. Nine large interpretive signs covering painted dog ecology, husbandry and conservation follow Chester Zoo's colourful branding (Figure 2d). Additional interpretation includes a small cinema (featuring a five-minute documentary narrated by Martin Clunes).

Sampling methodology

Covert observations

Covert visitor observations were conducted in indoor exhibit areas to assess visitor behaviour in each exhibit. Visitors were selected for observation as they entered indoor exhibit areas using a continual selection method (Moss and Esson 2010). Only one individual from each group of visitors was selected for observation, with the first member of the group to enter the exhibit being selected. No evidently vulnerable adults or minors were observed.

Covariates including animal activity, animal proximity, approximate visitor age and assumed gender were determined visually (Table 1). To minimise 'social desirability bias', in which visitors alter their behaviour according to perceived social norms or expectations (Grimm 2010), the researcher wore plain clothes and cases where uniformed zoo staff were present were excluded. Covert observations recorded 'attraction power', 'hold time' and overall 'dwell time' at each exhibit (Serrell 1998). Attraction power (the percentage of visitors who stopped) was calculated separately for animal viewings and engagements with interpretation according to a binary scale (0=did not stop, 1=stopped). Visitors were recorded as 'stopped' if they paused within 3 m of, and facing, an animal viewing point or an interpretive element for at least 2 sec. Hold time was calculated as the total time visitors spent either viewing animals or engaging with interpretation. Dwell time was the total time visitors spent in the indoor area.

Visitor surveys
Visitor surveys were conducted at the entry and exit points of each exhibit, incorporating both indoor and outdoor areas. Covert observations and visitor surveys were conducted separately on different participants, so observed and surveyed visitors formed independent groups. The same selection criteria as described for covert observations were applied to surveys. While repeated measures survey designs are recommended for zoo visitor education studies (Mellish et al. 2019), repeating surveys within a short space of time can create a 'priming' effect where

Figure 1. Photographs of the outdoor (a, c, e) and indoor (b, d, f) areas of the three exhibits: The Giraffe House (a-b), Tsavo Black Rhino Reserve (c-d), and Mkomazi Painted Dog Reserve (e-f).

participants' scores are inflated in the second survey (Chalmin-Pui and Perkins 2017). Therefore, different participants were surveyed at the entry and exit of exhibits. Participants completed surveys independently of the researcher, to minimise social desirability bias. A survey acceptance log was maintained throughout.

Visitor surveys were in paper format and comprised of three sections. Section 1 collected demographic information on gender, age, group type, Chester Zoo membership and visit frequency (Table 1). Section 2 was a PMM (Falk et al. 1998). Participants were asked to create a mindmap of phrases or concepts that they associated with the species displayed at the exhibit. Section 3 was an open-ended questionnaire that assessed visitors' understanding of conservation and pro-conservation behaviours, habitat preferences and threats to species, and in situ and ex situ conservation actions conducted by Chester Zoo and partners. Survey responses were digitised into an MS Excel spreadsheet.

After completing the survey, participants were invited to elaborate upon any concepts included in their PMM. If no elaboration was forthcoming, the researcher selected a concept from the participant's PMM and encouraged them to elaborate on this concept. Relevant elaboration was noted by the researcher in pencil to distinguish from the participant's original PMM, which was completed in pen (Figure 3). After Falk et al. (1998), PMMs measured four dimensions of knowledge: extent, range, depth and mastery:

- Extent: The total number of relevant responses provided in the PMM.
- Range: The number of distinct concepts in the PMM, derived from content analysis.
- Depth: The amount of elaboration provided by the participant, measured on a 0–4 scale.
- Mastery: The complexity of vocabulary and concepts included in the PMM, including those mentioned during elaboration.

Figure 2. Comparison of typical interpretive signage at the three study exhibits. At TGH (a) large, attractive signage is installed on the back wall behind visitors as they view giraffes. At TBRR, interpretation includes a mock 'book of field notes' (b) and a small species information sign lacking Chester Zoo branding (c). At MPDR, several large, striking signs cover a range of topics including painted dog ecology, husbandry and conservation (d).

