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ABSTRACT

Science museums can be excellent learning environments for engaging citizens in the complex societal issues of our time—such as climate change, fishery collapse, social prejudice, and wealth inequities—by fostering experimentation and metacognition about visitors' own social behaviors. The authors studied a low-cost metacognitive tool—*Question Asking*—in exhibit labels through a within-subjects, quasi-experimental research design with 59 randomly selected adult and teen dyads. Results indicated that the inclusion of an exhibit-specific question increased the proportion of time visitors spent in metacognitive conversations by at least a factor of three. Following that specific question with a more generally applicable real-world question maintained the already elevated proportion of time spent in metacognitive talk but did not boost that proportion further. The authors recommend including an exhibit-specific question at social science exhibits (and potentially adding another, broader real-world question as well) to prompt or enhance users' metacognitive responses to exhibit content.

Science museums can play an important role in engaging and educating citizens in the most pressing issues of our times, such as climate change and energy use, inequities in food production and distribution, water pollution, and ecosystem collapse. Solutions to such environmental harms, once viewed mainly as the dominion of natural science, have come to be seen as the purview of social science as well. A 2009 report by the Center for Research on Environmental Decisions states that to tackle our dire climate-related issues, "the public must be able to interpret and respond to often bewildering scientific, technological, and economic information" (Shome & Marx, 2009, p. 1). Effective reactions to environmental crises require understanding human perceptions of risk, learning new cooperation strategies, and balancing short-term personal benefits with long-term community gains. Fortunately, social exchanges and decision-making processes are becoming better understood through research in the social sciences (e.g., Fisher, 2008; Greene, 2013; Kahneman, 2011), allowing educators to involve learners of all ages in thinking about the interpersonal interactions underlying complex global problems (Shome & Marx, 2009).

Science museums are well positioned to engage the public in inquiry-based explorations of such social phenomena, just as they have been fostering experimentation with physical phenomena for nearly 50 years. An inquiry approach requires learners to ask and answer their own questions of a phenomenon with the tools at hand. Inquiry-based exhibits may successfully engage members of the public with morally-cast societal issues by encouraging them to investigate their own social interactions (Hein, 1998, 2012; National Research Council, 2009). By grappling with well-studied social dilemmas like the Tragedy of the Commons (Greene, 2013; Ostrom, 2008), the Prisoner's Dilemma (Kahneman, 2011; Rapoport & Chammah, 1965), and the Volunteer's Dilemma (Diekmann, 1985; Fisher, 2008) in an emotionally safe museum context, the public may develop a greater understanding of the forces at play in local, national, and global ecological and social conflicts such as deforestation, nuclear arms proliferation, and gun control.

The present study was part of *Science of Sharing*, a National Science Foundation-funded exhibition development project, designed to foster public experimentation with cooperation, competition, and collaborative problem-solving at the San Francisco Exploratorium. Many of the exhibits focus on social dilemmas in which visitors must choose between personal short-term gains and group-related long-term rewards. *Science of Sharing* exhibits highlight the fact that inquiry into social phenomena is not only critical to understanding psychological mechanisms and principles but is of fundamental importance in maintaining a citizenry capable of meeting real life global challenges. Such inquiry constitutes exploring and reflecting on one's own cognition and the cognition of others. In other words, inquiry about social phenomena at *Science of Sharing* exhibits may generate a form of metacognition.

Definition of metacognition

Metacognition, often described as thinking about thinking (Abell, 2009; Dunlosky & Metcalfe, 2008; Ritchhart, Turner, & Hadar, 2009), encompasses three main facets: metacognitive knowledge, metacognitive experiences, and metacognitive skills (Efklides, 2001, 2006, 2008; Flavell, 1979; Ruffman, Slade, & Crowe, 2002; Veenman & Elshout, 1999). *Metacognitive knowledge* refers to a person's conceptions of cognitive processes, such as thoughts about mental images, beliefs, and insights. "I'm a visual learner" exemplifies this well. *Metacognitive experiences* comprise a person's awareness of thoughts or feelings, such as frustration or excitement, during a cognitive task. An illustration of this would be, "I am so bored reading this article on metacognition." *Metacognitive skills* involve strategies aimed at monitoring cognition, such as orientation, planning, and evaluation. Take, for example, "When I'm not sure if I understand something, I try to ask a question."

These three aspects of metacognition were originally conceptualized as cognition about one's own cognition. More recently, theorists and experimenters have broadened the construct of metacognition to include social metacognition—thinking about others' thinking (Efklides, 2008; Jost, 1998; Olekalns & Smith, 2005). In this view, people have cognitions (such as perceptions, awareness, and beliefs) about others' knowledge, mental experiences, and skills. An example of social metacognition might be, "I can't believe you think that climate change is a hoax." In the study described in this article, we sought to encourage and assess any aspects of personal or social metacognition, without trying to distinguish among the three subcategories.

