Empowering Learners through Effective Emotional Engagement:

Project Review

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Empowering Learners through Effective Emotional Engagement: Project Review

The Museum of Science, Boston (MOS or the Museum), in partnership with EdTogether and in collaboration with researchers and engineers across a range of affective science and technology disciplines, implemented a two-year exploratory research and development initiative titled Empowering Learners through Effective Emotional Engagement (ELEEE), with funding from the Argosy Foundation. Through the ELEEE project we sought to develop a framework for leveraging emotion in design where visitors are empowered to have meaningful, self- or socially-directed, and intrinsically motivated learning experiences.

This report summarizes key findings from **three strands of work**, addressing **three primary audiences,** and concludes with a discussion of the implications of leveraging affective science and technologies to support the work of informal science learning professionals.

Strands of work	Audiences
Landscape Assessment of current research on emotion, affective technologies, and strategies to leverage emotion to support learning **Front-end Research Activities** exploring Museum visitors' and professionals' perspectives on this work **Formative Development and Summative Evaluation of Prototypes** addressing the practical applications of this work in the Museum context	**Visitors** **Exhibit Developers** **Museum Educators**

Strand 1: Landscape Assessment

Through an initial review of literature, the team generated knowledge to support decision-making during later prototyping activities, focusing on three themes: 1) emotion in the museum; 2) theoretical grounding from the affective sciences; and 3) emotion measurement and detection.

Emotion provides the basis for the emergence of motivated behavior, interpersonal experience, decision making, self-regulation in the face of meaningful challenge, and overall well-being.

Emotion in the Museum

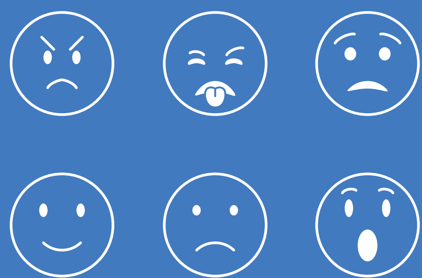
The future of research and development in informal science learning environments will require careful attention to emotional engagement. Emotion provides the basis for the emergence of motivated behavior, interpersonal experience, decision making, self-regulation in the face of meaningful challenge, and overall well-being [1, 2]. The museum field has established frameworks addressing varied goals and standards for exhibit and program development, based on impacting behavior, knowledge, interests, attitudes, and skills [3], which have resulted in significant and positive outcomes in visitor learning, self-efficacy, and science identity development [4 - 6]. Yet, without attention to emotion in all of its rich complexity, our designs can be rendered inaccessible, leaving many people out of deep learning experiences [7].

Research and development initiatives focused on emotion in informal learning environments have been expanding at a rapid pace over the last decade. Broad interdisciplinary initiatives across informal learning, museology, and cultural heritage fields have emerged to grapple with questions about the role of emotion in design, pedagogy, and visitor experience more broadly [8 - 10]. Research and development addressing emotion emerging from the MOS has focused on unpacking core questions about the nature of emotion experiences in the Museum and the role of technology to enable new pathways for emotion in design.

Theoretical Grounding: Emotion and Affective Science

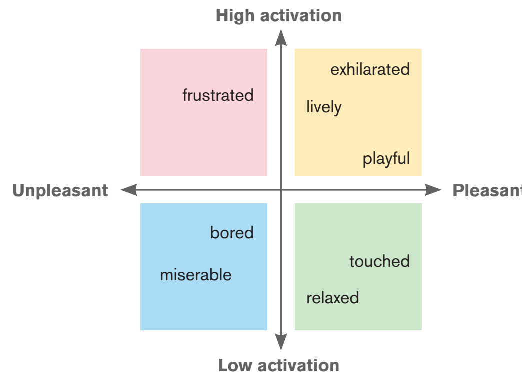
There are competing frameworks of emotion research, but unpacking commonalities between these theories can enrich our understanding of the role of emotion in our work.

Classical Theory of Emotion



The *classical view of emotions* posits that emotions are innate and universal (cross-cultural), defined by distinct, essential facial and physiological signatures [11].