Table 1. Categorisation of explanatory variables for covert observations and visitor surveys. [a]Determined visually for covert visitor observations and occasional errors may have occurred. Self-reported for visitor surveys. [b]Treated as continuous variable in data analysis due to small cell sizes. [c]As measured from nearest indoor viewing point.

Variable	Categorisation
Gender[a]	0=Male
	1=Female
Age (years)[a]	1=18–30
	2=31–45
	3=46–60
	4=61+
Animal activity[b]	1=Animal not visible
	2=Sleeping
	3=Awake, not moving
	4=Awake, moving around
Animal proximity[b,c]	1=Animal not visible
	2=Back third of exhibit
	3=Middle third of exhibit
	4=Front third of exhibit
Membership	0=Non-members
	1=Chester Zoo members
Visitation rate	1=First time
	2=Less than once per year
	3=Once a year
	4=At least twice a year

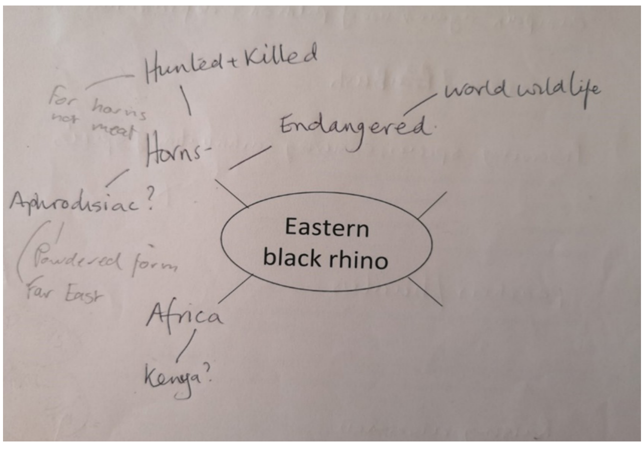

Figure 3. Example of a completed Personal Meaning Mindmap (PMM) from Tsavo Black Rhino Reserve. This is a relatively high-scoring example: Extent=6, Range=5, Depth=2, Mastery=3.

Mastery was measured on a 0–4 scale. Ethical approval for this study was provided by both Chester Zoo and the Faculty of Biological Sciences Research Ethics Committee at the University of Leeds (reference BIOSCI 18-028).

Data analysis

Covert observations

All statistical analyses were conducted in IBM SPSS 25. Attraction power, for both animal viewing and engagement with exhibit interpretation, was analysed using binary logistic regression with significance determined by Wald χ^2 tests. Observations where animals were not visible were excluded for animal viewings, but not engagement with interpretation. Attraction-power (0=did not stop, 1=stopped) was modelled against the explanatory variable exhibit, along with animal proximity, animal activity, visitor age and gender. Due to small cell sizes, interaction terms were omitted, and variables of animal activity and proximity were treated as continuous. To achieve a more parsimonious model, the demographic variables of age and gender were removed sequentially if non-significant (after Bonferroni correction for multiple tests) to produce a minimum adequate model (MAM). Exhibit, activity and animal proximity were always retained in the MAM as the primary variables of interest. Bonferroni-adjusted P values are cited here, according to the number of variables retained in the MAM.

All measures of hold time and dwell time were highly heteroscedastic. Generalised linear models (GzLMs) were used to analyse these data: for each dependent variable, models using normal and gamma error distributions were compared using Akaike Information Criterion (AIC; Akaike 1974), and models using ln-transformed data were compared with untransformed data using Equation 1.

Equation 1: $$AIC_x = AIC_y + 2(\sum \ln(x))$$

where x=untransformed data, AIC_x=AIC for untransformed data and AIC_y=AIC for transformed data (Akaike 1978). The best fitting combination of error distribution and transformation was then used in the analysis. The same explanatory variables used for attraction power were used for hold and dwell time, and interactions between exhibit and other explanatory variables were included here.