The importance of metacognition

Metacognition has been tied to myriad positive educational outcomes (see e.g., Baird, 1986; Gama, 2004; Mevarech & Fridkin, 2006; Pugalee, 2010; Wang, Haertel, & Walberg, 1990; White & Frederiksen, 1998), and higher levels of creative thinking, which is considered increasingly valuable for dealing with "the complex social and environmental issues facing this world" (Hargrove, 2013, p. 90). This connection has been recognized in formal education:

According to a recent review, environmental educators are increasingly working to develop learning experiences that enable citizens to think critically and creatively when considering environmental situations (Marcinkowski et al., 2013, as cited in Adler, Zion, & Mevarech, 2015). Supporting metacognitive critical thinking about oneself, others, and their relationship to environmental issues is paramount (Adler et al., 2015). Furthermore, practicing a skill, even a mental one like metacognition, improves performance of that skill (Alloway, Bibile, & Lau, 2013; Charness, Krampe, & Mayr, 1996; Ericsson, Krampe, & Tesch-Römer, 1993; Pesce et al., 2016). Would it be possible, we asked, to enhance metacognition in science museum visitors, thereby promoting practice of this key learning skill? The current research study investigated the effect of a simple exhibit design change on visitors' metacognitive discussions about their thoughts and strategies at social science exhibits.

Prior studies of metacognition

Metacognition has been examined in many domains, including reading and writing (Brown, Bransford, Ferrara, & Campione, 1983; Wilson & Smetana, 2011), problem-solving (Downing, Kwong, Chan, Lam, & Downing, 2009; Joseph, 2009), and science (Abell, 2009; White & Frederiksen, 2005), to name a few. A small number of studies have assessed metacognition in informal learning environments. For example, Anderson and Nashon (2007) investigated metacognition in a theme park setting, measuring students' engagement in metacognition during and after a physics class field-trip to the park. In a later study, Thomas and Anderson (2013) explored parents' metacognition regarding their children's thinking and learning during a science museum visit. Anderson and Thomas (2014) recently reviewed their own methodological struggles when looking for metacognition in a new arena (field trips and science museums) and called for more research on metacognition in naturalistic settings such as science museums. The current study builds on the definitions and codes from their work and aims to expand on their findings by investigating metacognition during hands-on science exhibit exploration.

In another study related to metacognition in museums, Ma (2012) characterized the nature of "self-reflection" at science museum exhibits and identified the types of exhibits that engaged visitors in more self-reflective talk. Ma's study investigated the conversations of 33 pairs of visitors to the Exploratorium's *Mind* exhibition about emotion, judgment, and attention (Exploratorium, 2008). Ma was able to identify several aspects of self-reflective talk at the *Mind* exhibits as she listened for indications that visitors were thinking about and assessing their own thoughts, performance, feelings, and attention. This type of self-reflection aligns with many definitions of metacognition. Ma pinpointed the importance of three exhibit design features that better elicited self-reflective talk amongst visitors: interactivity, space for multiple users with defined roles, and challenges for visitors to meet. The current study adapted Ma's definitions and codes and built on her findings. In the present study, we began with interactive exhibits containing challenges and roles for multiple users and sought to further boost visitors' metacognition with an additional design approach: labels that ask metacognitive questions.

How to enhance metacognition

Several strategies for promoting metacognition have been developed in both classroom and informal learning contexts. A literature review identified seven methods for promoting metacognition. Four of those strategies hail from formal schooling:

1. Question asking, which may use questions generated by the teacher (Abell, 2009; Joseph, 2009), peers (Choi, Land, & Turgeon, 2005; King, 2008), or the students themselves (White & Frederiksen, 2005; Wilson & Smetana, 2011);
2. Mental modeling, where teachers or students read aloud while offering comments on their thinking strategies as they work through the material (Joseph, 2009; White & Frederiksen, 2005; Wilson & Smetana, 2011);
3. Comparing ideas with those of a computer (Kerly, Ellis, & Bull, 2008) or of cartoon characters (Abell, 2009); and
4. Solving real-world problems, where students monitor, analyze, and direct the process of problem-solving based on real-world cases or issues, such as interviewing a scientist and writing a journal article (Downing et al., 2009; Joseph, 2009).

