

Magnetism, light, structures, and rotational motion: mixed-methods study of visitors engaging with four exhibits at a science museum

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Mixed-methods research was conducted at four exhibits by four teams of graduate students and museum practitioners at MOXI, the Wolf Museum of Exploration + Innovation, in southern California. These four focal exhibits were Turn Tables, Keva Planks, Magnetic Islands, and Light Patterns. All four teams were interested in identifying guest behavior at the focal exhibits. However, teams from Turn Tables and Keva Planks were additionally interested in assessing whether a modification or manipulation to the physical exhibit impacted guest stay time at the exhibit. The first project examined Turn Tables, a set of rotating tables. This team found that adding a graphic to the exhibit had a significant impact on engagement with increasing complexity ($p < .05$). The second project investigated Keva Planks, which are small wooden planks guests can use to make structures. Researchers assessed how the presence of a museum floor facilitator or existing structures at the exhibit influenced stay time and engagement with the Keva Planks, and found a statistically significant difference in mean stay time in the case of both facilitator and structure present compared with only a structure present ($p < .05$). The final two studies used mainly qualitative observations to identify guest behaviors when interacting with each exhibit. The team that studied Magnetic Islands, a small magnetic structure guests can attach washers to, documented three engagement types: basic playing, building structures, and exploring magnetism. Findings from this project indicate that when children engaged with peers rather than visiting the exhibit alone, they exhibited more complex engagement types such as building and exploring magnetism. The final study examined Light Patterns, a large color peg board that covered an entire wall, focusing specifically on the behaviors of guests in early childhood to characterize the different ways young children chose to engage with the exhibit. Findings suggest that children exhibited many different behaviors at Light Patterns that demonstrated evidence of engagement with STEM practices such as asking questions, making observations, and recognizing patterns. This research contributes to topics about Research Practitioner Partnership (RPP) models, mixed-methods research, museum facilitation, learning affordances in museum spaces, and the impact of exhibit design on the museum guest experience.

I. INTRODUCTION

MOXI, The Wolf Museum of Exploration + Innovation, is a hands-on science museum in Santa Barbara, California whose exhibits promote "interactive learning through experiences in science and creativity" [1]. The exhibits focus on physics phenomena such as light, sound, force, and energy. Exhibits were designed with the Next Generation Science Standards (NGSS) in mind, and as such the museum functions as a space for guests to engage in NGSS-aligned learning experiences [2]. Furthermore, museum staff are trained to guide guests through the exhibits using open-ended questions that prompt guests to engage in NGSS science and engineering practices and crosscutting concepts. MOXI's open-ended exhibits lend themselves to learning through: low floors (the exhibit has easy entry points), high ceilings (the exhibit provides potential for complex learning experiences) and wide walls (the exhibit has multiple pathways for learning) [3].

MOXI serves visitors of all ages and is a free-choice learning space. The museum space was designed to encourage guests to engage in science and engineering practices to develop new ideas, a goal we refer to as *practice-based learning* [4]. In this paper, we look at the design and facilitation of four specific exhibits in order to add to our understanding of how to best support practice-based learning.

II. CULTURAL HISTORICAL ACTIVITY THEORY

Cultural Historical Activity Theory (CHAT) provides a framework for investigating how people act, learn, and negotiate meaning with others [5]. In the broadest sense this refers to human activity, through which we "transform our social conditions, resolve contradictions, generate new cultural artifacts, and create new forms of life and self" [6]. As a unit of analysis, activity refers to specific sociocultural contexts such as play, formal education, or work [7]. In this research, CHAT allows us to consider the complex design and implementation of museum stations and facilitation within the social and cultural context of a science museum.

Activity systems feature *subjects*, individuals or groups, an *object*, the focal point or objective, and *tools*, physical or conceptual cultural artifacts used by the subject to influence the object and achieve the desired objective [8]. Other components include *community*, people with a shared interest in the objective, *rules*, cultural norms and patterns of behavior, and *division of labor*, participant roles and distribution of tasks [6]. CHAT is ideal for characterizing informal learning environments and their partnerships with educators, researchers, and administrators while also considering visitor experiences, learning processes, and exhibit design [9].