Lowest AIC was observed using gamma distribution with log link for animal viewings, and normal distribution with identity link using transformed data for both engagement with interpretation and overall dwell time. Once the suitable model type had been selected, backwards model simplification was performed where non-significant terms were removed sequentially to produce a MAM. Due to inherent heteroscedasticity in the data, robust standard error estimates were generated for all models. For animal viewings and engagement with interpretation, only visitors who stopped were included in the model and zero values were removed.

Visitor surveys

Following a constructivist approach to quantifying learning in an informal setting, PMMs were analysed using inductive content analysis (Lelliot 2009; Bengtsson 2016). PMM concepts were categorised continuously, rather than assigning responses to pre-conceived categories. Categorisation was reviewed three times throughout the data collection process by the principal researcher (TS), and responses were re-categorised whenever new patterns emerged in the data (Bengtsson 2016). PMM responses were divided into categories (e.g., Behaviour) and sub-categories (e.g., Social behaviour; Supplementary Info 3). The total number of relevant PMM responses prior to elaboration produced scores for extent of knowledge. The number of distinct sub-categories included in PMMs prior to elaboration provided scores for range of knowledge. Depth and mastery of PMM responses were scored using a 0–4 scale, as were responses to open-ended questions on conservation, pro-conservation behaviours, species habitat preferences and threats. Questions asking participants to name in situ and ex situ conservation actions of Chester Zoo and partners were also open-ended, however no single action was considered more important than any other, and these responses were converted to binary format (0=incorrect, 1=correct). To ensure reliability and repeatability of scoring, approximately 20% (n=60) surveys were re-coded by a second researcher working at Chester Zoo. PMM depth, mastery and all open-ended questions were re-coded, and Cohen's Weighted Kappa (K) was calculated to assess inter-coder reliability.

PMM extent and range scores at exhibit entry and exit points were compared using analysis of variance (ANOVA) when data met ANOVA assumptions. In these cases, covariates of visitor age, gender, group type, membership and visitation rate (Table 1) were included alongside the independent variable of position (0=entry, 1=exit), followed by backwards model simplification. When no transformation rendered the data suitable for ANOVA, non-parametric Mann-Whitney U tests were performed with position as the explanatory variable. PMM depth and mastery scores were analysed using ordinal logistic regression. Questionnaire responses were analysed using ordinal and binary logistic regressions, depending on the question.

Results

Covert observations

A total of 1,546 visitors were observed across the three exhibits: 510 at TGH, 519 at TBRR, and 517 at MPDR. Attraction power for viewing animals was highest at TBRR, followed by TGH and MPDR (Figure 4a). Mean animal activity and proximity were both highest at TGH, followed by MPDR and TBRR. Attraction power was significantly higher at TBRR than both TGH (Wald $\chi^2_{(1)}$=101.1, P<0.001) and MPDR (Wald $\chi^2_{(1)}$=191.3, P<0.001), after controlling for animal activity and proximity (Figure 4a). Attraction power of exhibit interpretation differed significantly between exhibits (Wald $\chi^2_{(2)}$=32.4, P<0.001), and was highest at MPDR, followed by TBRR and TGH (Figure 4a). After controlling for the significant effects of group type, the odds of a visitor engaging with interpretation was 1.79 (95% CL 1.26–2.56) times and 2.55 (95% CL 1.85–3.52) times higher at MPDR than at TBRR and TGH, respectively. Gender and age were not retained in the MAM for attraction-power for either animal viewings or exhibit interpretation.

Mean hold time for animal viewings was highest at TGH (118.2 seconds, 95% CL 106.3–130.1), followed by TBRR (72.0 seconds, 95% CL 65.6–78.5) and MPDR (49.7 seconds, 95% CL 45.1–54.3; Figure 4b). A significant interaction between exhibit and animal activity was detected here (Wald $\chi^2_{(2)}$=14.6, P=0.004), after controlling for animal proximity. Perhaps surprisingly, the positive effect on hold time of increased animal activity was much weaker at MPDR than at either TGH or TBRR. Mean hold

