

Cognitive Consequences of Interactivity

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Abstract

When children encounter objects, design constrains and affords action and cognition. An observational study in the wild revealed how manipulable objects afforded greater complexity of cognitive outcomes, including testing cause-and-effect and expressing abstract ideas about phenomena in the natural world. Evidence comes from video analysis of children's speech, gesture, and action when using a wide range of natural history exhibits. In the museum—an environment expressly designed for learning—children sought information with their moving bodies, eyes and hands. They explored sensorimotor contingencies, looking while touching, pushing, and pulling; they probed the perceptual affordances of different types of museum media, including graphic panels, specimens, models, and interactive exhibits. Children spoke more about the museum's content when they touched the exhibits, but the content of their speech changed depending on the object's affordances for interaction. With static specimens and models, children most often referred to objects' concrete properties. With interactive exhibits, children's speech involved references to dynamic relations among exhibit elements. Use of abstract speech and iconic gestures also suggests that they perceived interactive exhibits as representations of objects and phenomena beyond the here-and-now. In summary, when children used interactive exhibits, the content of their speech was relational, representational, and at times, both representational and relational; they employed modes of conceptualization not seen when using non-interactive exhibits.

Keywords: Distributed cognition; embodied cognition; situated cognition; interactivity; perceptual and cognitive affordances; representation; design; learning; museums

Introduction

What kinds of thinking does interaction make possible? This observational study takes a deep dive into one thin slice of everyday cognition—outside the laboratory, in the wild—in a natural history museum. While contributing to a compendium of human cognitive accomplishments in the wild, describing cognitive consequences of interactivity can inform design of learning technologies.

Museum professionals call manipulable exhibits “interactive.” Interactive exhibits allow for reciprocity; when a user takes action, the exhibit responds in some perceivable way (McLean, 1996).

To understand the cognitive nature of interactivity requires examination of the cognitive ecosystem, and what people, objects, and social and cultural practices all contribute to accomplishing a cognitive task.

From the perspective of distributed cognition, the organization of mind—both in development and in operation—is an emergent property of interactions among internal and external resources. In this view, the human body and the material world take on central rather than peripheral roles. (Hollan, Hutchins & Kirsh, 2000).

Cognitive resources internal to individuals include the functions enabled by human bodies, broadly speaking, perception, action, and other forms of cognition accomplished by brains (e.g. object recognition, memory, imagination). Cognitive resources external to individuals include artifacts, constructed environments, other people's actions, social organizations, norms, and cultural practices which shape behavior and thought (Ibid; Clark, 2010; Hutchins, 2000). We look for organization of intelligent activity in the coordination of internal and external resources (Ibid).

Touch is a primary mode for interaction with the physical world. The complexity of the human tactile system, in tandem with proprioception, allows for rich uptake of information. Touching enables knowing about object properties—in gestalt and in details—such as size, shape, texture, material, spatial location and adjacencies (Hatwell, 2003). Perception informs action, e.g. sight of a hand tool activates premotor regions in the brain, readying the body for action (Grafton, Fadiga, Arbib, Rizzolatti, 1997). Action serves perception, e.g. eyes and hands move over objects to drive sensory input. The structures of human sensorimotor systems—evolved for survival in a material world and tuned through lived experience—subserve the functions of action-perception loops. In museums and elsewhere, we use these biological endowments for aesthetic enjoyment, conceptualization, learning, and more.

Grounded cognition theories assert that embodied experience and situated action provide the building blocks for modal simulation and the perceptual symbol systems, proposed as underlying all cognition (Barsalou 2008; Barsalou, 1998). During infancy, interaction with objects in space may enable the development of abstract image schemas, which act as conceptual primitives that provide the foundation for categorization and abstract thought (Mandler, 2004). For crawling babies and pilots in their cockpits, interaction with objects changes what is available for perception, with consequences for memory, problem solving, and action (Hutchins, 1995b). Through the placement and arrangement of objects in space, humans can create conceptual relationships among categories of objects and organize their world for preferred types of action (Kirsh, 1995; Tversky, 2011.)