Three remaining strategies, identified by Ma (2012), have been used in informal learning environments:

5. Interactivity, where an exhibit "reacts to visitors' changing inputs by changing its state beyond simply being turned on or off" (p. 145);
6. Assuming roles, such as subject and experimenter at multi-user exhibits to promote deeper discussion; and
7. Meeting challenges posed by the exhibits (e.g., find all the Яs in a sea of Rs), which may encourage visitors to monitor and evaluate their performance.

In the present study, we chose question asking via exhibit flip labels as an important strategy to test, given its potential for encouraging learners to engage in metacognition, and its low cost and ease of future replication.

We designed label questions to prompt "metacognitive talk," conversations in which learners reveal awareness of their own thinking processes. Metacognitive talk may be systematically identified by coding learners' conversations and quantifying frequency or duration of metacognitive utterances. Indeed, conversational analysis procedures have been used to measure learning in myriad studies in informal environments (e.g., Allen, 2002; Callanan, Shrager, & Moore, 1995; Crowley et al., 2001; Gutwill, 2005; Gutwill & Allen, 2010, 2012; Leinhardt, Crowley, & Knutson, 2002; Szechter & Carey, 2009). Some have argued that verbal utterances are particularly important when measuring metacognition: "Awareness and verbal reporting are the most likely ways to exhibit or share knowledge about thinking" (Paris & Winograd, 1990, p. 21). Unfortunately, metacognitive verbalization underrates the true amount of metacognition a learner may be executing because it excludes nonverbal thinking. This drawback may be mitigated in experiments that compare metacognitive talk in different treatment conditions.

To stimulate metacognitive talk, we developed two types of questions in exhibit labels: exhibit-specific and real-world (see Figure 1 and Table 2). The former asked about the particular mental strategies learners used at the exhibit. For example, at an exhibit about lying called *Poker Face*, the exhibit-specific label question was, "Some people look at eyes, others look at something different. How did you try to tell when your partner was lying?" This question was created to encourage learners to articulate their own cognitive process for detecting deception. Real-world questions, in contrast, were constructed to elicit metacognitive talk about the broader cognitive strategies learners utilize in similar situations in their lives. For instance, the real-world question at the *Poker Face* exhibit was, "In your life, what strategies do you use to conceal a white lie?" We expected that adding an exhibit-specific question (EQ) would lead to increased metacognitive talk beyond that inspired by the exhibit alone, and that the further addition of a real-world question (RQ) would have an additive effect leading to a significant gain in metacognitive talk even above that of the EQ.

Figure 1. Exhibits in the study.

The exhibit design strategy for prompting metacognitive talk—question asking in a label—had to match the museum's educational model of engaging visitors in inquiry. According to Serrell (2015), open-ended label questions, when crafted carefully, can inspire visitors to bring their own knowledge and experience into the exhibit interaction. Based on the *Science of Sharing* goal of encouraging people to consider the societal-scale consequences of their individual responses, we developed both EQs and RQs. To ensure that participants would see the questions only after fully using the exhibit, our design used flip labels (also called *flappers*), which hide information under a physical layer and appear among Perry's (2012) design principles for intrinsically motivating exhibits. According to Screven (1992), successful flip labels direct learners' attention and can "dramatically reduce random looking and increase focused, active attention" (p. 201). The EQ was under the first flip label, while the RQ lay under a second flip label.

Ultimately, we studied question asking as a strategy for encouraging metacognition because it had not yet been tested in a non-mediated, hands-on, informal setting, raising the potential for our research to contribute new knowledge to the learning sciences.

RQs

This research sought to answer the question: Does using a question asking strategy in a flip label at a social science exhibit enhance visitors' engagement in metacognition? Specifically, we wanted to know:

- Does asking a question that is specific to the exhibit experience spur metacognition (Exhibit-specific Question)?
- Does adding a question more generally applicable to the wider world encourage additional metacognition (Real-world Question)? In other words, is the effect of question asking additive, with more questions leading to more metacognition?

Method

Experimental design

The study used a within-subjects design, in which a pair of museum visitors (dyad) used a single exhibit in three conditions: baseline, EQ, and RQ. We tested the effect of EQs, and then the additive effect of RQs, on metacognitive talk between participants in the dyad (see Table 1).

Table 1. Within-subjects experimental design ($N = 59$ dyads).

Sub-sample	*N* (dyads)	Baseline (use exhibit)	Exhibit-specific Q	Real-world Q
1	20	Exhibit 1	Q Flip Label 1	Q Flip Label 2
2	21	Exhibit 2	Q Flip Label 1	Q Flip Label 2
3	18	Exhibit 3	Q Flip Label 1	Q Flip Label 2

Note. Exhibits are depicted in Figure 1; their descriptions and label questions are detailed in Table 2.