Theory of Constructed Emotions



The theory of *constructed emotions* argues that the experience of emotion is a state of mind that is informed by one's core affect (experience of valence and arousal in the moment) and concepts of emotion (labels and concepts constructed over time) in a particular situation [12].

While tensions exist between these theories, some concepts about the nature of emotions do converge across these theoretical camps. These areas of overlap can provide a foundation for ISL professionals seeking to understand current perspectives on the nature of emotion, and apply this knowledge in practice.

Based on current understandings from the affective sciences, emotions…

… involve continuous evaluations of our environment and bodily sensations [13, 14].

… involve both conscious and subconscious components, but increasing emotional awareness can enhance emotional self-regulation [15, 16].

… are socially learned and culturally sensitive [17].

… have some universal components shared across human beings [18, 19, 20].

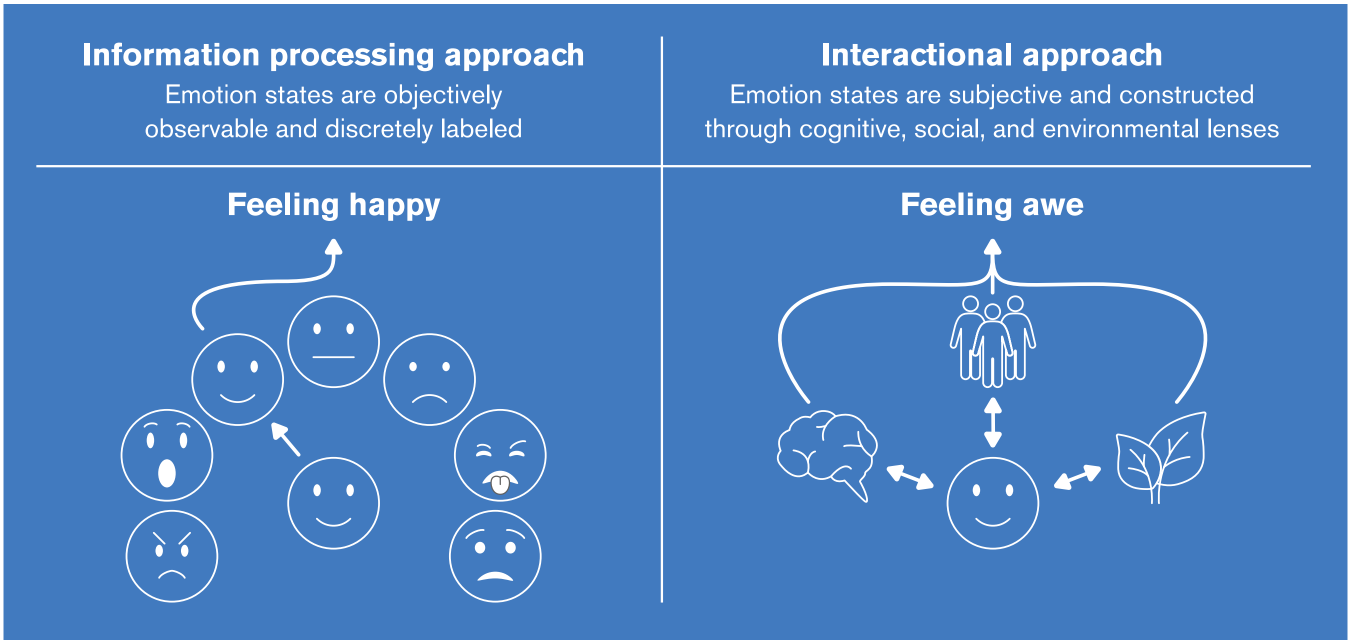
… have observable characteristics such as facial movements, gestures, vocal patterns, other social signals, and physiological responses [21, 11].

… mediate our relationship to the world [22, 23].

… influence key aspects of learning, including motivation [24], memory [25], decision-making [26], reasoning [27], and creativity [28, 29].

