Science on the Move:

A Design-Based Research Study of Informal STEM Learning in Public Spaces

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Abstract

This article describes a design-based research (DBR) study conducted as part of a larger initiative, *Science on the Move*, intended to bring non-facilitated and unexpected science, technology, engineering, and math (STEM) learning experiences to public transit stations. Drawing from prior research on situational interest, pedestrian navigation, and design affordances, the study was intended to (a) support the development of exhibit prototypes in transit stations and (b) build a theoretically-grounded conjecture map of multi-stage visitor attention, including factors which support or discourage engagement in these settings. The team iteratively tested and refined two exhibit prototypes, collecting data through tracking and timing, naturalistic observation, and structured interviews. The final conjecture map posits three stages of attention and situational interest, an underlying appraisal process guiding movement across these stages, and specific environment-person factors relevant at each stage. Findings also suggest several critical differences in designing for attention and interest in transit centers, given the importance of mental schemas and social norms in navigation and choice. These results, while specific to the local context of the study, provide researchers and practitioners with theoretical frameworks to build upon with regard to audience attention and engagement and the design of informal learning experiences in public spaces.

Keywords: Design-based research, situational interest, attention, design affordances, informal learning, science education

This article describes a design-based research (DBR) study conducted by the Oregon Museum of Science and Industry (OMSI) as part of *Science on the Move*, a National Science Foundation-funded initiative intended to bring non-facilitated and unexpected science, technology, engineering, and math (STEM) learning experiences to Portland-area public transit stations. This project responded to a need identified by the National Research Council (NRC) for life-long learning opportunities to help adults understand and interpret complex scientific information with the potential to impact their lives (NRC, 2009). Research indicates that free-choice learning experiences constitute significant contributors to adult science knowledge (Falk & Dierking, 2010; Falk & Needham, 2013) and that science centers and museums offer a combination of structure and freedom that differs from other venues for free-choice learning (Falk & Dierking, 2013; NRC, 2009). However, while Americans spend over 80% of their waking hours outside schools (Banks, 2007) and science museums have been found to be effective in providing STEM education to those who visit (NRC, 2009), only 25% of the adult public visits such institutions, with visitorship by adults with no college experience remaining as low as 8–16% (NSB, 2014).

Science on the Move was intended to explore creative avenues to better reach adults, particularly those without college degrees, by providing location-relevant STEM content in public spaces. Importantly, the implementation of a DBR approach allowed us to increase our theoretical understanding of factors that encourage or discourage engagement in these settings. DBR, also known as “design research,” is characterized by iterative cycles of research and design, investigations in authentic learning environments, the development and testing of theories and conjectures, and collaboration with practitioners (Cobb, Confrey, diSessa, Lehrer, &

Schauble, 2003; Collins, Joseph, & Bielaczye, 2004; Kelly, Baek, Lesh, & Bannan-Ritland, 2008).

The educational goals of this project were to (a) engage Portland-area adults with STEM-rich experiences in public transit stations and (b) communicate contextually-relevant messages about STEM topics through the creation and iterative refinement of two exhibit prototypes. In keeping with the project's DBR framework, we simultaneously pursued our research goal of developing and refining a high-level conjecture of multi-stage visitor attention. This conjecture was intended to serve as a connector between relevant theoretical principles and real-world primary data collected and analyzed over the course of the project and was designed to articulate the factors of greater or lesser importance in affording or constraining visitor behavior within this unique context. In order to accomplish this, we employed a technique known as conjecture mapping; this approach involves the explicit articulation of theoretically-supported claims (or conjectures), with key elements of the educational intervention being clearly mapped as an "embodiment" of one such conjecture (Sandoval, 2013). Based on prior research regarding interest development, we identified the concept of *situational interest* (SI) as a desired behavioral outcome for participants. By using the conjecture mapping process, we hoped to refine our understanding of how SI is triggered and maintained in public spaces.

Literature Review

The theoretical conjectures posited and refined over the course of *Science on the Move* informed by two primary bodies of scholarship: (a) situational interest and (b) pedestrian navigation. Together the concepts formed the foundation for the interactive STEM exhibit prototypes developed during the project and our initial conjecture map provided at the conclusion of this section, as well as the contextual theoretical model that took shape throughout iterative data collection and refinements.

Situational Interest

The specific context of this study led us to focus on the concept of *situational interest* (Dohn, 2011; Hidi & Renninger, 2006; Renninger & Hidi, 2011; Renninger & Su, 2012; Rotgans & Schmidt, 2011; Silvia, 2006). Situational interest (SI), broadly speaking, is the excitement, curiosity, and positive emotions triggered by a specific topic, object, or event that motivates individuals to focus attention and exert effort (Dohn, 2011; Hidi & Renninger, 2006; Renninger & Su, 2012; Rotgans & Schmidt, 2011; Silvia, 2006). For the *Science on the Move* project, we felt that sparking SI might offer a promising approach to capturing participants' attention and encouraging engagement with the prototypes, particularly in light of its role as a precursor to the development of more enduring personal interest (Renninger & Hidi, 2011; Renninger & Su, 2012).

Interest in general, and SI specifically, is widely acknowledged as an essential motivational variable critical to learning and education (Renninger & Hidi, 2011). SI has been positively associated with attention and focus, persistence, goal setting and self-regulation, comprehension and cognitive processing, memory and recall, and use of effective learning strategies (NRC, 2000, 2009; Kang, Scharmann, Kang, & Noh, 2010; Lewalter & Scholta, 2009; Renninger & Su, 2012). In their influential four-phase model of interest development, Hidi and Renninger (2006) distinguish between triggered SI and maintained SI, with triggered SI being associated with short-term changes in affective and cognitive processes and maintained SI reoccurring or extending over a longer time period. Other scholars have described these two phases as the "catch" and the "hold" (Linnenbrink-Garcia et al., 2010, p. 648). The four-phase model of interest development posits that SI is a critical first step in the development of more enduring, individual interest (Hidi & Renninger, 2006; Renninger & Hidi, 2011).