Treatment: Question asking in flip labels to foster metacognition

Pairs of visitors were randomly selected from the public floor of the Exploratorium. Each dyad used only one of three exhibits while wearing a microphone and being videotaped. Each dyad was instructed to use the exhibit for as long as they wished. When they felt they were finished, they were instructed to flip a label flap open to the first question page, which contained a question specific to the exhibit experience (EQ), and read and discussed the label as they normally would. When they felt they were finished with that task, they flipped to a second question page, which contained a question more generally applicable to the wider world (RQ). Figure 1 shows the exhibits used in the study. Table 2 provides descriptions of both the exhibits and the label questions. After using the exhibit and reading and discussing the label questions, participants completed a short demographic questionnaire.

The exhibits in the study use Ma's (2012) three design principles for engaging visitors in self-reflective talk: interactivity between exhibit and visitors, roles for multiple users, and a challenge or goal for visitors to meet.

Table 2. Descriptions of exhibits and label questions used in study.

Exhibit	Description	Exhibit-specific question	Real-world question
Common Knowledge	Visitors sit across from one another. Both try to answer multiple choice questions in the way they think "most people" would answer, and find that they often choose the same response. These so-called "Schelling Points" indicate that people share a great deal of common knowledge about the world.	Some people try to pick the most obvious answers to these questions; others pick answers a different way. How did you make your choices?	In your life, what strategies do you use when you're trying to figure out what someone is thinking?
Poker Face	Visitors sit across from one another. One visitor is asked to bluff about one of four poker hands dealt to them by a computer (saying they have no aces when in fact they do have aces). The other person tries to identify the bluff when the hand holding the aces is dealt. Visitors are encouraged to switch sides and play again. The exhibit helps people think about the importance of facial expressions in building (or eroding) trust.	Some people look at eyes, others look at something different. How did you try to tell when your partner was lying?	In your life, what strategies do you use to conceal a white lie?
Trading Places	Visitors sit across from one another. In a modified Implicit Association Test, each person tries to sort cards into categories that either support or defy gender stereotypes. Typically, people sort the cards faster on the side of the exhibit with categories that support stereotypes, revealing to visitors their own gender biases. Participants are encouraged to switch sides and sort again.	Some people put the cards where they think they should go, others sort them a different way. How did you sort the cards?	In your life, what strategies do you use to stop yourself from using stereotypes?

In an attempt to increase generalizability of the findings, we included three exhibits with varied social science topics. For example, the Common Knowledge exhibit engages visitors with the concept of focal points—unconsciously shared knowledge used to solve coordination problems when communication is prohibited (Schelling, 1980). Poker Face challenges visitors to detect a friend's lie by observing only the face, thus connecting cognition, facial expression, and credibility assessment (Ekman, 1993; Ekman, O'Sullivan, & Frank, 1999). Finally, Trading Places gives visitors a visceral understanding of their "implicit associations" between gender and work/home roles (Greenwald, Nosek, & Banaji, 2003). By testing metacognitive label questions at exhibits that focus on disparate social science phenomena, we hoped that any results about metacognition would generalize for social science exhibits broadly.

Participants and setting

As with prior museum-based studies that explored aspects of metacognition, this study focused on dyads (Allen, 2002; Ma, 2012; Thomas & Anderson, 2013). In part, this was necessary, as the exhibits were chosen to be multi-user. Studying dyads also helped ensure that visitors would engage in conversation, the cornerstone of our outcome variable: time spent engaging in metacognitive talk.

The research sought a representative sample of adult and teen visitors, because the exhibits were designed for those age groups. As teens are a small sample of the museum's overall visitor makeup (only 6.5% of casual visitors), we chose to purposively sample one dyad containing a teen at each of our three exhibits (three per condition). For the remaining dyads, we recruited adult-only groups using random sampling techniques on the museum floor.[1] Consequently, the results from this study will apply only to groups of museum visitors comprised of adults or adults and teens. For visiting groups originally composed of more than two adults (39% of those recruited), the group members decided amongst themselves who would participate in the study (similar to how a group of three or more would choose who would use an exhibit designed for two users).

In addition to age, the project had three further criteria for eligibility: participants had to speak primarily English at home to ensure that the conversations could be coded by English-speaking researchers; museum members were excluded to avoid the possibility of prior experience with the exhibits (that could impact baseline exhibit use); and homeschoolers were excluded because they often use the museum according to a lesson plan, which varies greatly from how casual visitors use the exhibits. Once visitors were determined to be eligible, researchers asked if they would be willing to try out an exhibit in an off-floor research lab while being audio- and videotaped, and answer a few short questions to help the museum learn more about its exhibits. Of those invited, 44% agreed to participate.