Emotion Measurement and Detection

Competing theoretical perspectives on the nature of emotion have also forged divergent paths for the work of practitioners and engineers who leverage emotion research toward technological innovation. In the computer science and engineering domains, professionals have leveraged different theories from affective science to drive technological innovation addressing emotion, also known as the field of *affective computing* [30]. Aligned with competing theories on emotion, two main theoretical camps anchor how emotion-detection in affective computing systems are framed. The *information processing approach* (emerging from classical theory of emotion) views emotion states as discrete (i.e., independent states, like happy, sad, etc.) and objectively observable in facial expressions and neurology. The *interactional approach* (aligning more with the theory of constructed emotions) views emotion as a subjective experience that requires personally constructed interpretation and meaning-making through environmental, social, and cognitive lenses [31].



Through varied instantiations of these approaches, affective computing systems currently have the capability to interpret several emotion expressions from an individual's face, voice, or even posture; to induce, impede, or respond to different affective states; and to include users in interpreting, monitoring, and responding to their own or others' affective states [32 - 36]. However, affective technologies have not yet realized their full potential to detect and leverage emotion data outside laboratory settings; to accurately detect a full, nuanced range of complex emotion states that are critical in different contexts; or to fully integrate recent trends in emotion theory into affective computing models [37, 38, 35].

Bridging Research and Practice

After synthesizing research across strands of literature related to emotion and learning, and how affective science and technologies might support the measurement and detection of emotional engagement, the ELEEE team generated questions that explored how affective theory might best support work in an informal learning context and how the current state of technology might be best employed. The work of the ELEEE project sought to examine the potential for innovation within these varied problem spaces. We asked:

- How can we leverage current understandings of the science of emotion to expand the ways emotional design is conceived and implemented?
- How can current affective technologies be most effectively leveraged in service of learning?

A full description of results from this literature review can be found in the document titled *Empowering Learners through Effective Emotional Engagement: A Landscape Assessment.*

Strand 2: Front-end Research Activities

To explore Museum professionals' and visitors' perspectives on the role of emotion and potential uses of affective technologies in Museum experiences, the team implemented several front-end research activities. Results grounded the team's practical and ethical approaches to developing and deploying affect-sensitive prototypes in the Museum's environment, and clarified opportunities for innovation.

Visitor Front-end Study:	Museum Professional Front-end Study:	Design Charrettes:
37 visitor groups recruited from the exhibit halls Semi-structured interviews lasting about 5-7 minutes	17 Museum educators, exhibit developers, and research and evaluation professionals 2 focus groups including 8-9 professionals each, lasting about 90 minutes	20 external partners and consultants with expertise in affective science, affective computing, engineering, and interactive exhibit design Small- and large-group brainstorming sessions around potential applications for design and development that leverage affective technologies

Guiding Principles Developed through Front-End Research Activities:

- Data from both visitors and professionals revealed a breadth of complex emotion states experienced in and supported by the Museum context.

  Although current technologies typically focus on basic emotions (happy, sad, etc.), **it is critical for the Museum to address complex emotion states** (such as frustration, confusion, curiosity, boredom, fascination, wonder, and awe). There is an opportunity for museums and technical partners to pursue mutual learning in this area.

> *"I felt awe at the [chick's] tiny little life." -Youth Visitor*

> *"The Butterfly Garden, people find when they go in there it's beautiful, it's opening your world. It's the thrill, novelty." -Museum professional*

- Staff and visitors emphasized the importance of social and contextual signals when making sense of emotions in the Museum. In response, we feel **it is vital to consider the role of social interactions in emotional experience** throughout our development processes. There is an opportunity to broaden participation in science and innovation by attending to social factors that influence the choice to engage with, and the opportunity to learn in, museums.
- **Prototype designs should integrate both human and technological strengths.** Our discussions with developers and educators indicated an interest in honoring visitor's subjective experience and meaning-making around what technology might measure.

  Designs that leverage the capacity of technology to detect expressive cues (particularly facial, vocal, or gestural), coupled with the capacity of visitors and staff to make sense of and build complex social-emotional understanding of emotion detection in context, have the greatest potential to enhance Museum offerings and make visitor experiences more meaningful.

> *"Even if there's a technology it might not [detect] the emotion [visitors] were thinking of at that time or their memory of what happened." -Museum professional*

> *"But feeding [the technology's outputs] back to [visitors], how do we understand emotions? … Why does the computer think you're happy? A conversation starter." -Museum professional*

- **We should prioritize professional learning about how emotion drives engagement.** Data collection showed that both visitors' and practitioners' views of emotion were inconsistent with contemporary affective science.