This paper presents studies on four MOXI exhibits. Each focuses on the visitor learning experience in an informal learning environment with a specific open-ended exhibit. The four research projects described below focus on relationships between the main parts of activity systems. All are concerned

with the object (learning outcomes), but each study focuses on different aspects of the activity including the physical tools (Turn Tables and Keva Planks), community (Magnetic Islands) and participant roles (Light Patterns).

III. STUDY DESIGN AND DATA COLLECTION

This research occurred within the context of a larger design-based research project to understand MOXI's visitor experiences and develop frameworks for effective facilitation [10, 11]. This was conducted through a Research-Practice Partnership (RPP) between the University of California at Santa Barbara (UCSB) and MOXI [12]. Researchers and practitioners at MOXI and UCSB have studied how the design and facilitation of exhibits engages visitors in practice-based learning by establishing a year-long training program for museum educators that culminates in a certificate in Informal STEM Learning [13]. Graduate student researchers from UCSB and MOXI museum practitioners formed teams to contribute to the ongoing research of the UCSB-MOXI RPP. In 2018, this involved establishing a framework to guide facilitation based on identifying engagement types for each exhibit [4]. To further understand the visitor experience at MOXI's exhibits, four teams each implemented a study of an exhibit.

Teams selected exhibits based on the following criteria: 1) Exhibit is open-ended, 2) Exhibit is permanent, and 3) Exhibit was not the focus of an earlier project. The four exhibits selected were Turn Tables, Keva Planks, Magnetic Islands, and Light Patterns. Each team determined engagement types and STEM practices, measured stay time and attendance at their exhibits, and developed research questions. Overall, the tasks and research questions focused on two themes: visitor learning experiences and exhibit manipulation.

Historically, "stay time" at a museum exhibit has been used as a measure of visitor engagement [14, 15], and is defined as the amount of time a guest engages with an exhibit. This is an efficient method to quantitatively compare guest engagement, but it is insufficient for determining the quality of that engagement. Thus, it is necessary to also observe or interview guests [14–16]. As such, all four teams conducted interviews lasting approximately 20 minutes with museum floor staff. These interviews included questions designed to elicit observations about how guests typically interacted with the focal exhibit and challenges guests and facilitators typically encountered. For example, staff were asked how they facilitate the exhibit and how they see different age groups use the exhibit.

All teams observed visitors at multiple times on different days over four weeks, wrote field notes about visitors' use of the exhibits, and recorded guest stay time. Then teams identified the ways visitors engaged with the exhibit and collapsed the observations into categories to result in 3–5 ways that collectively captured how most guests engaged with an exhibit. We refer to these observed behaviors as "engagement types". These engagement types were exhibit-specific and character-

ized by a variety of actions, such as building structures, collaboration with others, and exploring magnetism (see Tables I–IV for a complete list). Then, we identified STEM practices (adapted from the NGSS) for each engagement type [2]. Because the two are not identical, we use the term "STEM practices" to distinguish our practices from the NGSS.

Teams observed video of guests at their respective exhibits allowing for further data collection, both quantitative (how many guests interacted with the exhibit and how long they stayed) and qualitative (engagement type). Video and in-person observations were the central data source used to develop engagement types for the focal exhibits. Teams categorized the observed engagement types, which were then analyzed for evidence of STEM practices [2, 17]. The STEM practices that the four teams identified were: 1) observing, 2) asking questions, 3) defining problems, 4) planning investigations, 5) carrying out investigations, 6) analyzing and interpreting data, 7) designing solutions, 8) testing solutions, 9) developing models, 10) using models, 11) mathematical and computational thinking, 12) constructing explanations, 13) argue from evidence, 14) obtaining and evaluating information, 15) cause and effect, 16) scale, proportion, and quantity, 17) perseverance to achieve a goal, and 18) patterns. Complete descriptions of the focal exhibits, data collection and analysis, and findings follow. See Tables I–IV for engagement types for each exhibit and their associated STEM practices (as referenced by the numbers assigned above). Table V summarizes the findings from each of the focal exhibits.