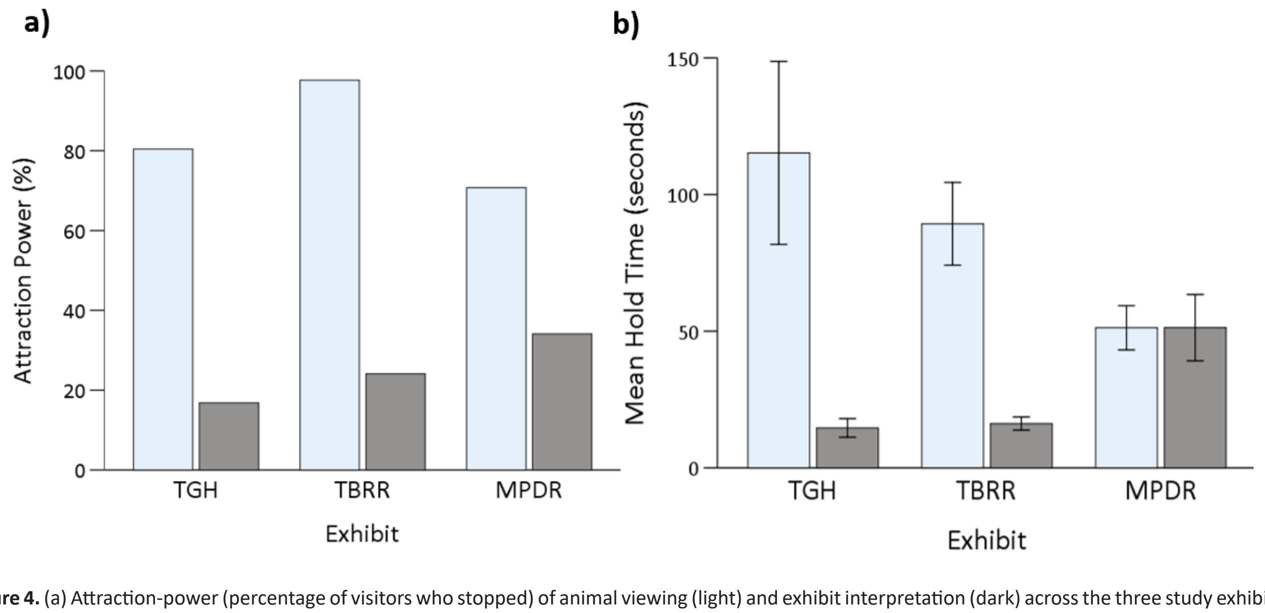

Figure 4. (a) Attraction-power (percentage of visitors who stopped) of animal viewing (light) and exhibit interpretation (dark) across the three study exhibits. Instances where animals were not visible were excluded for animal viewings but included for engagement with interpretation. (b) Hold time (seconds) for animal viewings (light) and engagement with exhibit interpretation (dark) across the three study exhibits. Error bars mark the 95% confidence intervals.

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time for engagement with exhibit interpretation was highest at MPDR (48.8 seconds, 95% CL 37.9–59.6), followed by TBRR (16.0 seconds, 95% CL 13.6–18.4) and TGH (15.6 seconds, 95% CL 12.2–18.9; Figure 4b). Mean hold time was significantly higher at MPDR than both TGH (Wald $\chi^2_{(1)}$ =30.2, P<0.001) and TBRR (Wald $\chi^2_{(1)}$=19.8, P=0.003).

Mean dwell time per unit area was higher at TGH (3.82 seconds/m^2, 3.49–4.16), than TBRR (2.17 seconds/m^2, 2.02–2.32) or MPDR (0.78 seconds/m^2, 0.72–0.84). As with hold time of animal viewings, a significant interaction between exhibit and animal activity was detected (Wald $\chi^2_{(2)}$=97.1, P<0.001), after controlling for animal proximity. This interaction followed the same pattern as hold time animal viewings, with the positive effect on dwell time of increased animal activity being considerably weaker at MPDR than at the other exhibits. Again, the demographic variable of gender and age were non-significant and not retained in the MAM for hold time of either animal viewings or exhibit interpretation. The demographic variables of age and gender, and their associated interactions, were non-significant in all cases and were removed from the MAM for all attraction-power, hold time and overall dwell time models.