  49% of visitors suggested that negative emotions hinder learning, but affective science suggests negative emotions can also promote deep learning [39].

  Prototyping activities should support institutional knowledge-generation and professional development around how emotion supports our existing goals; such knowledge building will also work (by influencing design and research practices) to support visitors' understanding of the role of emotion in their own learning.

- Visitors and staff should have a key role in their autonomy over meaning-making with respect to the outputs of affective technologies. Through prototype development, we would address concerns related to the ethical and effective use of affective technologies. To do this, **we should provide clear, transparent communication about how we are using affective data.**

A summary of results from these front-end activities can be found in the document titled *Empowering Learners through Effective Emotional Engagement: Front-end Evaluation Synthesis.*

Strand 3: Formative Development and Summative Evaluation of Prototypes

Preliminary prototypes applied the knowledge generated through the literature review and front-end studies to test affective data collection and reflection strategies in the naturalistic context of the Museum. Following best practices for evaluation in informal science learning environments [3], formative evaluation studies explored these various analog and technology-enhanced strategies for affective data collection and emotion reflection. Small-scale studies involving visitors and staff ranging from 4 to 30 participants each, allowed the team to adjust quickly when confronted with obvious challenges. This agility also allowed the team to rapidly test more types of technologies and self-report strategies than larger studies might have allowed. Questions that guided this prototyping stage looked towards a future of innovative Museum experiences:

- In what ways can we best present emotion data to visitors and museum professionals?
- What are the outcomes of encouraging visitors and educators to reflect on their emotion data?
- Is it possible to create exhibits that recognize and respond to learners' emotional cues?

Methods and Processes across Formative Studies:

273 Museum visitor participants
30 Museum professional participants
14 prototypes and small-scale studies

Low-tech, paper-based activities:	High-tech tools and systems:	Post-experience data collection:
Journey maps	Facial expression detection	Interviews
Word clouds	Electrodermal activity measurement	Surveys
In situ emotion mapping	Eye-tracking	Focus groups
Emotional previewing reflections		

Key Findings from Preliminary Prototyping:

Strategies to encourage **self-report of emotions provided valuable ground truth and heightened metacognitive awareness**. Data describing visitors' rich and varied emotional experiences in the Museum could be leveraged to validate findings from biometric measures. Emotional self-reflection strategies served as affective interventions that helped visitors attend to their surroundings and behavior in deeper ways.

4 of 6 participants in one study suggested the reflection tool they tested impacted their experience or decision-making:

"It made me stop and think. I don't think I would have asked the volunteer about the broken butterfly wing."
–Adult visitor

Eye-tracking technologies are efficient in static environments but lose functionality in unpredictable environments. For example, data collected from point of view eye tracking glasses could be automatically analyzed for a seated, screen-based exhibit but required more manual analysis for data collected in an immersive, physically active museum experience.

Wearable electrodermal sensors frequently generated missing and noisy data. The sensors sometimes failed to gather complete datasets from our participants, and the diversity of unpredictable stimuli in the Museum prevented clean interpretation of data streams.

We were not able to productively use real-time facial expression detection technologies to encourage visitors to reflect on internal emotion states. Real-time read-outs from these systems were engaging, but focused participants' attention on facial movements rather than internal feeling states. Post-processed outputs of visitors' naturalistic expressivity were more informative for team member and stakeholder interpretation. Logistically, these technologies required participants to be oriented toward, and in close proximity to, a video camera, as faces were only detected 10%-43% of the time in immersive environments.

All 6 participants in one study recognized the system was designed to measure facial movements, rather than focusing solely on emotions:

"It's trying to measure muscles in your face." –Adult visitor

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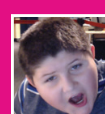
Observable behavior emerged as an important source of information for interpreting affective data. When possible, we automated processes for documenting context (e.g., development of digital interaction logs), or at least documented relevant contextual characteristics manually during data collection (e.g., behavior, discussion topics).