Metacognition may be difficult to measure in the frenetic and exuberant nature of learning in the buzzing context of a museum floor (Ma, 2012; Toon, 2000). Consequently, we chose to conduct the study in an off-floor laboratory setting, where ambient noise and visual distraction could be minimized. Moreover, the reactivity engendered by the laboratory environment helped ensure that visitors would in fact flip the additional labels and read the questions, an effect that would be equivalent across all treatment groups. Comparative studies of learning in situ often must navigate the tension between obtaining ecological validity and sufficiently reducing noise to measure a signal. Our method of using an off-floor laboratory to reduce aural and visual distraction represents a best case scenario in terms of visitor attention and focus.

After entering the laboratory, visitors were randomly assigned a single exhibit to use; no visitors who had previously experienced the target exhibit were included in the final sample. Visitors were further informed about their participation and asked to read and sign a consent form. Ultimately, 59 dyads were included in the study.

Measuring metacognition

Metacognition may be assessed via online methods occurring in real-time (such as think-aloud protocols or eye tracking) and offline methods conducted pre- or posttask (Anderson & Thomas, 2014; Veenman & Elshout, 1999; Veenman, Van Hout-Wolters, & Afflerbach, 2006). We elected to use the online method of recording and coding videos because our research questions focused on strategies for sparking metacognition while using an exhibit (Thomas, 2012). This choice was further supported by Ma's (2012) experience administering interviews during formative evaluations in which she found that the questions themselves prompted visitors to self-reflect.

Coding video data has become a ubiquitous method in learning sciences research (Derry et al., 2010). We began developing our coding scheme of metacognitive talk by adapting three existing schemes for metacognition and self-reflection. The first two were developed for use in the context of science center exhibits (see Ma, 2012; Thomas & Anderson, 2013), and the third in a classroom setting (Artzt & Armour-Thomas, 1996). We expanded the prior schemes' definitions to ensure evidence of all aspects of metacognition, including elements that align with social metacognition (Efklides, 2008; Jost, 1998), while reducing the number of subcategories. Consequently, our study did not delineate between metacognitive knowledge, experiences, or skills, nor between metacognition about the self or others. Still, any definition of metacognition requires a clear characterization of cognition. For that we turned to several scientific dictionaries and found that most psychologists define cognition as "any class of mental 'behaviors' … where the underlying characteristics are of an abstract nature and involve symbolizing, insight, expectancy, complex rule use, imagery, belief, intentionality [or] problem-solving" (Reber, 1995, p. 133). Using this definition of cognition, we returned to the simple construct of metacognition as cognition about any cognitive process (whether individual or social). We also reworked definitions to increase interrater reliability.

Our categorization scheme defined two levels of metacognitive talk: The first, All Metacognitive Talk (A-MCT), captures utterances that reflect at least a basic awareness of a cognitive process. For an utterance to be coded A-MCT, participants must show that they were aware of some aspect of their own or someone else's thinking. Examples include, "We just know each other so well" (awareness of knowing) and "You're lying" (awareness of the other person's deceit). The second level of coding, stringent metacognitive talk (S-MCT), requires stronger evidence of metacognition: Utterances must indicate an explicit cognitive process (beyond awareness) about another cognitive process. An example of S-MCT is, "I know you better than you think" (explicit mention of knowledge of the other's thinking). Table 3 shows the coding scheme and offers more examples.

Coding required identifying instances of metacognitive talk (A-MCT and S-MCT) made by either member of the dyad and quantifying the duration of each.[2] Utterances that included metacognitive talk were measured from the beginning to the end of the utterance, in seconds. Once coders located the core of the metacognitive talk, they created a temporary code that

Table 3. Metacognition coding scheme.

Code	Definition	Examples
Cognitive process (not metacognition)	Mental actions, occurrences, or states of being. Identifying the cognitive process was necessary for A-MCT and S-MCT (described below).	Thinking Feeling Believing Planning Picturing/imagining Choosing
All metacognitive talk (A-MCT)	Mention of awareness of a cognitive process in addition to all instances of S-MCT described below.	"I **think** it was the third time." "You are **lying**." "We **chose** the same one." "I **want** to trade places now." "Your partner **knows**."
Stringent metacognitive talk (S-MCT)	Mention of a more specific cognitive process (beyond awareness) about a second cognitive process.	"What started **making more sense** was when you were **trying to pick** the common one, as opposed to before, when you were just **picking** random things." "I **know** you better than you **think**." "I was trying to **pick** what I **thought** you would **pick**." "I **feel** like I'm not supposed to **know** when my mother is **lying** to me."

included this core statement. Then, they listened to the 1.99 s before and after the core statement. If the visitor did not engage in any relevant talk (essentially on-task talk) outside of the core, coders started and ended the code at the edges of the core statement. If the visitor did engage in relevant talk during the 1.99 s before or after the core statement, they extended the code to include the relevant talk. Then, from the new edge of the code, they listened again to the 1.99 s before or after, continuing until the visitor did not engage in any further relevant talk. Note that our scheme removed any time spent reading the graphic aloud verbatim.