Despite its potential relevance, minimal research has been conducted to date on the factors related to SI in informal learning environments. Based on various studies (Hidi & Renninger, 2006; Lewalter & Scholta, 2009; Palmer, 2004; Renninger, 2010; Renninger & Hidi, 2011; Rotgans & Schmidt, 2011; Silvia, 2006; Dohn, 2011), commonly cited factors that help to trigger and maintain SI include (a) novelty; (b) personal relevance; (c) appropriate levels of challenge; (d) hands-on activities and experiences; (e) intensity; (f) understandability; (g) computers, including attractive software design; (h) social interaction; and (i) individual choice. There is also some evidence that positive feelings are critical for sparking and maintaining interest and that personal relevance and meaningfulness are particularly important for sustaining SI (Hidi & Renninger, 2006; Renninger, 2010).

In this study, we began with the assumption that interest is a fundamental motivator of human behavior. We then used Hidi and Renninger's (2006) model of interest development as a guiding framework to conceptualize how individuals first become aware of a new experience in a public setting, feel an initial spark of triggered SI, and, in some cases, maintain this SI long enough to engage with the experience more deeply. The triggers of SI listed above were also used to develop initial conjectures about the aspects of the prototypes that might or might not support individuals moving through different stages of attention and interest, as well as particular ways that design characteristics could be embodied for specific prototypes.

Pedestrian Navigation

Once the project team had identified SI as a key concept to frame the desired outcomes of attention and engagement, we became acutely aware of the importance of understanding *pedestrian navigation*, or the ongoing process of conscious and non-conscious appraisals and reactions by individuals as they navigate the environments in which they find themselves during the course of their daily activities (Bitgood, 2002, 2011; Gibson, 1979; Golledge & Stimson, 1997; Kaplan, Kaplan, & Wendt, 1972; Lynch, 1960). As we hoped to posit and test conjectures regarding the ways in which specific elements of the designed environment (referring both to the prototypes themselves and to the surrounding transit stations) influenced pedestrian navigation and engagement patterns, we drew particularly from literature regarding *design affordances* (Gibson, 1979; Norman, 1988), with a specific focus on their usage in the field of informal learning environments (Achiam, May, & Marandino, 2014; Allen & Gutwill, 2004; Eberbach & Crowley, 2005; Mortensen, Rudloff, & Vestergaard, 2014; Wineman & Peponis, 2010). This literature also provided a point of connection between established operationalizations of individual attention and the concept of SI.

Studies of navigation explore the processes by which individuals' conscious and non-conscious needs, desires, expectations, and preferences shape the ways in which designed environments and experiences are navigated. As noted above, the experiences developed during the *Science on the Move* project were intended to engage public transit users who were not seeking or anticipating an informal learning experience. In order to draw pedestrians[i] to the experience where SI might be triggered, it was critical to understand how these pedestrians were navigating transit stations and what overarching concepts and principles were guiding their movement through and interaction within the environment.

A number of studies have included aspects of economizing behavior (Gibson, 1979; Golledge & Stimson, 1997; Kaplan, 1992; Kaplan et al., 1972; Lynch, 1960). In *Science on the*

Move, we drew particularly from Bitgood's (2010) behavioral economics perspective, which focuses on *attention* and *value ratio* as key concepts.

Attention and value. The project team recognized that attracting the *attention* of pedestrians in transit stations would be a critical first step in eliciting engagement. Bitgood (2010, 2013) described attention as including a continuum of three stages—capture, focus, and engagement—and posits that (a) combinations of variables elicit different responses across these three stages; (b) the responses in each stage are influenced by interactions of person and environment factors; and (c) each of the three stages is characterized by a different set of outcomes or dependent variables (Bitgood, 2013, pp. 17–18). He argued that capturing, focusing, and engaging attention is dependent on perceived value, and defined the perceived *value ratio* as benefit (utility, satisfaction) divided by cost (time, money, effort). By identifying the person-environment factors, or *design affordances*, that are part of the perceived value ratio and identifying the appropriate dependent variables representing attention, it is possible to manipulate and measure humans' attention within a setting.

Design affordances. Affordance frameworks (Gibson, 1979) have seen substantial use in a number of creative endeavors, including the development of virtual environments (Dickey, 2003, 2005; Ho, Nelson, & Müeller-Wittig, 2011), electronic and computer-mediated interfaces (Gu, 2014; Levy, Aiyegbayo, & Little, 2009; Louw & Crowley, 2013; Sommerauer & Müller, 2014), and human interaction in general (Erickson, 2010; Fayard & Weeks, 2007). However, it is Norman's (1988) *design affordance* terminology that has been most widely employed in studies of informal learning environments (Achiam et al., 2014; Allen, 2005; Eberbach & Crowley, 2005; Monti & Keene, 2013; Mortensen et al., 2014; Reich & Parkes, 2005; Rowe, 2002).

The specific design characteristics of access and visibility within museums have been found to afford or, by their absence, constrain behaviors of exploration, engagement, and understanding (Wineman & Peponis, 2010). Allen and Gutwill (2004) noted the remediation of physical affordances as a means by which common exhibit pitfalls may be addressed. In addition to recognizing the ways in which specific characteristics of exhibits might afford or constrain intended (or unintended) visitor behavior, recent research (e.g., Achiam et al., 2014; Calvera & Pombo, 2011) emphasized the importance of recognizing the significance of individuality in shaping visitor experiences. Every visitor brings idiosyncratic meanings and interpretations that will be assigned to a designed object or experience based on personal histories, beliefs, desires, and perceptions (Calvera & Pombo, 2011).

Initial Conjectures and Research Questions

Taking the prior research and theory described above into account, a number of conjectures began to emerge. Individual interest acts as a central motivator of human behavior, and within the context of creating and refining informal learning experiences in public spaces, SI offered a promising outcome toward which to direct our efforts. There was also some evidence that we could characterize different and incrementally deeper stages of attention and engagement through observation of individual behavior. Related to this, we believed that movement from one stage of attention to the next, as well as overall navigation of the experiences and surrounding spaces, would be contingent upon both conscious and non-conscious choices on the part of participants. These choices were likely to be based on some form of appraisal arising from cues and affordances present in the designed and natural environment, including affordances related to unexpectedness, novelty, understandability, and perceived interestingness and personal relevance.

Building upon this foundation, we developed an initial conjecture map, including a set of conjectures that we felt could be "embodied" through specific design choices:

- Different types of strategies will be necessary to move audience members from unaware to capturing attention, from capturing to focusing attention, from focusing attention to engaging, and from initial engagement to prolonged or deeper engagement.
- Design characteristics (including surprising or incongruous presentation, visual cues, audio cues, motion cues, text and other content placed at a broadly accessible level) will increase the likelihood of visitors noticing an exhibit or experience.
- Certain factors (including novelty, understandability, personal relevance, individual choice, and hands-on activities) will increase the likelihood of visitors attending to an exhibit or experience.