Strategies for collecting and reflecting on data could either be unimodal (focusing on one data stream at a time, such as electrodermal activity) or multimodal (synchronizing multiple sources of data, such as aligning electrodermal activity with events logged in an exhibit). **Multimodal data integration showed the most promise for characterizing participants' emotional experiences and fostering meaningful interpretation.**

Example from a Mystery Skulls activity:

Social context: One visitor did the activity with his sister.

Activity context: They answered some questions incorrectly.



Facial movements were meaningful within this context: Jaw dropped 40% more often during wrong answers.

A full summary of these studies can be found in the document titled *Empowering Learners through Effective Emotional Engagement: Prototype Development – Formative Report.*

Results from formative evaluation led to development of three final affective systems.

A final set of affective systems and layered data collection and reflection strategies were developed addressing each of the core audiences. Summative evaluation studies assessed context-specific research and evaluation questions for each system.

These final prototypes were:

- Visitor-facing Prototype: The Many Emotions Visitor Interactive Study
- Exhibit Developer-facing Prototype: The Productive Struggle Social Study (Mystery Skulls)
- Educator-facing Prototype: The Educator-Visitor Synchrony at the HHL Hub Study

Final Visitor-facing Prototype:

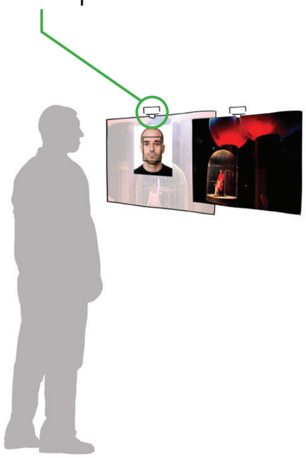
The Many Emotions Visitor Interactive Study

Objectives:
This interactive sought to create an experience that would help visitors think about the emotions that they are experiencing, and that their face may not always express those emotions. The team wanted to explore how visitors engaged with this idea, while also assessing the potential outcomes of encouraging visitors to reflect in-the-moment on their own emotions.

Experience:
Visitors (n = 32) watched short video clips of emotionally evocative Museum experiences, rated emotions they felt, and then reviewed their own facial expressions, reflecting on a final prompt that suggested that facial expressions do not always reflect internal emotion states.

Measurement Strategies Used:

Facial expressions



Self-reported emotion ratings

Summary screen to prompt reflection

Post-experience Data Collection:

Semi-structured interviews probing visitors' experience and learning

Guiding Questions:
1. What types of meaningful emotion data can we capture and represent to visitors to encourage self-reflection with Museum experiences?
2. What can we learn about the alignment, if any, between visitors' naturalistic expressions of emotion and subjectively felt emotion in response to varied Museum experiences?
3. What are visitors' perceptions of Museum experiences embedded with affective technologies like this?

Key Findings from the Many Emotions Visitor Interactive Study:

Two strategies for affective data collection and real-time reflection fostered metacognition and heightened awareness to the environment: (1) Inviting visitors to reflect on their own subjective emotional experience (evident in 17 of 18 groups), and (2) the social aspects of the experience (evident in 7 of 14 social groups).

"It was neat… you don't always watch yourself or slow down to think. Like, do I actually like this?" –Adult visitor

"Doing it with my daughter was… more fun, interactive." –Adult visitor

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Observing their own facial expressions seemed to subvert some visitors' understanding of the exhibits' main message, with three groups thinking something was "wrong" with them, or they were behaving "robot"-like, if they were not as expressive as they felt.

"It made me a little self-conscious. I feel things, but I don't show them on the outside." –Adult visitor

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Facial expressivity did not emerge as a strong indicator of subjective emotion states. Visitors tended to report a broad range of emotions, but were minimally expressive while watching the videos. Those who tended to be more expressive suggested that they could more easily select a face that communicated what they felt.

Most visitors who watched the Lightning Show clip (30 of 32) reported positive feelings related to it, such as being curious, excited, and/or surprised, but over half of participants (17 of 32) registered no positive expressivity according to the affective technology.