People use “epistemic action” when they manipulate objects to produce knowledge in order to solve problems; they don’t just solve problems “in their heads” (Kirsh & Maglio, 1994). Objects in the environment can provide structure for thought by serving as material anchors for conceptualization, e.g. the systematic arrangement of numbers and moving hands on a clock face supports the conception of episodes and passages of time (Hutchins, 2005). Tools change the composition of functional cognitive systems and the nature of cognitive tasks by changing the distribution of cognitive labor (Cole & Griffin, 1980; Hutchins, 1995a,b). As an example, compare mental multiplication of two very large numbers to computing the product with pencil and paper, or with a calculator.

Museum exhibits can serve as tools for exploring and representing ideas. External representations permit inference making by sharing the cognitive load with sensory systems (Kirsh & Maglio, 1994). They can provide a substrate on which one might “project” imagined structure (Kirsh, 2009), as when eyes trace a path on a map. Additionally, when objects can be manipulated, their representational potential expands by changing what is available for both perception and imaginary projection. Alignment of structure between aspects of perceptual experience and mental content may provide the basis for analogical reasoning and conceptual understanding (Gentner, 2010). Research has shown how interaction with external representations—in particular, diagrams and gesture—serves critical functions in achieving insight through processes that engage perception, juxtaposition of elements, imagination, and representation through abstraction (Nersessian, 2012; Bechtel, 2013; Becvar, Hollan & Hutchins, 2005; Hutchins & Palen, 1998).

Learning scientists and educational researchers have stated the need to more deeply explore the cognitive constraints and affordances of interactive museum exhibits (Rennie, Feher, Dierking & Falk, 2003). Some researchers have articulated strategies for designers to focus users’ attention, limit sensory overload and frustration, and promote understanding (Allen, 2004; Allen & Gutwill, 2004). Indeed, museum exhibits can be powerful tools to promote learning and to study how learning happens (Feher, 1990). Researchers working in the realm of embodied mathematics learning are exploring exhibits as mathematical “instruments” for the development of perceptuomotor attunement, fueling mathematical imagination, merging action and conceptualization (Nemirovsky, Kelton, & Rhodehamel, 2013). There is widespread acknowledgement that interaction with objects provides the means for important cognitive work in learning environments (Bell, Lewenstein, Shouse & Feder, 2009). A growing research community conducts microanalytic ethnographies of interaction in environments designed for learning (Norris, 2004), yet we have not exhaustively documented the cognitive consequences of interactivity.

Methods and Analysis

Observing individuals and groups engaged with social and physical environments, we see how sequences of action enact and embody trains of thought (Alac & Hutchins, 2004). Translating distributed cognition theory into methods, we use cognitive ethnography (Williams, 2006), an evolving methodology that bounds units of analysis based on cognitive tasks (Hollan, Hutchins & Kirsh, 2000). Cognitive ethnography focuses on interaction among elements in cognitive ecosystems, both human and environmental. Qualitative and quantitative methods used are multimodal, multiparty, multiscale (Johnson, 2010).

For this research, primary data were comprised of video recordings of six bilingual fourth-grade children, each spending approximately 40 minutes in a natural history exhibition focused on geology and paleontology. Video recordings involved hand-held cameras following children as they moved through the museum. In addition, head-mounted cameras worn by children captured their literal point of view in an attempt to get inside the activity, deliberately taking an endogenous perspective (Stevens, 2010). Qualitative, descriptive analyses derive from the video recordings. Coding and annotation of the video generated secondary data, used for quantitative analyses related to abundance, diversity, distribution, sequences, and co-occurrences of cognitive events. The coding scheme, developed during the exploratory phases of this study, involved codes informed by theories of Distributed and Embodied Cognition, as well as emergent codes in the tradition of Grounded Theory related to the consequences of action and cognitive function (Charmaz, 2000).