Two research assistants, uninformed of the purpose of the study, were trained on the scheme until they reached 90% agreement on both the identification of each instance and its duration. Once trained, the two research assistants coded the 59 videos that comprised the dataset. Twenty percent of the videos were co-coded; these videos were randomly distributed across the full set to be coded, and research assistants were unaware of which videos were assigned for double coding. At regular intervals, we checked agreement between the two assistants and discussed and agreed upon final codes. These discussions kept the two assistants aligned with the scheme and one another. Our measure of interrater reliability produced a kappa of .77, which is considered excellent (Fleiss, Levin, & Paik, 2004). A debriefing meeting at the close of coding revealed that neither of the assistants had determined the study's aim.

Results

Demographic characteristics of the participants

A review of the demographic variables revealed that most dyads were comprised of male–female participants (73%) and were visiting the museum together with no additional group members (64%). The majority of participants were young adults in their late teens through their 30s (79%; probably due to our eligibility criteria that groups must be adults without children) and had either a bachelor's (46%) or graduate degree (24%). In response to our survey question about whether participants have "any background, experience or training in social sciences," which includes both courses taken and careers, a majority (66%) stated that they had. We also asked participants about their motivations for visiting the

Table 4. Participant characteristics.

Demographic variable	*n*	%
Gender		
Male	55	47
Female	63	53
Age		
14–17	4	3
18–29	57	48
30–39	36	31
40+	21	18
Dyad gender composition		
Male–Male	6	10
Female–Female	10	17
Male–Female	43	73
Dyad age composition		
Adult–Adult	51	86
Adult–Teen	8	14
Education		
Up to Bachelor's	36	31
Bachelor's	54	46
Graduate	28	24
Training or special interest in social sciences		
Yes	39	66
No	18	31
Unclear	2	3
Motivation for visiting		
Spend time with family/friends	31	28
Curious about Exploratorium	31	28
Fun experience	24	22
Interest in art and science	14	13
Educational experience	9	8
Exhibits/special event/other	2	2

museum; their most common reasons were to spend time with family or friends (28%) and curiosity about the Exploratorium (28%). Table 4 shows the demographics of study participants.

Metacognition

We conducted two one-way repeated measures analyses of variance (ANOVAs) with planned comparisons and a Bonferroni adjusted alpha level of .006 per test. Analyses focused on the proportion of time spent engaging in metacognitive talk in each condition. We chose to focus on proportions because we expected visitors would spend more time using an interactive exhibit than they would discussing a label question; proportions allowed us to normalize and compare baseline exhibit use to question asking. Proportions were calculated by dividing the amount of time spent in metacognitive talk by the total amount of time spent in each of the three treatment conditions.

The three treatment conditions consisted of (a) baseline exhibit use—time spent with the exhibit before flipping to the first label question, (b) EQ—time spent with the exhibit while the label is flipped open to the first question designed to prompt metacognition, and (c) RQ—time participants spent with the label flipped to the second metacognition question. In this way, treatment (baseline exhibit use, EQ, and RQ) was a within-subjects factor, and the dependent variables included the overall measure of A-MCT and the more strict measure of S-MCT. The mean proportions and standard deviations for time spent engaged in metacognitive talk are presented in Table 5. The mean percentages are illustrated in Figure 2.

Table 5. Proportion of treatment time spent engaged in metacognitive talk.

Treatment condition	Mean proportion of treatment time spent	
	All MC Talk (*SD*)	Stringent MC Talk (*SD*)
Baseline exhibit use	.133 (*.096*)	.046 (*.061*)
Exhibit-specific question	.433 (*.246*)	.261 (*.245*)
Real-world question	.417 (*.267*)	.252 (*.237*)

For the measure of A-MCT, the overall repeated measures ANOVA indicated a significant treatment effect, Wilks' Lambda = .325, $F = 59.18$, $p < .001$. The effect size, partial eta squared = .66, well above the .14 that is considered large (Green & Salkind, 2003). These results did not differ when we used the more restrictive S-MCT code. The results for the overall repeated measures ANOVA for S-MCT indicated a significant treatment effect, Wilks' Lambda = .434, $F = 37.20$, $p < .001$. Here, the effect size of partial eta squared = .57.[3]