Most visitors (22 of 32) reported feeling "very comfortable" with the Museum building exhibits that collect varied types of emotion data, but **visitors reinforced the need for the Museum to develop and deploy such systems transparently and with a focus on educating the public about the data collection strategies being used.**

"Make people more aware of the technology around them … since it's part of your mission." –Adult visitor

"I'd be very comfortable as long as it's for the right reasons… some people don't want to be recognized, or for someone to know how they feel." –Youth visitor

Final Exhibit Developer-facing Prototype:

The Productive Struggle Social Study (Mystery Skulls)

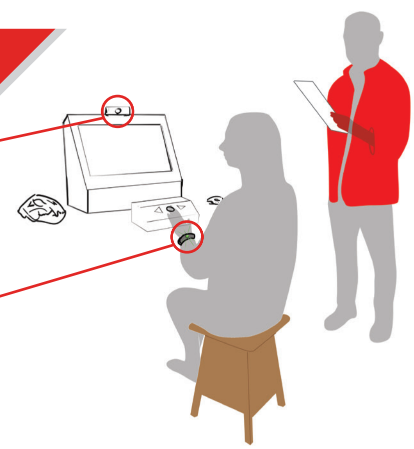
Objectives:
The affective data collection systems developed for the Mystery Skulls exhibit were built to support existing exhibit development processes by collecting data that might help assess the extent to which visitors experienced a particular emotional arc - productive struggle - and help exhibit developers leverage these emotional data toward exhibit improvement.

Experience:
At this exhibit, visitors select a skull to examine, make an initial guess about what animal it might have belonged to, answer questions about the skull's features to gain clues, and finally confirm or disconfirm their initial guess as they discover what the animal is. This exhibit was developed as part of an NSF-funded project (DRL-1612577) aimed at fostering productive struggle, an emotional experience when a learner engages with disequilibrium (a sense of imbalance that can be experienced as confusion, frustration, surprise, or unease) in order to navigate a challenging task and achieve a satisfying resolution. To enhance this team's work, the ELEEE project conducted a study focused on integrating affective technologies into the Productive Struggle team's process. In particular, the study investigated the social dynamics of productive struggle by randomly assigning visitors (n = 33 groups) to use the exhibit alone (45%) or with at least one group member (55%), and using affective technologies to compare these two conditions.

Measurement Strategies Used:

Facial movement analysis

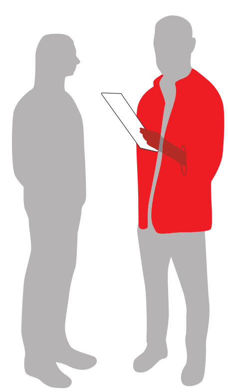
Electrodermal activity data



Post-experience Data Collection:

Surveys and interviews

Full-team data reflections



Guiding Questions:
1. How do visitors' social experiences with an exhibit relate to exhibit goal achievement?
2. To what extent are affective technologies able to provide meaningful data about visitors' experiences to inform developers' work?
3. In what formats are emotion data presentations most effective for developer meaning-making?

Key Findings from The Productive Struggle Social Study (Mystery Skulls)

The affective data sources provided nuanced understanding related to the team's goals. In particular, these data helped the team determine that the exhibit was successful in supporting productive struggle for both individuals and social groups. It also provided insight that social (n = 18) and solo (n = 15) groups leveraged different design elements to reach that goal.

For example, when making decisions about how to navigate the exhibit, more solo participants (43%) relied on their prior knowledge and past experiences than social participants (13%): ***"I tried to think back on if I'd learned anything in other parts of the Museum." –Youth visitor, solo condition***

Social participants leveraged each other (31%): ***"We talked about it and put all our ideas together." –Youth visitor, social condition***

Automated log files were more useful for characterizing indicators of productive struggle than electrodermal activity and facial movement data.

Average measures of electrodermal activity and facial expressivity showed few differences between visitors who experienced the full arc of productive struggle and those who did not.

Data from the log files (built-in analytics about visitors' use of the digital aspects of the exhibit), however, showed several differences. On average, people who experienced productive struggle used the exhibit more thoroughly than those who did not. Visitors who experienced productive struggle explored more skulls (3.9 vs 2.7 skulls, out of 5 total) and more features of the skulls (8.5 vs. 7.4 features per skull).