Children’s behaviors determined the parsing of activity in the museum. The video was annotated to mark engagement of perceptual and expressive modalities, i.e. when children looked, touched, talked, and gestured with exhibits. The coding scheme also specified how behaviors were coupled with the environment, as different targets of touch have different qualities and affordances (e.g. they touched smooth graphic panels, irregularly-shaped and textured touchable specimens, and manipulable interactive exhibits). Speech was coded in multiple ways, related to the presence or absence of the referent, and to differentiate exhibit-related from non-exhibit-related speech. Coding enabled categorization of utterances as exhibit-related and concrete, abstract, or a blend of concrete and abstract (Figure 1). In addition, use of parts of speech referring to objects and actions supported interpretations of the cognitive functions of speech (to name, describe, evaluate, direct attention, ask a question, etc.). The gesture codes simultaneously indicate form and function (indexical and iconic).

This study draws from video data of six children’s activity in four of six galleries, totaling 166 minutes, including 194 events defined by a participant’s sustained visual attention on an exhibit, with some of that time in proximity close enough to touch. The video data has 30 frames per second; a frame-by-frame analysis allows for coding of behavior at a resolution of 33 milliseconds.

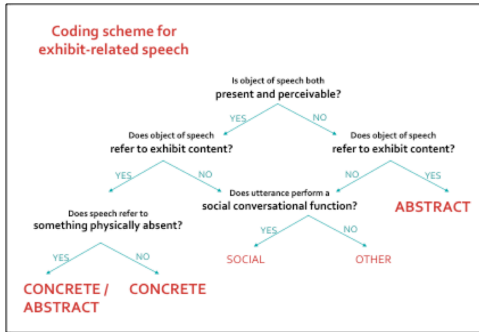


Figure 1. Coding scheme for exhibit-related speech.

With training and a great deal of patience, research assistants coded video, focusing on observable behaviors such as: Look, Touch, Manipulate, Talk, Gesture, Read. Definitions of behaviors in an ethogram and a decision tree for types of talk (Figure 1) guided their judgments. Studying the complexity of cognition in the wild requires perception tuned by knowledge and experience, what Goodwin calls “professional vision” (Goodwin, 1994). Consequently, the lead researcher confirmed the accuracy of the coding done by assistants.

The cognitive ethnography approach aligns with Multimodal Interaction Analysis, informed by strategies and orientations from Conversational Analysis, Multimodal Discourse Analysis, and Interaction Analysis (Norris, 2004). The cognitive task defines the unit of analysis in cognitive ethnography. In this case, the cognitive task for the children was to make sense of the novel museum environment, so the analysis involved the children and objects in the environment. The video and annotation data allow purchase on the question: What are cognitive consequences of interactivity for children in a museum?

Study participants attended a special museum immersion program. One girl and one boy from each of three classes were purposefully selected by the researcher with no prior knowledge of their personal or academic history. Results from this study derive from six participants, all bilingual, (5 English/Spanish bilinguals, 1 English/Vietnamese), during fall of their fourth-grade year. This study sits within a larger research agenda with the goal to describe a unique cognitive ecosystem at the intersection of formal and informal education in a natural history museum. The larger ethnography included observations and recordings of the three classes, attending adults, interviews with teachers and museum educators, subsequent museum observations, and classroom conversations.

Results

Allocation of attention influences other forms of cognition. Actions of the eyes and hands serve as a proxy for attention. When in the museum galleries, children looked at exhibits 90-95% of the total time, and touched exhibits 25-60% of the total time. Among the 194 events defined by sustained visual attention on a singular exhibit

within arm’s reach, the vast majority (79%) involved touching. Forms of touch differed with the targets for touch and their affordances for engagement. Children touched the smooth surfaces of exhibit cases and graphic panels in 53% of all manual events (384 total across six children); they touched irregularly shaped specimens and models in 25% of manual events; they manipulated exhibits in 22% of manual events. The percentages of look-only, touchable, and manipulable exhibits, relative to the overall number of exhibits, is equivalent. However the amount of time spent at interactive exhibits, relative to overall time, is greater than the percentage of interactive exhibits relative all exhibits. Children often watched others while waiting in line to take their turn with an interactive exhibit.