Given these overarching conjectures, and bearing in mind our goals of (a) engaging Portland-area adults with STEM-rich experiences in public transit stations, (b) communicating contextually-relevant messages about STEM topics, and (c) developing and refining our understanding of factors that afford or constrain visitor behavior within the unique context of public transit stations, the following research questions were identified:

*Research Question 1***:** In general, how are audience members noticing, using, and reacting to the exhibit prototype?

*Research Question 2***:** What elements of the designed prototype, as well as other social, physical, and personal context factors, afford or constrain the achievement of the intended project impacts?

Bitgood's (2013) three-stage model of attention offered what we considered a key point of potential conceptual and operational overlap between navigation and the team's desired behavioral outcome of SI. As noted above, no clear and consistent operationalizations of SI have yet been established (Azevedo, 2015; Renninger & Hidi, 2011). It was our hope that the integration of an established multi-stage framework of attention might provide a possible starting point for the measurement of SI and the understanding of attention and engagement at exhibits in public spaces.

Method

In order to test and refine the initial and subsequent iterations of our conjecture map, a design-based research study design (Brown, 1992; Cobb et al., 2003; Collins et al., 2004) was employed to provide a framework for the theoretical and practical components of the project. Design-based research, most commonly used in school settings to improve instruction, includes the methodological goals of (1) "[improving] the initial design by testing and revising conjectures as informed by ongoing analysis" (Cobb et al., 2003; p. 11), and (2) "[developing] a class of theories about both the process of learning and the means that are designed to support that learning" (pp. 9-10). Building on this conceptualization as a framework for our research goals, design-based research in the context of the current study refers to the flexible and iterative development, testing, and revision of contextually-relevant educational interventions (in this case, science exhibits) that contribute to the emergence of small theories through the establishment and ongoing refinement of multiple distinct and measurable embodiments of guiding theoretical conjectures. Based on the principles of design-based research (e.g., Cobb et al., 2003; Cobb & Gravemeijer, 2008), the *Science on the Move* research study included three main phases: (1) *preparing for the experiment*; (2) *progressive refinement*; and (3) *retrospective analysis*.

Preparing for the Experiment

During this initial phase, researchers reviewed relevant prior studies, including research on situational interest and bus stop behavior; conducted a secondary analysis of data from the General Social Survey (National Data Program for the Sciences, n.d.) to assess relevant trends among national and local populations; and interviewed members of the project's target audience and other adults at local transit stations. Responses collected during these interviews were intended to (a) determine unique characteristics of the target audience, as well as any perceptions and beliefs they might hold regarding science, and (b) identify topics or themes that are interesting and personally relevant to the target audience and bus riders more generally. These front-end findings, documented elsewhere (Cardiel & Pattison, 2014), guided the development of the team's initial theoretical conjecture in preparation for progressive refinement.

Progressive Refinement Phase

The research process employed during progressive refinement included approximately ten months of conjecture map testing through the use of "design mini-cycles" (Cobb & Gravemeijer, 2008) during project year two. During each mini-cycle, the team engaged in tracking and timing, naturalistic observation, and structured interviews to explore whether the assumptions elaborated in the conjecture map were upheld or contraindicated, as well as how the design and content of the exhibit and characteristics of the environment and the audience influenced the nature and outcomes of the experience. This allowed the research team to test and refine its interrelated conjectures regarding how best to engage adults in non-facilitated, interactive informal learning experiences outside museum walls.

Two prototype exhibits, entitled "Chicken Scene Investigation" and "Make Me a Monster," were used during the progressive refinement phase. "Chicken Scene Investigation" was a multi-component exhibit that invited audience members to explore a mock crime scene to find evidence regarding which urban predator was responsible for a recent “chicken-napping.” Participants could share their guess and rationale about which suspect committed the crime via text or by writing on a large chalkboard. “Make Me a Monster” was an interactive touchscreen exhibit that invited participants to capture an on-screen picture of themselves with a digital “monster mask” on their face. Participants were offered the opportunity to upload their photo to the OMSI website, after which the prototype provided information about animators and technology experts at Bent Image Lab, a local animation company. Each of these prototypes was revised continuously throughout progressive refinement in parallel with changes to the conjecture map.

Data collection during this phase was guided by the overarching research questions, as well as more analytic questions specific to each mini-cycle. An example of one such analytic question is “What information is available and salient to visitors at each stage of the engagement process?”. In general, during the first week of each mini-cycle, one prototype was tested at transit stations for approximately two days to determine any small changes that should be made in order to best facilitate target audience impacts, with the remainder of the week devoted to implementation of these small changes by the design team. During the second week of the mini-cycle, the exhibit prototype was tested at transit shelters for an additional two days, resulting in a total of four days of data collection per mini-cycle. At the conclusion of these testing periods, researchers assembled a brief report of results and discussed any relevant findings with the larger project team. Based upon these results, the project team then devoted several weeks to making larger adaptations to the exhibit prototype and the conjecture map.

Sampling and recruitment. During the course of progressive refinement, researchers observed and recruited participants from among adult TriMet riders at the Gresham Transit Center and the Rose Quarter Transit Center, both of which are located within the greater Portland, Oregon area. These sites were chosen, based on census data (United States Census Bureau, 2013) and recommendations from TriMet staff, to maximize the inclusion of adult riders without college degrees (the target audience of the project) and ensure suitability for prototype placement (e.g., electrical access). Data collection at these sites took place over a period of 3–4 calendar days per mini-cycle for a total of 23 days. Data were collected for approximately two and a half hours per day, for a total of approximately 10 hours of data collection per mini-cycle. Every effort was made to ensure that the testing location, time of day, and day of the week remained constant across data collection shifts across (and, when appropriate, within) mini-cycles.

When conducting observation-based research activities, researchers employed a systematic sampling method (Lewis-Beck, Bryman, & Liao, 2004) with a sampling frame consisting of all individuals present at the two selected transit stations during the periods of researcher observation. The sampling method employed for audience interviews was the same; however, the sampling frame consisted of all *adults* (18+) present at the two selected transit stations during the research period. During data collection, two bilingual (Spanish and English) signs were placed approximately 25 feet from either side of the exhibit, indicating that research activities were currently underway[ii].