As we expected, planned comparisons indicated significant increases in the proportion of time spent engaged in A-MCT between baseline exhibit use (13%) and the introduction of the EQ (43%), $F(1, 58) = 89.93$, $p < .001$, with an effect size of partial eta squared = .61. We expected and found the same result in the proportion of time spent engaged in S-MCT between baseline exhibit use (5%) and the introduction of the EQ (26%), $F(1, 58) = 45.09$, $p < .001$, with an effect size of partial eta squared = .44. This means participants spent a significantly larger proportion of their time in metacognitive talk in the EQ condition than in the baseline exhibit condition.

However, contrary to our expectations, no significant differences were found in the proportion of time spent engaged in A-MCT after adding the RQ following the EQ (43% with EQ to 42% with RQ), $F(1, 58) = .17$, $p = .68$, partial eta squared of .003; nor in S-MCT after adding the RQ following the EQ (26% with EQ to 25% with RQ), $F(1, 58) = .06$, $p = .82$, partial eta squared of .001). But it is of interest that the increase in proportion of time spent engaged in A-MCT and S-MCT from baseline exhibit use to EQ remained at the high increased rate after adding the RQ. In other words, the addition of a second label question did not increase the proportion of metacognitive talk beyond what we found for the first question, but did sustain its elevated level.

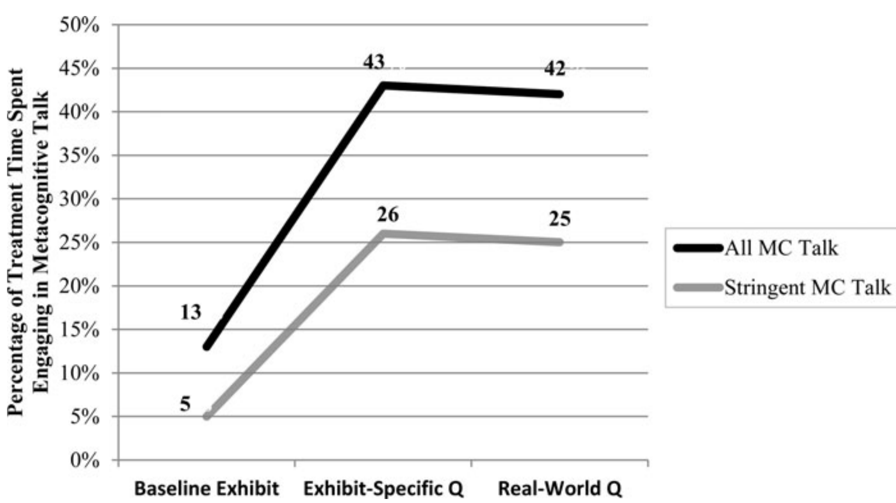

Figure 2. Mean percentage of treatment time spent engaged in metacognitive talk.

Discussion

Our results indicate that using a question asking strategy via a flip label led museum visitors to spend a substantially larger proportion of their time engaging in metacognitive talk than in conditions without such a manipulation. In particular, asking a question specific to the exhibit experience in the label significantly increased metacognitive talk over simply using the social science exhibit. The effect was large: The exhibit-specific label question increased the proportion of all metacognitive talk by a factor of three and increased stringently-measured metacognitive talk by a factor of five. Following the specific question with a more generally applicable RQ maintained the already elevated proportion of time spent in metacognitive talk but did not boost the proportion further, a result found for both our broader and more stringent measures of metacognitive talk. These findings are robust and provide support for the inclusion of a question asking metacognitive strategy at social science exhibits.

The pattern of results did not vary by exhibit, despite variation in content goals, suggesting that the question asking strategy may be generalizable to other social science exhibits. (It remains to be seen if this approach would work well with STEM exhibits beyond the social sciences.) The results also held for visitors with and without special interests, experience, or training in the social sciences. This underscores the potential of question asking as a general design strategy for promoting metacognition among a variety of visitors, not just those well-versed in the social sciences.

Notably, there was considerable metacognitive talk even in the baseline condition, before visitors encountered the first question in our manipulation. This represents an important finding in itself, providing replication support for prior work by Ma (2012) on exhibit design features involving interactivity, multi-user capability, and the presentation of user challenges—features that successfully promote metacognition. As Ma points out, additional study is needed to determine whether such additions apply to collections not focused on social phenomena. For example, Allen (2002) found very little metacognition or meta-performance at exhibits about frogs, which contained few interactive, multi-user, and challenge-posing exhibits.