Of all the speech events uttered by children while in the galleries (n=496), 69% related to exhibit content (e.g. “That’s a starfish”); the remaining 31% involved social coordination, such as “I’m going to take you over here,” and “We gotta go.” Touch and talk tend to co-occur. When children touched exhibits, they simultaneously talked about half the time. When children talked about exhibits, they simultaneously touched 70% of the time.

The content of children’s speech changed depending on the object’s affordances for interaction. Children commonly used speech related to concrete objects on display and concrete actions (67% of all exhibit-related speech events). With static specimens and models, children most often referred to concrete objects’ properties, naming, describing, and evaluating, using nouns, pronouns, adjectives, and indexical gestures.



Figure 2. “That’s where we are,” representational speech with indexical gesture.

Children infrequently talked about representational content; 19% of multimodal utterances were coded as representational, i.e. they made reference to a museum object that was present and perceivable and also something physically absent, blending abstract and concrete speech. Examples include when a child pointed to a dynamic world map with moving continents and said “That’s where we are” (Figure 2) or pointed to a geologic model, saying “That’s lava.” Although representational utterances were less common overall, when the children engaged with interactive exhibits, they were much more likely to use concrete/abstract representational speech. Two-thirds of 55

instances of concrete/abstract representational speech occurred while children manipulated or watched another child manipulate an interactive exhibit. Concrete speech is three times more abundant than representational speech. Yet, speech describing relations among exhibit elements was three times more abundant in representational than concrete speech, always occurring with interactive exhibits. Referring to dynamic cause-and-effect relations among exhibit elements, the children used verbs, adverbs, and prepositions in addition to other parts of speech. Their use of abstract speech and iconic gestures suggests that they perceived interactive exhibits as representations of objects and phenomena beyond the here-and-now.

Discussion

When museum exhibits afford interaction, they yield consequences for attention and conceptualization. When children manipulated interactive exhibits in the museum—opportunities that they actively sought—they achieved feats of cognitive complexity. With non-interactive exhibits, children tended to focus on questions related to concrete objects. With interactive exhibits, they went beyond naming the concrete objects. They explored opportunities for taking action and expressed representational meanings of museum objects in speech and gesture. Additionally, interactive exhibits seem to attract and hold the attention of children for longer time periods, a finding consistent with many museum studies (Serrell, 1998). This longer “stay time” may influence outcomes for speech and cognition.

Various lines of research assert that language use can bootstrap cognitive development (Spaepen, Coppola, Spelke, Carey, Goldin-Meadow, 2011; Balcomb, Newcombe, Ferrara, 2011; Carey, 2011). At multiple levels, whether behavioral associations or purported neural connections, talking about experience can form and strengthen linkages between percepts and concepts (Gentner & Boroditsky, 2001; Ayoub & Fischer, 2006). Different forms of talk involve different cognitive functions. Naming a concrete object involves perception, recognition, and mental linkage with a verbal label. Naming that which an object represents involves both seeing the object, and *seeing as*, invoking the imagination to form a representation (Goodwin & Goodwin, 1996; Alac & Hutchins, 2004). This *seeing as*, marked by the use of representational speech and gesture, happened more frequently with exhibits that had opportunities for interaction.

Especially when interactive, the exhibits served as tools, as pivots for the imagination (Vygotsky, 1934), and as material anchors for conceptual blends (Hutchins, 2005), a purported process by which humans weave together ideas from two distinct yet related mental spaces (Fauconnier, 1994). As material anchors for conceptual blends, museum exhibits instantiate a physical analogy for a set of concepts. The imagination links what is present with what is not present, creating representational relationships. When children used concrete/abstract speech and iconic gesture as vehicles of expression, they made these representational

relationships available for observation, for themselves and others.