A total of 767 individuals (53.9% male) were included in timing and tracking data collection across the six mini-cycles. A substantial majority of these individuals (92.8%, *n* = 712) were estimated to fall within the 19–35 age group or older. A total of 102 individuals were approached for participation in post-use interviews, with 13 declining to participate; this resulted in a response rate of 87.3% and a final sample of 89 individuals (52.8% male, 75.3% with no formal college degree and 78.7% with no more than an Associate's degree or equivalent). Lastly, 180 individuals whose attention was at least captured but who did not engage with the prototypes provided brief non-use survey responses; no demographic data were collected regarding these individuals.

Data collection procedures. Prior to the first mini-cycle, researchers conducted pilot testing of the complete data collection procedure outlined below, including testing of the various data collection instruments being developed for use, as well as training sessions with research support staff involved in data collection.

Timing and tracking. At the beginning of each mini-cycle, two researchers and other members of the project team set up the exhibit prototype at a transit shelter and then positioned themselves in locations that permitted a clear view of all angles of approach to the prototype. Using a checklist-based instrument with sections capturing both hold time and the presence of specific behavioral markers (e.g., taking a picture, pointing, collaborative use with others), the first of the two researchers (Researcher A) timed and tracked the first audience member to pass within 25 feet of the prototype until they either moved beyond the 25-foot threshold or their attention was diverted from the prototype for at least 60 seconds. As soon as either of these conditions was met, Researcher A ceased tracking that individual and repeated the process with the next audience member to pass within 25 feet of the prototype, with this process continuing throughout the data collection shift. During these timing and tracking activities, Researcher A also approached every fourth tracked audience member (provided their attention was captured by and/or focused on, but they *did not engage with*, the prototype) and asked them to share (a) the reason(s) why they chose not to engage with the prototype, and (b) their general impressions of the prototype. After responding to these questions, the audience member was thanked for their time and Researcher A returned to timing and tracking activities as outlined above.

During the first data collection shift of each Mini-Cycles 1 through 5, interrater agreement was assessed through the involvement of an additional researcher collecting timing and tracking data alongside Researcher A, with results assessed prior to the subsequent data collection shift. Interrater agreement for all categorical variables was assessed through simple percent agreement and was generally very high, with 83% of the variables remaining above 90% agreement. Interrater agreement for the continuous variable of hold time was calculated using Pearson product moment correlation and demonstrated a nearly perfect level of agreement, $r(142) > .99$, $p < .001$. Only one variable, the estimated age group of the individual being tracked, was assessed at below 80% agreement; this variable achieved an overall agreement level of 70%, which was considered to indicate an acceptable level of agreement due to its inclusion of six possible response categories in contrast to the dichotomous nature of the majority of the other variables assessed.

Naturalistic observation. Tracking and timing data collection occurred simultaneously with naturalistic observations conducted by a second researcher, Researcher B. Rather than tracking dwell times and specific previously-operationalized behaviors, Researcher B observed audience behavior and interaction more broadly, drafting extensive fieldnotes, following Emerson, Fretz, and Shaw (2011). Using the theoretical constructs and related behavioral markers of interest and attention as “sensitizing concepts” (Blumer, 1969; Charmaz, 2006), Researcher B attended to the holistic research environment and the behaviors and characteristics of the individuals who passed within its boundaries.

Post-use interviews. In addition to conducting these naturalistic observations, Researcher B also regularly conducted post-use interviews with participants. The first observed adult who reached the "engage" stage (either direct engagement, involving touching the prototype, or indirect engagement involving watching others use the prototype) was approached after their engagement with the prototype ended or after they had engaged with the prototype for three minutes (whichever came first) and were offered the opportunity to participate in a brief post-use interview. Interviews with users included open-ended questions intended to assess which aspects of the exhibit prototype were especially appealing, engaging, confusing, uninteresting, and salient (examples of such questions include "If a friend asked you what this exhibit was about, what would you say?" and "Once you noticed it, what made you decide to go up and find out more about the exhibit?"); demographic questions; and eight Likert-style questionnaire items (Babbie, 2014) focused primarily on connections with STEM topics. Other variables that were tracked during data collection include participant characteristics (prior interests, age, gender, education, and transit use); weather; physical context, such as noise or crowding; and social context, including the presence of and relationship to other people.

The unit of analysis for all data collection activities was individuals, but researchers attended closely to group behaviors and dynamics, particularly as pertaining to influence (positive or negative) on likelihood of individuals to engage with prototypes and frequency of indirect audience experience. As is common in design-based research studies, some small changes were occasionally made on the spot based on the data collected by both researchers, such as moving the exhibit prototype from one location to another within the transit station or making small changes to the copy or the physical structure and layout of the prototype. For instance, when non-use survey responses indicated a misapprehension among passersby that

"Make Me a Monster" would cost them money to use, a handwritten note was quickly prepared and applied to elucidate the free nature of the experience. In all cases, however, any such changes were documented and carefully considered during team discussion, with any theoretical implications noted.

Data analysis. At the conclusion of the data collection phase of each mini-cycle, researchers prepared an express report to be shared with the project team and led a discussion regarding whether each embodiment and other elements of the conjecture map were supported or contraindicated. If parts of the conjecture map were not supported, this was documented, and the team discussed the changes and adaptations necessary to realign the conjectures based upon the most recent research findings. In order to document the process, notes from team discussions, relevant quantitative findings, and a summary of the changes made to the conjecture map were briefly summarized and archived. At this time, any open-ended fieldnotes compiled during data collection were also transcribed into digital form and archived for later reference. Responses to open-ended post-use interview and non-use survey questions were analyzed through an iterative process of initial open coding to identify emergent themes, followed by axial coding to assign responses to one or more of these themes while simultaneously permitting themes to shift as appropriate on the basis of newly-collected data. Lastly, based upon research findings and team discussions, research and design team members adapted the exhibit prototype to test new aspects of the conjecture map. This pattern continued through the entirety of the progressive refinement phase, with each mini-cycle and the continually evolving conjecture map being informed by lessons learned in the previous cycles, until the sixth mini-cycle was concluded.