Visitor surveys

A total of 320 visitors completed surveys, with 52–58 surveys completed at the entry and exit points of each exhibit. Acceptance rate was 80.5%. A total of 1,653 valid PMM responses were divided into 15 categories and 49 sub-categories. Here the effect is described of exhibit on survey responses when controlling for any significant demographic variables following backwards model simplification. Tables 2–4 show where such variables were significant. Extent and range scores did not significantly change at any exhibit. No significant changes in either depth or mastery scores were detected at TGH. Mean (95% CL) depth scores significantly increased at TBRR from 1.50 (1.16–1.84) to 2.04 (1.69–2.39; Wald $\chi^2_{(1)}$=4.4, P=0.037). At MPDR, mean (95% CL) Mastery scores increased significantly from 2.04 (1.76–2.31) to 2.36 (2.13–2.59; Wald $\chi^2_{(1)}$=4.4, P=0.036; Table 2).

TBRR significantly improved participants' ability to identify an ex situ conservation action by Chester Zoo and partners (Wald $\chi^2_{(1)}$=6.0, P=0.028). At MPDR, the odds of participants identifying an in situ conservation action were 2.38 (1.05–5.38) times higher for post-visit than pre-visit (Wald $\chi^2_{(1)}$=4.3, P=0.038; Table 3). By contrast, TGH did not significantly affect participants' ability to

Table 2. Summary of PMM scores for extent, range, depth and mastery at entry and exit points of the three study exhibits. Test statistics for ANOVA, Mann-Whitney U tests and ordinal logistic regression are presented. *Marginally non-significant effect of position (entry and exit) at 0.05<P< 0.1. **Significant effect of position at P≤0.05, [a]Significant effect of age at P≤0.05, [gt]Significant effect of group type at P≤0.05, [v]Significant effect of visitation rate at P≤0.05.

						Test statistics		
Dimension	Exhibit	Position	Mean	SE	95% CI	Test	df	Adj. P
Extent	TGH	Entry	5.13	0.45	4.24–6.03	Z=-0.750	1	0.453
		Exit	4.94	0.42	4.09–5.79			
	TBRR	Entry	4.43	0.39	3.66–5.20	F=0.276	1	0.600
		Exit	5.33	0.46	4.42–6.25			
	MPDR	Entry	4.89	0.50	3.88–5.89	F=2.839	1	0.181[gt]
		Exit	6.44	0.51	5.42–7.46			
Range	TGH	Entry	3.19	0.26	2.66–3.72	Z=-0.017	1	0.987
		Exit	3.12	0.19	2.74–3.49			
	TBRR	Entry	3.73	0.33	3.08–4.39	Z=-1.481	1	0.139
		Exit	4.45	0.35	3.75–5.16			
	MPDR	Entry	3.72	0.33	3.05–4.39	F=3.273	1	0.074*
		Exit	4.66	0.30	4.06–5.26			
Depth	TGH	Entry	1.17	0.13	0.90–1.44	X^2=0.179	1	0.672
		Exit	1.31	0.17	0.97–1.64			
	TBRR	Entry	1.50	0.17	1.16–1.84	X^2=4.350	1	0.037**
		Exit	2.04	0.17	1.69-2.39			
	MPDR	Entry	1.21	0.17	0.87–1.54	X^2=2.333	1	0.0238[gt]
		Exit	1.50	0.15	1.19–1.81			
Mastery	TGH	Entry	1.90	0.11	1.67–2.13	X^2=2.237	1	0.358[a,v]
		Exit	2.04	0.11	1.83–2.25			
	TBRR	Entry	2.20	0.15	1.90–2.50	X^2=3.046	1	0.081*
		Exit	2.61	0.12	2.38–2.84			
	MPDR	Entry	2.04	0.14	1.76–2.31	X^2=4.381	1	0.036**
		Exit	2.36	0.11	2.13–2.59			