IV. FOCAL EXHIBITS

In this section, we describe the four focal exhibits (Fig. 1) and the research questions, analysis, and findings specific to each exhibit. All statistical tests were done using R [18].

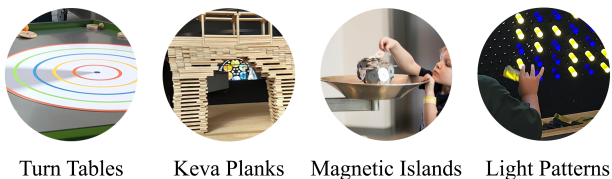


FIG. 1. Four Focal Exhibits. (Photographs courtesy of MOXI)

A. Turn Tables: Methods, Analysis, and Findings

The Turn Tables exhibit is a set of three rotating tables accompanied by various materials (e.g., straws, small wooden balls, and a dial that changes the speed of the table). According to interviews with museum floor staff, this exhibit is located in a high activity area. The multiple tables allow many guests to interact with the exhibit concurrently. Initially the tables were bare metal, and as part of this study, MOXI’s exhibit team collaborated with the research team to

design and install vinyl covers for two tables. This team investigated the influence of the graphic with colored stripes and a single gray radial stripe on guest stay time and engagement type (see Fig. 1). The research questions were 1) What STEM practices are evident when guests engage with Turn Tables? and 2) How does guest engagement type and stay time change after making an alteration to the exhibit?

The team recorded the number of guests ($n = 532$), guest stay time, and the quality of guest engagement. Interactions less than 1 minute were recorded as having a length of 0. If a single guest left the exhibit for more than 5 minutes and then returned, the second interaction was counted as new. It was otherwise considered a part of the initial interaction. Turn Tables had significantly more observations than the other focal exhibits due to its location and because there are three tables compared to one of each of the other focal exhibits.

The difference in mean stay time and engagement type before and after the graphic was added were compared using unpaired t -tests. Table I lists engagement types and STEM practices for Turn Tables. The team found that adding a graphic significantly increased average engagement ($p < .05$). Increase in engagement type meant that on average guests were more likely to place objects on the table with intent rather than throwing objects onto the table without intent, and therefore guests engaged in a higher number of STEM practices.

After adding the graphic, the mean stay time for guests who were engaged for at least one minute increased from 2.14 minutes to 2.66 minutes ($p < 0.05$). This indicates that manipulation of the exhibit increased guest stay time without compromising the open-ended nature of the exhibit; the visual representation did not provide the visitor any specific information or instructions. This implies that visual scaffolding designed to provide tools to the visitor but not constrain behavior may encourage more sophisticated exploration.

TABLE I. Turn Tables engagement and STEM practice(s)

Engagement Type	Definition	STEM Practice(s) (See Sec. III)
Touching	Touching the table or touching the objects on the table with no intention behind placement	1,2,4,6,12,14, 15,16
Manipulating Objects	Manipulating objects on the table with intent to change the motion of objects on the table or constructing unique objects for the table	1–10,12–18
Manipulating Speed	Changing the speed of the table with intent to manipulate the table objects	1–18

B. Keva Planks: Methods, Analysis, and Findings

Keva Planks are thin wooden blocks (4.5" x 0.75" x 0.25") that can be used to build a variety of structures. The planks are kept in a bin between two large tables with benches.

While this exhibit is simple in design, it allows for a wide variety of engagement. The research question was: How do the presence of existing structures and/or a facilitator at the exhibit affect guest engagement?