We found that the key increase in proportion of time spent engaging in metacognitive talk occurred when participants encountered the first exhibit-specific question. However, dyads spent significantly more total time engaged in the second, real-world question (79.83 s) than they did in the first, EQ (43.63 sec).[4] Time spent is one indicator of engagement in a free-choice museum setting because learners decide for themselves how long to spend on any one experience (Falk, 1983; Falk & Dierking, 2000; Gutwill, 2005). This result suggests that it is well worth exploring the effects of a real-world question without it being preceded by a specific question; we recommend future research on this point.

Limitations

Despite the robust findings in favor of a question asking approach for promoting metacognition, this study has several limitations. First and foremost, we chose not to counterbalance the sequence of specific and general questions because of limited resources and small sample sizes. Consequently, we cannot distinguish the order effects of questions that asked for reflections specific to the exhibit from those questions that were expanded to participants' real-world experiences. This means that carryover, practice, and fatigue effects in which prior treatment conditions affect subsequent ones (either positively or negatively) may be present.

Now that we have established a measurable effect and developed valid assessment tools, we hope to study such potential order effects more closely and encourage others to do so as well.

A second limitation arises from our assessment method of coding verbal utterances, which excludes unspoken thought. Participants may have engaged in silent metacognition, especially while using exhibits in the baseline portion of the experiment. Increased cognitive load alone may have inhibited verbalization of thoughts during that activity. We attempted to account for cognitive load by reporting the proportion of time spent verbally engaging in metacognition in each condition, but we still are left with measuring only articulations. This concern is partially mitigated by the large effect sizes we obtained, especially since metacognitive talk did occur during baseline exhibit use. To encourage talking, we chose exhibits that require two users; future research could investigate question asking at exhibits designed for individuals and large groups.

Finally, this study represents a best use scenario in that participants were in a quiet laboratory off the museum floor and the treatment involved a flip label. Using the exhibits in a lab undoubtedly heightened participants' reactivity to follow instructions thoroughly, including answering the specific and general questions posed in the labels. However, although the large effect sizes may be buoyed by such reactivity, it is unlikely the sole driver of these effects. Indeed, such reactivity is presumably highest early on in the videotaping process, so we would expect more talking during the baseline phase of the study. Still, it will be important for future studies to explore the effects in actual applied museum settings. Finally, we do not know if these results would hold if the questions were asked on the regular label without a flip component; we are interested in exploring the effects of an even lighter touch.

Broader relevance

This study sheds light on the value of question asking in labels for promoting metacognition in informal learning environments. We have noted that research in formal and informal educational contexts has found that metacognition tends to improve learning outcomes. But perhaps as importantly, metacognition seems essential for learning about many of the topics studied in the social sciences. The exhibits used in this study, for example, were designed to promote investigation of the cognitive processes underlying interpersonal trust, the categorization of people into social groups, and collaboration when communication is prohibited. Learning about these domains constitutes thinking about the social, ethical, and economic judgments that lie at the heart of some of the most critical problems facing our world, including sustainable resource use and responses to climate change (cf. Shome & Marx, 2009). For individuals to be part of the solution to such problems, they must understand the complex cognitive and social processes underlying them. By definition, building an understanding of the way people think means engaging in metacognition. Indeed, a recent comparative study at the Exploratorium found that visitors engaged in significantly more metacognition at exhibits about social science than at physics exhibits (Meluch, 2015). Science museums have been moving further into the social sciences with exhibitions on race (American Anthropological Association, 2016), mental health (Exploratorium, 2013), cognition (Exploratorium, 2008; Ontario Science Center, 2016), and social psychology (Exploratorium, 2014); as this trend continues, we hope exhibit and program developers will encourage metacognitive reflection as part of the experience.

In conclusion, metacognition is a vital part of the learning process and may play a crucial role in learning about the social interactions that drive human society. The results of our research indicate that a relatively inexpensive design change—adding one or two open-ended questions to an existing exhibit label—can help significantly increase the amount of metacognitive discussion among learners. And because metacognition may be a key way of helping people consider their reactions to some of the most important issues of the modern age, researchers should further explore the relationship between metacognition and learners' understanding of the social science concepts within a variety of museum exhibits and programs.

Notes

1. To sample visitors randomly, our recruiter imagined a line on the floor and then approached the third visitor who crossed it and appeared to be eligible.
2. We coded for both frequency and duration of metacognitive utterances. The findings were equivalent for the two. For simplicity, we chose to report durations.
3. We identified two potential confounding variables: exhibit and visitors' self-reported training or interest in the social sciences. Analysis indicated no interaction effects involving these variables.
4. $t(58) = -4.04, p < .001$.

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