identify any conservation actions for giraffes. Content analyses revealed that 52 (38.2%) of 136 correct answers for in situ conservation actions referred to breeding programmes. Beyond this, only education of local people featured in more than one-fifth of correct responses (n=31, 22.8%). Ex situ conservation actions identified by visitors were even more dominated by breeding programmes, with 185 (86.0%) of 215 correct responses identifying breeding of zoo populations as an ex situ conservation action conducted by Chester Zoo. This is despite just one of seven unique interpretive signs at TGH (indoor and outdoor), one of nine at MPDR, and none at TBRR explicitly referring to breeding programmes supported by Chester Zoo. Notably, only five visitors (2.3% of correct responses) identified research as a conservation action performed by the Zoo.

Open-ended questions assessed visitors understanding of conservation, pro-conservation behaviours, habitat preferences and threats to species in the wild, and were scored using a 0–4 scale. MPDR significantly improved participants' ability to identify pro-conservation and post-visit surveys found no significant effect of TGH on scores for any open-ended question (Table 4).

Inter-coder reliability for PMM and survey scores varied (K=0.61–1). There was a moderate to good level of agreement for most scores (K>0.7 in all but one case), although this is still sub-optimal and results should be interpreted with care, particularly for scores where visitors were asked to define the word 'conservation', where K=0.61.

Discussion

The findings of this study provide some support for the hypothesis that the immersive, third-generation MPDR would be more effective at educating visitors than the second-generation TGH or the intermediate TBRR. A tentative link may be drawn between engagement with exhibit interpretation and increases in visitor knowledge assessed by PMMs and open-ended questions. Covert observations revealed greater engagement with interpretive materials at MDPR than at any other exhibit (Figure 4), which may be due to its attractive, branded signage and the inclusion of multi-sensory interpretive elements such as a small cinema. By contrast, interpretation at TBRR lacked attractive branding, and at TGH signage was placed behind visitors as they viewed animals. Retrofitting exhibit interpretation may increase the educational potential of these exhibits, as demonstrated previously at Chester Zoo (Moss et al. 2010). Shortly after data collection was completed, interpretation at TBRR was updated with Chester Zoo branding, and future studies could use data presented here to compare visitor engagement with old interpretive elements and the current, branded signage.

By contrast, dwell time per unit area was almost five times higher in TGH than MPDR, and visitors spent more time viewing animals here than anywhere else. These results contradict several previous studies (e.g., Moss et al. 2010), which found that visitors spend more time in third-generation than second-generation exhibits, even when correcting for floor space. The unexpected findings may be due to differences in visitor species preferences, a limitation which is discussed below. However, visitor surveys found no evidence of increased knowledge at TGH. Time spent at an exhibit, therefore, is a poor indicator of visitor learning. Engagement with explicitly educational elements such as signage may be a more informative measure of visitor learning, although this must be complemented by methods such as surveys to confirm that learning has occurred (Moss et al. 2010).

Mean scores for PMM extent, range, depth and mastery consistently increased post-visit compared to pre-visit at MPDR and TBRR but remained stable or even decreased slightly at TGH (Table 2). Improvements in depth and mastery scores at MPDR and TBRR suggest that these exhibits added depth and precision to concepts which visitors already understood, such as rhino

Table 3. Binary logistic regression results for questions identifying in situ and ex situ conservation actions conducted by Chester Zoo and partners (0=incorrect, 1=correct). N^c Number of correct responses. N^i Number of incorrect responses. *Marginally non-significant effect of position (entry and exit) at 0.05<P< 0.1, **Significant effect of position at P≤0.05, [g]Significant effect of gender at P≤0.05

						Test statistics		
Question	Exhibit	Position	N^c	N^i	% Correct	Wald χ^2	df	Adj. P
Identifying in situ action.	TGH	Entry	13	38	25.4	1.172	1	0.279
		Exit	19	33	36.5			
	TBRR	Entry	24	33	42.1	4.075	1	0.088*,g
		Exit	31	21	59.6			
	MPDR	Entry	20	33	37.7	4.304	1	0.038**
		Exit	27	27	50.0			
Identifying ex situ action.	TGH	Entry	34	17	66.7	0.185	1	0.667
		Exit	36	16	69.2			
	TBRR	Entry	38	18	67.9	5.989	1	0.028**g
		Exit	47	6	88.7			
	MPDR	Entry	26	26	50.0	3.389	1	0.066*
		Exit	36	18	69.2			