The team recorded the number of guests ($n = 126$), guest stay time, and the type of guest engagement at the exhibit. Interactions 30 seconds or more were recorded; if a guest left and returned, this was included as part of their total interaction. Each observation included whether a structure and/or facilitator were already present at the exhibit. This team collected qualitative data to examine both how museum guests engaged with the exhibit and how facilitators interacted with guests at the exhibit.

This team used ANOVA with a Bonferroni post-hoc test to determine whether there was a difference in guest stay time when a facilitator and/or structure were present. Engagement types were evidenced through basic manipulation of the blocks, original creations with increasing complexity, modification of existing structures, or collaboration. Associated STEM practices included observing, designing and testing solutions, and perseverance to achieve a goal (Table II).

When a facilitator and structure were both present at the exhibit, mean stay time was 7.9 minutes. When only a structure was present, mean stay time was 3.9 minutes. When neither a structure nor facilitator were present, mean stay time was 5.4 minutes. Researchers only found a statistically significant difference in mean stay time between both facilitator and structure present and only a structure present ($p < .05$). This study shows that facilitators and features that maintain the open-ended nature of the exhibits increase opportunities for engagement in STEM practices as measured by stay time.

TABLE II. Keva Planks engagement and STEM practice(s)

Engagement Type	Definition	STEM Practice(s) (See Sec. III)
Observing	Looking at the planks or watching someone build	1
Basic Manipulation	Touching or moving planks with no attempt to build anything	1,2,3,15,16
Original Building	Simple stacks of planks without any change in pattern; Simple tower without variation in pattern, height can vary; Symmetrical balancing structure; Asymmetrical balancing structure; Building with a story/goal/function	1–11,15–18
Modifying/ Copying	Adding to an existing structure (continuing the pattern); Copying an existing structure (building their own)	1,2,3,6–11, 15–18
Collaboration	Working with a non-staff member to complete a project	1–4,6–11, 15–18

C. Magnetic Islands: Methods, Analysis, and Findings

Magnetic Islands consists of three metal "islands" branching out from a center pole at different heights. Each island contains two large, powerful magnets with metal washers stored in a bucket below. The exhibit-specific research question was: How does visitor type (alone, with peers, or with adults) impact stay time and engagement type? This team used primarily qualitative methods, collecting data regarding guest engagement ($n = 165$) and making connections to STEM practices, making note of specific actions, ways of using the exhibit, and interactions between guests at the exhibit. Specifically, researchers recorded whether guests worked alone or with others (> 5 seconds) at the exhibit. Researchers used emergent coding [19] for data analysis. Behaviors were coded according to four engagement types which were analyzed for evidence of STEM practices.

The team documented three main engagement types: playing, building structures, and exploring magnetism (See Table III). Findings indicate that all engagement types provided guests opportunities to engage in STEM practices such as asking questions and designing solutions. However, building structures and exploring magnetism were engagement types linked to a higher number of STEM practices. Importantly, this research team found that when guests engaged with others rather than alone, they were more likely to engage in building structures or exploring magnetism than playing.

TABLE III. Magnetic Islands engagement and STEM practice(s)

Engagement Type	Definition	STEM Practice(s) (See Sec. III)
Playing	Touching or pulling washers, placing washers in the bucket, or play with existing washers on exhibit	1,2,14,15,16
Building Structures	Bridges on or across islands, pyramids or vertical structures, or chains hanging down from buckets	1–9,12,14
Exploring Magnetism	Intentionally testing magnetic field. (e.g., placing a hand between a magnet and washer or testing different materials to see if they stick)	1–10,14

D. Light Patterns: Methods, Analysis, and Findings

The Light Patterns exhibit spans the length of one wall of the museum, approximately 15 feet long and 7 feet tall. The black wall is artificially backlit so that light shines through a grid of 1" holes spaced 2" apart. A trough at the foot of the wall contains 6" acrylic pegs of various colors. Visitors place the pegs into grid holes to create shapes and pictures. One side of the peg is slightly smaller than the other, which creates an alignment challenge for younger guests. When placed all

the way into the hole, the pegs become illuminated. Initial interviews with museum staff indicated the popularity of this exhibit with very young guests (ages 0–4 years), so this team chose to study this subset of the guest population.