Retrospective Analysis Phase

This phase of research took place over the course of the final six months of the project timeline. In keeping with Cobb and Gravemeijer (2008), retrospective analysis involved reviewing data collected throughout the design-based research study, distinguishing between “what is necessary and what is contingent” (p. 75) for the success of the impacts, documenting the research process, searching for alternative explanations through a constant comparative method, attending to issues of trustworthiness and generalizability, and establishing a final iteration of the conjecture map. To ensure rigor and trustworthiness, the team adhered to recommendations from design-based researchers (e.g., Cobb & Gravemeijer, 2008), including (a) documenting underlying processes and identifying important contextual factors; (b) making assumptions and theoretical perspectives explicit; (c) thoroughly documenting the analysis process; and (d) encouraging external critique.

The first portion of this phase was devoted to a holistic analysis of the data collected during front-end research and progressive refinement, as well as the meeting notes and other documents generated by researchers and other team members. Researchers reviewed these documents and data with the overarching purposes of (a) “telling the story” of the first 20 months of the project as holistically as possible; (b) checking the assertions made by the team against the full body of data collected in order to identify and explore any contradictory evidence; (c) reviewing and comparing the multiple iterations of the conjecture map, with particular attention paid to exploring changes made and the thoughts underlying those changes; (d) seeking out emergent themes across the full dataset that may not have been identified during more focused research phases; and (e) unifying and refining the maps developed for each of the two prototypes into a single final summative version based on holistic analysis of project data. In addition to this holistic data analysis, at two points during the retrospective phase, researchers scheduled an extended meeting with the project team to engage in shared reflection and discussion of research findings.

Results

The results of data analysis supported our high-level theoretical conjecture regarding multiple stages of attention and also informed more granular conjectures regarding specific theoretical embodiments. The following findings are structured in alignment with our key theoretical concept areas: Attention and interest, navigation and affordance, and emergent effects related to context and social norms. Additionally, although they were not included as a primary component of our initial preparatory research, the importance of social norms and contextual effects became clear within our first mini-cycle, affecting visitor perception of design characteristics, willingness to approach or engage, and connections with the STEM nature of experiences.

Attention and Interest

Through iterative reflection and refinement, and drawing upon evidence collected through the varied methods, a process of attention development emerged that clearly illustrates an increase in visitor hold time from stage to stage, both for each of the two individual prototypes and for the combined dataset overall. Based on Bitgood's (2013) framework, we identified distinct observable behaviors that served as indicators of movement into and through the three stages of attention. Table 1 provides a concise listing of the indicators employed during timing and tracking of visitors to assess movement into and through stages of attention.

Table 1
Behavioral indicators of attention stage

Phases of Attention (Bitgood, 2013)		
Capture	Focus	Engage
Eyes on for at least two seconds	Eyes on for at least five seconds	Eyes on for ten seconds or more
	Pointing	Touching exhibit
	Approaching with purpose	Taking pictures
	Eyes on for ten seconds or more, if no other indicators present	Collaborating with others who are engaging
		Reading signage or copy panels
		Talking to others about exhibit

An analysis of timing and tracking data across all 767 individual visitors tracked during the study indicated that 65% (*n* = 499) reached at least the "capture" stage, 48% (*n* = 366) reached at least the "focus" stage, and 32% (*n* = 245) engaged with the prototype either directly or indirectly. A full distribution of conversion rates is provided in Table 2, with hold times overall and for each stage of attention provided in Table 3.

Table 2
Visitor conversion rates by prototype

	Chicken Scene Investigation			Make Me a Monster			Overall		
Stage of Attention	*N*	% (from previous stage)	% (overall)	*N*	% (from previous stage)	% (overall)	*N*	% (from previous stage)	% (overall)
Unaware	441	--	100	326	--	100	767	--	100
Capture	302	68.5	68.5	197	60.4	60.4	499	65.1	65.1
Focus	232	76.8	52.6	134	68.0	41.1	366	73.3	47.7
Engage	147	63.4	33.3	98	73.1	30.1	245	66.9	31.9

Table 3
Visitor hold time by prototype

	Chicken Scene Investigation		Make Me a Monster		Overall	
Stage of Attention	Mean	Median	Mean	Median	Mean	Median
Overall, including Unaware	0:39	0:13	0:35	0:09	0:37	0:12
At least Capture	0:52	0:17	0:50	0:26	0:51	0:20
At least Focus	1:05	0:33	1:07	0:46	1:06	0:37
Engage	1:34	0:59	1:22	1:11	1:29	1:04

The identification of these stages and specific behavioral indicators allowed us to consider the ways in which certain design elements affect visitor navigation and afford or constrain movement into and through the process of attention.

Navigation and Affordance

In order to determine the specific elements of the prototype experiences that contributed to movement into and through stages of attention, participants were asked to describe both what caused them to initially notice the exhibit and what subsequently led them to explore it more deeply. An overall distribution of post-use interview themes related to self-reports of what elicited initial notice of the prototypes is provided in Table 4, with self-reported causes of attention provided in Table 5.

Table 4
Responses to "Do you know what made you first notice the exhibit?" by prototype

	Chicken Scene Investigation (*N* = 52)		Make Me a Monster (*N* = 37)		Overall (*N* = 89)	
Theme	*N*	%	*N*	%	*N*	%
Ancillary exhibit components	17	32.7	15	40.5	32	36.0
Primary exhibit component	19	36.5	8	21.6	27	30.3
OMSI signage/branding	8	15.4	7	18.9	15	16.9
Unusual or unexpected presence	7	13.5	8	21.6	15	16.9
Scale of exhibit	2	3.8	8	21.6	10	11.2
Audio components	6	11.5	0	0	6	6.7
Attention directed to it by others	4	7.7	2	5.4	6	6.7
Functional exhibit components	2	3.8	3	8.1	5	5.6

Note: Themes with an overall rate of ≤ 5% are excluded from this table

Table 5
Responses to "Once you noticed it, what made you decide to go up and find out more about the exhibit?" by prototype

	Chicken Scene Investigation (*N* = 52)		Make Me a Monster (*N* = 37)		Overall (*N* = 89)	
Theme	*N*	%	*N*	%	*N*	%
OMSI brand	11	21.2	9	24.3	20	22.5
Physical characteristics	12	23.1	6	16.2	18	20.2
General curiosity	12	23.1	5	13.5	17	19.1
Appeal of experience	8	15.4	8	21.6	16	18.0
Interaction with or because of others	4	7.7	5	13.5	9	10.1
Audio components	4	7.7	2	5.4	6	6.7
Something to pass the time	3	5.8	2	5.4	5	5.6

Note: Themes with an overall rate of ≤ 5% are excluded from this table

Overall, ancillary exhibit components were found to be the most common self-reported elicitors of initial notice, while the primary exhibit component was a close second. The presence of OMSI signage or the OMSI brand was also frequently noted as eliciting notice, as was the fact that the presence of these prototypes was unusual or unexpected. With regard to self-reported causes of attention, recognition of and fondness for the OMSI brand was the single most common theme to emerge from participant responses overall, followed by mentions of physical characteristics (e.g., the webcam in "Make Me a Monster" or the chalkboard in "Chicken Scene Investigation") and a sense of general curiosity regarding the experience.