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poaching or the social behaviour of painted dogs. There could be two possible explanations for this: visitors may preferentially engage with topics in which they have an existing interest, or already understand to some extent, and are less likely to engage with 'new' topics of which they have no understanding. This would be in line with the constructivist nature of free-choice learning (Falk and Storksdieck 2005) and has been observed previously in zoo visitors (Dove and Byrne 2014). Alternatively, it may indicate a lack of variety in the educational content presented by the exhibits. Here, the former seems more likely, as a wide variety of information was featured on exhibit interpretation, particularly at MPDR.

Age significantly influenced visitors' ability to identify pro-conservation behaviours and threats to rhinos at TBRR, and PMM Mastery scores at TGH. Surprisingly, the oldest age group (61+) received significantly lower scores for these measures than younger visitors. This contradicts constructivist theory where knowledge is accrued gradually and continuously through life experiences, implying that younger visitors should receive lower scores (Lukas and Ross 2005). The lower scores for older visitors here may hint at generational differences in biodiversity literacy. This repeated pattern is noteworthy and has been observed in previous studies of zoo visitors (Moss et al. 2017). However, the wider literature has found only inconsistent evidence of such generational differences in environmental awareness (Wiernik et al. 2013).

Visitor understanding of conservation and their ability to identify threats to endangered species did not significantly improve at any exhibit. These areas may be a focus for further educational interventions, but engaging visitors on these topics can be challenging, as visitors can find science-heavy or unsettling content overwhelming and off-putting (Moss et al. 2010; Esson and Moss 2013). For example, rhino poaching is a particularly distressing issue, which may explain why visitors more readily absorbed positive information such as conservation breeding of this species, which were particularly prevalent in responses

Table 4. Ordinal logistic regression results for open-ended questions at entry and exit points of the three exhibits. *Marginally non-significant effect of position (entry and exit) at 0.05<P< 0.1, **Significant effect of position at P≤0.05, [a]Significant effect of age at P ≤ 0.05, [g]Significant effect of gender at P ≤ 0.05, [m]Significant effect of Chester Zoo membership at P ≤ 0.05.

						Test statistics		
Dimension	Exhibit	Position	Mean	SE	95% CI	Test	df	Adj. P
Identifying pro-conservation behaviours.	TGH	Entry	1.90	0.18	1.54–2.27	1.105	1	0.647[a,m]
		Exit	2.23	0.14	1.94–2.52			
	TBRR	Entry	1.81	0.17	1.47–2.15	2.771	1	0.183[a]
		Exit	2.21	0.17	1.87–2.55			
	MPDR	Entry	2.00	0.17	1.66–2.34	4.889	1	0.027**
		Exit	2.41	0.15	2.11–2.71			
Species habitat preferences.	TGH	Entry	2.08	0.19	1.70–2.45	0.131	1	0.718
		Exit	2.15	0.18	1.79–2.52			
	TBRR	Entry	1.39	0.19	1.01–1.76	6.545	1	0.011**
		Exit	2.09	0.19	1.72–2.47			
	MPDR	Entry	1.62	0.19	1.22–2.01	0.133	1	0.715
		Exit	1.62	0.19	1.22–2.01			
Defining 'conservation'.	TGH	Entry	1.81	0.15	1.50–2.11	3.335	1	0.067*
		Exit	2.12	0.14	1.83–2.41			
	TBRR	Entry	2.02	0.14	1.74–2.29	1.684	1	0.194
		Exit	2.32	0.13	2.07–2.57			
	MPDR	Entry	1.96	0.14	1.68–2.25	2.875	1	0.090*
		Exit	2.31	0.13	2.05–2.57			
Identifying threats.	TGH	Entry	2.02	0.16	1.70–2.34	0.864	1	0.582[g]
		Exit	1.81	0.17	1.47–2.14			
	TBRR	Entry	2.18	0.15	1.87–2.48	1.932	1	0.303[a]
		Exit	2.45	0.14	2.16–2.74			
	MPDR	Entry	1.37	0.16	1.05–1.68	3.029	1	0.082*
		Exit	1.65	0.17	1.31–1.99			