Developers valued conversations about affective data, especially when the data presentations paired multiple, overlapping data sources. To support the developers, ELEEE team members experimented with a number of data presentation approaches (bar charts, line graphs, data tables, infographic placemats, animated visuals built by designers, video playback, etc.). The developers found that conversations about the affective data supported their work, generating valuable meaning-making, raising further questions for additional analyses, and suggesting new opportunities for design. The team also came to a consensus that it preferred to look at multiple data sources together in time series.

"Without the data, we probably wouldn't have had some deep conversations about individual differences in emotional expression." -Developer

"I don't think I would be comfortable making a decision from any one piece of affective data, but seeing them together is really helpful." -Developer

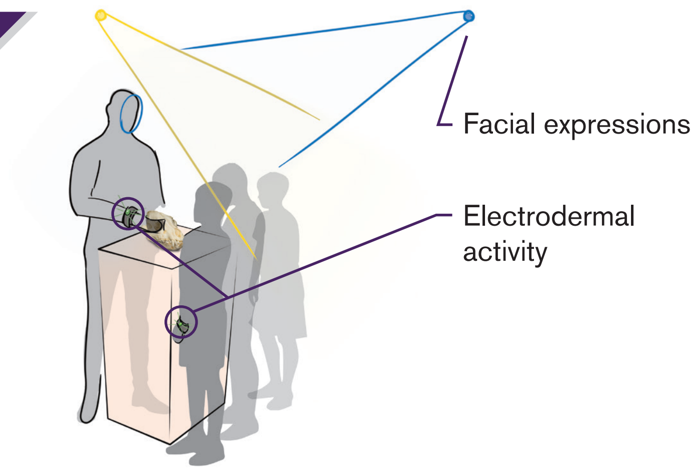
Final Educator-facing Prototype:

The Educator-Visitor Synchrony at the HHL Hub Study

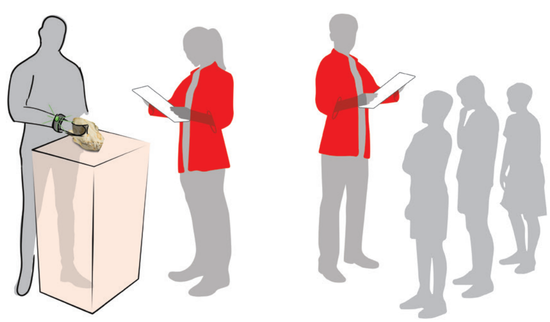
Objectives:
Educators working with the ELEEE team expressed an interest in better understanding the different factors that might influence how they relate with visitors during live programs. Instead of considering how affective systems might be used to assess *emotional* experiences, the objective of the Educator-Visitor Synchrony study was to learn more about the *communicative* and *relational* aspects of affective signals to help educators better connect with their audience.

Experience:
Visitors (n = 14) engaged in a program in *The Hall of Human Life* (HHL), facilitated by educators (n = 4). Programs selected for this study included a Skeleton Mystery program, in which visitors used physical clues and educator prompts to put together a skeleton and guess from what animal it might have originated, and an Eye Dissection, in which educators dissect a real sheep's eye and explore different features and mechanisms of the eye with visitors. Educators' goals for these programs often focused on ensuring that visitors' interests would lead the engagement, thus fostering development of science identity and skills.

Strategies Used:



Post-experience Data Collection:



Surveys and interviews

Full-team data reflections

Guiding Questions:
1. How do visitors' social experiences with an exhibit relate to exhibit goal achievement?
2. To what extent are affective technologies able to provide meaningful data about visitors' experiences to inform developers' work?
3. In what formats are emotion data presentation most effective for developer meaning-making?
4. What can we learn about visitors' emotional experiences at exhibits that might inform future development efforts towards creation of responsive exhibits?

Key Findings from The Educator-Visitor Synchrony Study:

Affective sensors captured subconscious indicators of synchrony between educators and visitors. Educators and visitors were synchronous along some non-verbal dimensions of expressivity (e.g., smiling), but educators and visitors attended to different features of an interaction when assessing synchrony.