The precipitants to the "focus" stage was found to be more challenging to assess through the use of self-report measures due to its largely subconscious nature; however, open-ended naturalistic observation and resultant fieldnotes provided some insight into this stage. Based on our observations, possible contributors to movement into this stage include (a) the presence of other individuals already engaged with the prototype, (b) the surprise and novelty offered by the experience, and (c) a generally welcoming and inviting atmosphere that does not discourage attention. Additionally, the findings that emerged over the course of the progressive refinement mini-cycles illuminated a dynamic that has not been explicitly captured in our previous theoretical conjectures: There appear to be different types of appraisals being made at each stage of attention, focusing on varying salient factors and made on the basis of information available at that point in the attention process. This dynamic was made particularly evident through responses such as *"Because I saw the yellow tape and I thought it was being made"* (Mini-Cycle 1), and *"It looked interesting, like it was staged because of the yellow tape and coop. I also saw the OMSI signs"* (Mini-Cycle 1). These two responses each refer to a specific feature of the prototype—the first response was provided by an individual who attended to this feature during the initial "capture" stage, but felt the crime scene tape provided information that discouraged them from engaging. The second response reflects the psychological processing of the same feature during the "focus" and "engage" stages, at which point the information may be perceived and processed differently.

Contextual and Normative Effects

A final broad category into which our primary findings fell was that of contextual effects and social norms; while these concepts were not explicitly addressed during our initial research, it became readily apparent that they would play a significant role in shaping visitor perceptions and attention and engagement patterns. The effects of the transit station context and the social and cultural norms present within the space emerged in a number of ways, including several that were initially unexpected by the team. During the first mini-cycle—the only period of time during which yellow "crime scene" tape was affixed to the prototype—14% of the 44 non-use survey participants (n = 6) indicated a belief that the caution tape meant the prototype was either under construction or an actual crime scene, and that it should not be approached. Likewise, open-ended observation of the prototyping space indicated that a substantial number of transit users believed the "Make Me a Monster" kiosk was in fact a RedBox DVD dispenser, a belief that was also mentioned by four non-use survey participants. This misapprehension was due both to the similar design and color scheme and to the classic movie "wolf-man" cut-out affixed to the top of the prototype during the final mini-cycle.

An additional cross-cutting theme of note relates to environmental characteristics that appeared to influence transit users' willingness to engage with the prototypes once their attention was captured and focused. Naturalistic observation of transit user behavior within the research area provided strong evidence in support of the need for a welcoming environment with clear entry points to facilitate engagement. This was particularly evident during Mini-Cycles 2 and 3, during which the "Chicken Scene Investigation" prototype was deployed under an overpass at the Rose Quarter Transit Center in an area immediately abutting a storage facility for trollies and other equipment. A large number of transit users appeared reluctant to approach the prototype during these mini-cycles, with several indicating their perception that this space was for "TriMet stuff" and that the prototype was currently under construction or otherwise not intended for public use. However, it became readily apparent during naturalistic observation that the presence of even a small crowd visibly focusing on or engaging with the prototypes was a powerful predictor of further movement into and through stages of attention by others in the area.

The final point to be discussed with regard to contextual and normative effects of the research context relates to the relative rarity of unprompted explicit connections made by visitors between the experiences offered by the prototypes and any STEM topics. Tables 6 and 7 outline the themes that emerged during post-use interviews in response to questions pertaining to take-away and general impressions of the exhibits' purpose, respectively.

Table 6
Responses to "What did you take away from this exhibit?" by prototype

	Chicken Scene Investigation (*N* = 51)		Make Me a Monster (*N* = 33)		Overall (*N* = 84)	
Theme	*N*	%	*N*	%	*N*	%
General positive comments	17	33.3	16	31.4	33	39.3
Responses closely tied to STEM content messaging	18	35.3	5	9.8	23	27.4
Responses reflecting exhibit content or experience but not tied to STEM content messaging	7	13.7	5	9.8	12	14.3
Explicitly mentions "science" or "technology"	1	2.0	1	2.0	1	1.2
Nothing new learned	8	15.7	8	15.7	8	9.5
Other general comments	9	17.6	9	17.6	9	10.7

Table 7

Responses to "If a friend asked you what this exhibit was about, what would you say? (Probe if not addressed: 'Do you feel like there's any connection between this exhibit and any science topics?')" by prototype

	Chicken Scene Investigation (N = 49)		Make Me a Monster (N = 33)		Overall (N = 82)	
Theme	*N*	%	*N*	%	*N*	%
Responses reflecting exhibit content or experience but not tied to STEM content messaging	8	16.3	26	78.8	34	41.5
Unprompted responses loosely tied to STEM content messaging	31	63.3	0	0.0	31	37.8
Prompted responses closely tied to STEM content messaging	0	0.0	12	36.4	12	14.6
Unprompted responses closely tied to STEM content messaging	4	8.2	7	21.2	11	13.4
Research/outreach being conducted by OMSI	7	14.3	2	6.1	9	11.0
Prompted responses loosely tied to STEM content messaging	5	10.2	0	0.0	5	6.1
No connection to science (explicitly stated by participant)	2	4.1	1	3.0	3	3.7
Other general comments	3	6.1	1	3.0	4	4.9

When asked "What did you take away from this exhibit?", the most common theme that arose was that of generally positive feelings (e.g., *"That you guys are pretty cool for putting this out here!"*, Mini-Cycle 4), with responses tied to STEM content messaging provided by only 27.4% of participants. Likewise, when asked "If a friend asked you what this exhibit was about, what would you say?", participants were more likely to provide responses that reflected the experiential elements of the prototype than to refer to a topic related to the intended content messaging of the experience. It is worth, noting, however, that this was not universally the case across the two prototypes—in fact, visitors to "Chicken Scene Investigation" were more likely to provide responses loosely related to content messaging than any other type of response. An example of this type of response by a visitor during Mini-Cycle 1 is *"It's the most exciting place around here, you've got to figure out clues to guess who killed the chicken."* Interestingly, while many of their unprompted responses showed no connection to content messaging, visitors to "Make Me a Monster" were also significantly more likely (12/37) to provide *prompted* responses that were closely tied to STEM content messaging than were visitors to "Chicken Scene Investigation" (0/52) (Fisher's exact, $p < .001$, Cramer's $V = .22$). The most common type of response focused on computer programs or technological capabilities, with a small number of visitors mentioning people in science or technology careers; an example of such responses, provided by a visitor during Mini-Cycle 6, after being prompted to consider any connection to science or technology, is *"Technology, yeah, because this whole thing is being done on a computer."*