With exhibits as tools, children can give form to their imaginations. Among the children, iconic representational gestures were rare and not evenly distributed throughout the exhibition. The majority of iconic gestures occurred at a plate tectonics exhibit, designed to represent a subduction zone. The design of the exhibit strongly evoked representation of volcanoes among the children, yet the physical design left out a critical conceptual component—the eruption of lava from the Earth’s surface. With iconic gestures, the children gave form to imagination and, with their hands accompanied by sound effects, they filled a gap in the physical design by enacting eruptions and explosions (Figure 3).



Figure 3. Enacting a volcanic gesture coupled with subduction exhibit.

Children expressed the representational potential of exhibits by coordinating their resources for action-perception-cognition with the material resources of the exhibits, asynchronously collaborating with the designers who deployed strategies of visual-spatial abstraction and temporal-spatial compression. Interactive exhibits can instantiate analogies for phenomena, objects, and processes, but people create representations, sometime observable in speech and gesture.

When children manipulated exhibits, they experienced contingent relationships between the actions of their hands and changes in their visual field. Speech and gesture that accompanied manipulation served specific cognitive functions, i.e. making reference to analogical and dynamic relations using abstract nouns, verbs, prepositions, and representational gestures, resulting in greater cognitive complexity. Talk that accompanied touching static objects, not involving manipulation, had simpler cognitive outcomes: naming, describing, evaluating, using concrete nouns, adjectives, the verb “to be,” and indexical pointing gestures.

When exhibits can be manipulated, this seems to motivate their inclusion in a category endemic to museums, a category of objects that are supposed to be representational. A child expressed this expectation of representation when he approached an interactive model and asked, not the most

common question “What is it?,” rather “What’s this supposed to be?”

The richness of this cognitive accomplishment—using exhibits to create representations, personally meaningful and publicly shared—involves a distribution and integration of cognitive labor. A child’s eyes focus on an exhibit, supporting visual perception while the line of sight can serve as a pointer for others’ attention. The hands manipulate an interactive exhibit, creating movement that changes the visual field, highlighting how the elements relate to each other and demonstrating how action causes effects. Speech can label the objects and express how they relate, and gesture can locate those objects in space and express dynamics of phenomena in concrete and/or abstract terms. And multiple parties can get involved, watching, moving, talking, gesturing—collaborating to create representations in the museum.

When opportunities for multimodal and multiparty engagement expand the potential for cognitive complexity, coherence or confusion can result. To increase the probability of perceptual-conceptual coherence and reduce the probability of confusion, the results of this research suggest implications for design.

To accomplish the cognitive achievement of perceiving and expressing representational content, museum exhibits should instantiate a direct isomorphic mapping between concrete objects and abstract concepts—“structural alignment” (Gentner, 2010) enhances the probability of achieving intersubjective agreement on the representational content. If multiple conceptual steps are required to achieve correspondence between the object and concept, intellectual scaffolding (ideally in material form) must support making those steps, and sufficiently hold attention to complete the conceptual journey.

Physical aspects of exhibits channel attention and focus perception. With interactive displays, manipulation of an exhibit changes what is available for perception, and movement highlights specific features. Interactive exhibits instantiate dynamic relationships of cause-and-effect, and through analogical reasoning, can represent abstract, more generalizable, relationships. With affordances of manipulation and interaction, exhibits can serve as technologies for exploration and imagination, rather than solely as media for transmitting information.

Hands—these uniquely human, extraordinarily flexible tools—can be put to good use in museums, schools, and other learning environments. Children will touch whatever is available. In many museums, the most abundant touchable resources—graphic panels—offer the least tactile information. The least abundant resources—interactive exhibits—offer the most multisensory information and potential for cognitive complexity. Touching and manipulating objects compels the allocation of both individual and joint attention, influencing what and how children see, and the ideas they activate through speech and gesture. Educators and designers may take stock of their investment in these different learning resources and assess

their potential for engagement involving perception/action/cognition.

Interactive exhibits enhance the potential for conceptualization that is relational, representational, and a combination of relational and representational. When children engage multiple perceptual and expressive modalities, interacting with objects and coordinating with the actions of others, an opportunistic distribution of cognitive labor results, offering great potential for cognitive complexity and richness of meaning-making.

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