The team used primarily qualitative methods. They collected data regarding the type of guest ($n = 130$) engagement and linked this engagement to STEM practices, noting specific dialogue, actions, ways of using the exhibit, and guest-guest interactions. An interaction was recorded as long as the guest touched any part of the exhibit; if they left and returned, this was included as part of the initial interaction. Researchers used emergent coding [19] during data analysis. Behaviors were coded according to four engagement types and analyzed for evidence of STEM practices (See Table IV).

TABLE IV. Light Patterns engagement and STEM practice(s)

Engagement Type	Definition	STEM Practice(s) (See Sec. III)
Tactile Exploration	Holding, throwing, touching, feeling pegs	1,2,14,15
Selection Process	Choosing specific colored pegs to make a picture (e.g., red pegs to make a heart)	1,15–18
Peg and Wall Interaction	Play with inserting pegs into wall	1,2,3,14–18
Peg Play	Focusing on the pegs independent of the wall (e.g., balancing pegs on previously inserted pegs in the wall)	1,2,5,15

Findings show that the engagement types of young children at Light Patterns are associated with STEM practices such as asking questions, making observations, and recognizing patterns. However, researchers found that young children were often directed by adults to interact with the exhibit by placing the pegs in the wall and pushing them in to light up (peg and wall interaction). This directed instruction detracted from the natural ways young children explored Light Patterns (e.g., tactile exploration or peg play).

These results show that overly-directed learning experiences limited the creative ways that young children engaged with the exhibit and reinforce the importance of supporting multiple ways of interacting with exhibits. The toddlers in this study interacted in ways that were developmentally appropriate and yet adults redirected their play because it was not seen as the "intended" way to use the exhibit.

V. DISCUSSION

In museums, guests may interact with the exhibits for as little or long as they want. These four studies whose findings are summarized in Table V and others [17] describe the complex ways that visitors engage with exhibits which lead

to powerful learning experiences. The work presented here focuses attention on how to design exhibits to engage guests in NGSS-aligned learning experiences.

Guests benefit from practice-based learning through collaboration with peers or museum facilitators but if the goal is to provide open-ended experiences, as ours is, interactions should allow guests to ask their own questions, design solutions, or construct explanations. These experiences encourage extended exploration, providing time and space to meaningfully engage in STEM practices. Findings from the studies of the four focal exhibits indicate that visually interesting and engaging exhibits and room to play with others are important for stay time and guest engagement. This suggests that small design changes to the physical exhibits and increasing opportunities for social interaction and collaboration can increase stay time as well as lead to more complex engagement.

These four studies also have implications for researchers and practitioners interested in collaborating on research in informal learning spaces. Researchers contributed expertise on the study design and practitioners contributed expertise on the setting. Teams worked together in the initial stages to effectively share their knowledge in order to progress cohesively throughout the research process. Furthermore, there were opportunities and challenges in working in an informal space. A wide variety and large number of guests visited the museum, which provided many opportunities for detailed observations. However, research teams could not control whether a guest stopped at their exhibit or the kind of collaboration that occurred between guests (e.g., they could not facilitate the exhibit). Finally, developing Research-Practice Partnerships (RPP) between institutions of higher education (e.g., UCSB doctoral students) and museums or other informal science learning institutions (e.g., MOXI facilitators) provides opportunities for collaboration at multiple levels.

TABLE V. Summary of focal exhibit findings.

Focal Exhibit	Findings
Turn Tables	Exhibit design that is interesting and engaging without being overly-directive led to a statistically significant increase in engagement
Keva Planks	Presence of an existing structure and facilitator resulted in a statistically significant increase in guest stay time
Magnetic Islands	Children exhibited more complex engagement types when engaged with peers rather than when they visited alone
Light Patterns	Simple exhibit design provided young children opportunities to engage in creative and complex STEM practices

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