at TBRR. That said, visitor knowledge of in situ and particularly ex situ conservation measures could still be diversified, because correct responses were dominated by references to breeding programmes, while other important actions of Chester Zoo, such as research, seem poorly understood. Again, visitors may be less receptive to such science-laden topics, whereas topics that evoke emotional and empathetic responses, such as the birth of baby animals, are easier to communicate (Moss et al. 2010).

Despite only occasionally achieving statistical significance, knowledge increases at TBRR and MPDR were consistently observed, and overlaps in 95% confidence intervals were often small even for non-significant results (Tables 2 and 4). Despite a high acceptance rate of 80.5%, overall survey sample size was limited to 320 completed surveys. While Chalmin-Pui and Perkins (2017) detected significant differences with comparable sample sizes at the BUGS exhibit at London Zoo, the Chester Zoo exhibits were smaller and the opportunity for learning at each exhibit was reduced. This relatively small sample size, combined with small effect sizes, created a high risk of false negative results. However, significant increases could also be a product of chance because scores were compared for each question at each exhibit, leading to repeated testing. A longer-term study with increased sample size would have more statistical power and would allow for more concrete conclusions. While small effect sizes may limit statistical inference, Chester Zoo received over 2 million visitors in 2019 (Chester Zoo 2019), so even small increases in visitor knowledge are valuable (Jensen 2014).

Statistical inference was also limited by a lack of replication in the study design. Due to limited time and resources, only three exhibits were studied, each housing a different species. Taxon can significantly affect visitor behaviour and engagement at zoo exhibits (Carr 2016). Ideally several exhibits housing the same or similar species would be compared, but this was not possible for a short-term study at a single zoo, where each exhibit is unique and houses a different species. While these results cannot be generalised and wider conclusions about the educational impact of immersive exhibit designs cannot be drawn directly from this study, results generally agree with other exhibit design studies, which suggest that immersive exhibits can improve visitor engagement and learning (Nakamichi 2007; Moss et al. 2010; Chalmin-Pui and Perkins 2017).

Another limitation was that the survey component did not use a repeated measures design recommended for zoo education studies (Mellish et al. 2019). However, it was impractical and inappropriate to ask visitors to repeat the survey at either side of exhibits of this size. Furthermore, a previous study found a significant 'priming' effect of completing PMMs at the entry and exit point of the BUGS exhibit at London Zoo (Chalmin-Pui and Perkins 2017). Visitors who had completed an entry survey scored significantly higher when repeating the survey at the exit point than visitors who completed the survey at the exit only. This would not be suitable for a comparison between several exhibits, as it would be impossible to distinguish the educational effect of the exhibit from the priming effect of the first survey. However, the Grasslands exhibit will be sufficiently large that repeated measures designs would be much more appropriate for future studies.

Conclusions

This study provides evidence that the immersive, third-generation exhibit is more effective at educating visitors than the other exhibits, despite the apparently contradictory finding that visitors spent significantly less time there. This demonstrates how mixed-methods approaches provide a more nuanced picture of visitor education than purely quantitative measures of behaviour. Despite a relatively low power, improvements in visitor knowledge were detected at MPDR and TBRR. This suggests that Grasslands, which will be much larger and will provide greater opportunities for free-choice learning, has significant educational potential if it is accompanied by high quality and attractive interpretive elements. Visitor observations at MPDR found the short documentary to be very popular; and including a mix of traditional and digital media in exhibit interpretation should facilitate free-choice learning. Intelligent placement of interpretation may also be important, as evidenced by low engagement with interpretation at TGH. Immersive, third-generation exhibits such as Grasslands will only become more common in modern zoos, and will be of vital importance if zoos are to achieve their educational goals in the coming decades.

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