Discussion

Our objectives in embarking upon the *Science on the Move* project were manifold, including educational goals centered upon engaging Portland-area adults with STEM-rich experiences in public transit stations and communicating contextually-relevant messages about STEM topics through the creation and iterative refinement of two exhibit prototypes. Concurrently, we pursued our research goal of developing and refining a context-specific conjecture map of multi-stage visitor attention that articulates the factors that are of greater or lesser importance in affording or constraining attention for adults engaging with interactive exhibits in transit stations. In the discussion below, we begin by summarizing our main findings and then describe the final conjecture map that resulted from the project.

Summary of Findings

Through triangulation of data collected across methods (naturalistic observation, timing and tracking, and post-use interviews), we established additional evidence to support the existence of multiple stages of attention through which individuals may move with regard to experiences encountered in their everyday lives. The relationships between specific design characteristics and movement into and through stages of attention were on occasion different from those we initially posited, but we feel this multi-stage high-level conjecture holds promise as a framework for future projects and research efforts.

We also found evidence, aligned with the pedestrian navigation literature, that the movement of transit users into and between stages of attention—from unaware, to having attention captured, to focusing attention, to engaging, to deeper levels of engagement—is a process of ongoing conscious or non-conscious appraisal of environmental characteristics and stimuli. While this appraisal process was varyingly afforded or constrained by social norms, physical characteristics, and personal factors, it appeared to be fundamentally reliant upon the information available to an individual transit user at each stage of interest. This finding was central to the development of our final conjecture map, deepening our understanding of the ways in which individuals move (or fail to move) from one stage of attention to the next.

Finally, over the course of this project we became increasingly aware of the ways in which contextual factors, including social and cultural norms, vary between public spaces and those environments that are explicitly defined as informal learning environments. Design elements like crime scene tape are common within museum and science center exhibitions, with visitors generally understanding that they are not intended to be taken literally. However, no such implicit understanding exists within transit stations or similar spaces. Likewise, context and setting play a significant role in determining the extent to which visitors are willing to take time in the midst of their commute to engage with an exhibit. The behaviors and actions of participants provide an additional level of nuance to our understanding of the ways in which perceptions and expectations are likely to differ between public spaces and environments clearly delineated as intended for informal learning.

Related to this, it seemed that visitors in public spaces are operating using mental schemas (Dharshan, 2013; Piaget, 1936; Shen, 2013; Wadsworth, 1996) that differ from those brought to bear on experiences within museums and science centers. This was particularly evident with regard to the relative infrequency of visitors who interpreted their experiences with the prototypes as explicitly related to STEM topics; depending upon the perceived necessity of such explicit linkages, we feel this has important implications for the ways in which STEM-rich experiences are framed outside the walls of informal learning institutions. Further support for this claim was provided by a small supplemental data collection and analysis effort[iii] conducted on the OMSI floor to explore possible similarities and differences in visitor engagement with the "Make Me a Monster" prototype when compared to that observed in public spaces. There was evidence that visitors could (and did) connect their experience using the prototype with other proximal STEM-related exhibits and experiences.

Revised Conjecture Map

Bearing all of this in mind, our refined high-level conjecture map of multi-stage attention with unexpected STEM experiences in transit stations is presented in Figure 5. This map describes the key tenets of our conjecture with regard to the alignment between stages of attention (Bitgood, 2013) and phases of situational interest (Hidi & Renninger, 2006), offering a potential foundation for operationalization of the latter concept. . The map also outlines the specific observable behaviors that serve as indicators of each stage of attention, along with environment-person factors that were found to afford movement into each stage.

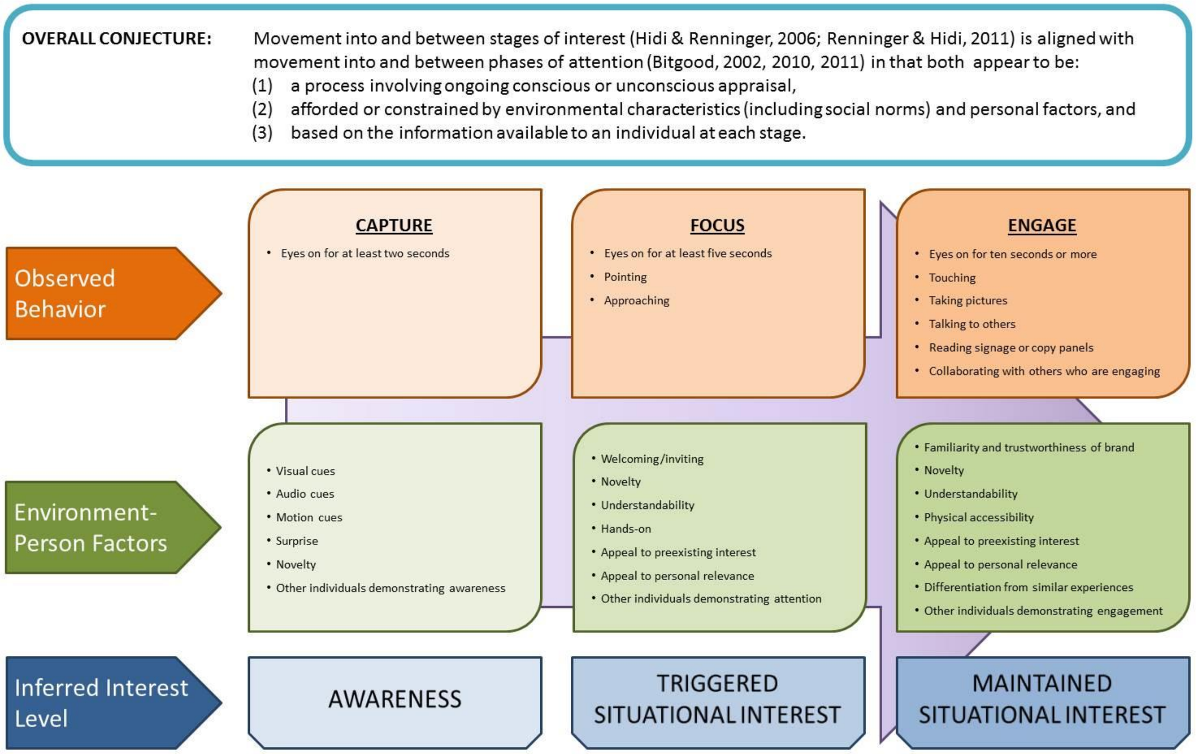

Figure 1: Final conjecture map

This conjecture, grounded as it is in our process of iterative refinement based on real-world observations and experiences, holds implications both for the practice of informal education and for the theory upon which such activities are based. The following sections outline these implications from the perspective of both research and experience design and offer suggestions for ongoing exploration in future projects.

Implications for Informal Learning Experience Design

Our study of attention and engagement in transit centers highlighted several considerations for those interested in supporting exhibit-based STEM learning outside the boundaries of museums, science centers, or other structured educational settings. First, it would be difficult to overstate that individuals in these settings are often not expecting to encounter designed informal learning experiences; as a result, significant effort should be dedicated to simply moving passersby from *unaware* to *capturing* their attention. Through various embodiments of our guiding conjectures, we found that bright colors, strange and unusual audio cues (e.g., the "squawking chicken" sound effects emanating from "Chicken Scene Investigation"), and stimuli that are generally unexpected in the context of a transit station (e.g., a chicken coop, the monster cutout affixed to the top of "Make Me a Monster") helped to elicit initial attention.

A second and equally important consideration is that potential users must, through the affordances provided by the designed experience, be able to recognize (a) what the experience is, and (b) that they are not only allowed but *encouraged* to approach and engage. Methods that were found to be effective in accomplishing this included signage noting that the experience was available free of charge, explicit calls to action (as with the sign affixed to "Chicken Scene Investigation" exhorting passersby to "Help solve this crime!" and the stool positioned in front of the "Make Me a Monster" kiosk), and the balancing of novelty (for instance, the opportunity for differing experiences over multiple visits) with familiarity and understandability (as with intuitive touchscreen interfaces or accessible and unintimidating content).

It is also of crucial importance to consider ways in which an experience might be interpreted on the basis of contextual cues and mental schemas likely to be present within a public space. What and how people learn depends on the context (Falk & Dierking, 2013; NRC, 2009), and whereas visitors to science centers and similar institutions recognize that the exhibits in these spaces are 1) about STEM topics and 2) meant to provide educational opportunities, neither of these assumptions are made by transit station users. As a result, in order to establish explicit cognitive connections between these informal learning experiences and desired learning outcomes, information must be provided explicitly and through multiple modalities. This is generally considered good practice within museum walls (Falk & Dierking, 2000; Falk, Dierking, & Foutz, 2007), but it is of even greater importance in spaces not delineated as "informal learning environments."

Lastly, although the *Science on the Move* project reached an audience that was in many ways atypical of the general visitor demographics at many museums and science centers, we found that people tended to both recognize and trust the OMSI brand, and in fact this was the single most commonly-stated reason for choosing to engage with the prototypes. While specific dynamics are likely to vary from location to location, given the cultural cachet frequently enjoyed by informal learning institutions, it seems safe to assume that the clear branding of experiences offered in public spaces may increase the likelihood of engagement by individuals who might otherwise be reluctant to interact.

Implications for Research and Future Directions

While the role of context may seem self-evident, the development and research of informal learning experiences beyond the walls of museums and science centers remains uncommon, and we are pleased to provide evidence of the importance of devoting attention to this dynamic in future studies. We also hope that this study supports ongoing explorations of a design-based research approach within an informal learning setting, as opposed to formal classroom interventions that traditionally serve as the focus of such examinations. This approach yielded a number of notable benefits, not least of these being the rigorous, iterative refinement of a contextual theory posited by our conjecture map, but also brought with it certain requirements which necessitated significant resources to meet. The timeframe for a design-based research study is longer than for a similar project employing rapid prototyping without the explicit inclusion of theoretical conjecture-testing as a desired outcome. Similarly, this approach necessitates robust and consistent collaboration between researchers, educators, designers, and developers in order to achieve success. While this constituted a deeply rewarding component of the *Science on the Move* project, the feasibility of this integrated approach should be carefully considered prior to embarking upon a design-based research study of informal learning experiences.

In sum, while we feel there is still much to be learned with regard both to the implementation of design-based research in informal learning contexts and the study of the intricacies of human interaction and attention in public settings, we believe this study provides a necessary foundation for further exploration. Although there are many similarities between attention and engagement patterns in explicitly-defined informal learning environments and those evident in public spaces, our findings indicate some key areas of divergence that may benefit from more focused examination. We are also intrigued by the theoretical and practical connections that emerged between the multi-stage framework of attention outlined by Bitgood (2013) and others and the observable behaviors that have been linked to situational interest. We believe deeper exploration of this system of operationalization is warranted.

In considering the generalizability of our study results, we follow the recommendations of Sandoval (2013) and Cobb and Gravemeijer (2008) in conceptualizing the process of generalizability not as the goal of a single study but the task of a series of investigations, each successively exploring the extent to which specific theoretical claims and educational practices apply to different settings and different groups and identifying factors and processes that are unique and variable across these. Keeping with the tenets of design-based research as a theory-building methodology, we must emphasize that the findings of this study and the resultant conjecture map are intentionally limited to the context in which the research was conducted. It seems likely, however, that the underlying principles discussed above will be transferrable to some degree to other similar public settings (such as shopping malls, public parks, and other environments that may be of interest to developers of informal education interventions). From this perspective, we view the findings from this study and the resulting conjecture map as a series of tentative hypotheses to guide future investigations, and we encourage the exploration of the extent to which our results transfer to other research and education contexts.

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[i] Experiences were designed with pedestrian accessibility in mind, including people using mobility-assist devices.

[ii] All sampling, recruitment, informed consent, and data collection procedures were reviewed and approved by Heartland Institutional Review Board.

[iii] The results of this data collection and analysis effort were intended primarily to inform internal decision-making and are not reported in this article