Educators focused on verbal engagement to assess synchrony: ***"I did a lot of talking at them… I wanted them to make a guess." –Educator***

Visitors focused on what they learned, and if they felt supported: ***"She was super enthusiastic to teach… and she was also patient." –Adult visitor***

Educators and visitors had different goals when engaging in Museum programs. While educators tended to perceive more variability in levels of program goal achievement between visitor groups, visitors typically perceived interactions with educators as positive and educational.

All educators focused on intangible goals, with some attention to content learning: ***"A big goal is just fostering that science identity." –Educator***

13 of 14 visitors thought content and learning goals were the primary focus: ***"I learned how the eye works." –Adult visitor***

Triangulating data sources provided context and ground-truth to make sense of visitors' experiences across programs. Further, leveraging more complex analytical techniques that account for the dynamic, temporal nature of these data further elucidated patterns of synchrony.

One educator-visitor pair had particularly synchronous physiological arousal. The youth's description helps ground this synchrony in context: ***"She [the educator] helped me understand, so I got more excited." –Visitor***

Reflecting on affective data supported educators' practice. Educators found the aggregate data presentations useful to understand how their results compared to other educators, while case examples of time series data and visitors' subjective reports were useful to highlight discrepancies between educators' perceptions of visitors' perspectives of engagement.

"Seeing this data helps me confirm that I have a good read on how things are going… and I can be harsh on myself, but that overall people tend to have a really positive experience." –Educator

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Educators sometimes **mislabeled visitors' emotional experiences based on stereotyped ideas about visual indicators of engagement.** This highlighted the **importance of collecting rich multimodal data to validate the outputs of any automated system.**

"It gives more context. Like [one visitor said], 'I was a bit confused.' But I thought he was just bored. Maybe I could stop and ask more questions. What are ways I can be supportive?" –Educator

Discussion

The work of the ELEEE project is, at its core, about attending to emotion as a way to initiate a fundamental shift toward embracing the whole visitor – social, cognitive, corporeal, and emotional – in real time and as an ongoing reflective process. ELEEE outcomes and learnings provide the foundation, practical basis, and ethical perspective needed to develop and deploy designed informal science learning (ISL) experiences that are affect-sensitive.

Affective science can enhance museum professionals' understandings of the complexity of emotion experiences, supporting their abilities to develop practical applications for affective technology in museum contexts.

- Everyone experiences emotion, but our personal understanding of emotion is not always aligned with contemporary research in the affective sciences. Partnering with experts from outside the museum field can be invaluable to practitioners who wish to apply current research to leverage emotions in their design.
- For example, multiple external partners helped equip the ELEEE team with tools to productively apply the constructed theory of emotion to the museum environment, informing our approach to research and development by helping us integrate technologies and human experience in the museum context.

> An insight from the theory of constructed emotions that has been valuable for us is to think of emotions as states of mind informed by individuals' bodily sensations and their own culturally-situated concepts of emotion.

Future directions for ISL research and development:
- Build museum professionals' capacities for leveraging emotion in design by fostering connections with emotion researchers and developers from varied fields
- Expanding possibilities for multimodal data collection that provides insights from technology and self-report in a non-obtrusive way

Attending to affect and emotion can support museum professionals' work, and subsequently enhance the visitor experience, both in real-time and as an ongoing process of reflection and development.

- Developing affect-sensitive systems that addressed the contexts, interests, and needs of museum visitors, exhibit developers (including evaluation and research professionals), and educators provided each of these stakeholder groups with unique insights into their own behavior, cognition, and decision-making processes.
- As one visitor suggested, offering multiple opportunities to reflect on her emotional experience throughout the Museum might further enhance how she would engage and make sense of her experience.

> *"I notice sometimes when I come here that, depending on if you're here for an hour or if you're here a lot longer, you'll start to rush through more things. You sometimes come in to see the things you want to see and the rest of it you're kind of like, look at it and go… It would be kind of cool actually, if you go through the whole Museum, if we had something to indicate, 'How did you feel at this exhibit? How did you feel walking through the halls?' To show what people are feeling as they go through the museum." -Visitor*

Future directions for ISL research and development:
- Integrate affective technologies into existing exhibit systems to deepen engagement and learning
- Leverage the affordances of affective technologies and big data to address emotional engagement through design at the gallery- or museum-wide level
- Apply machine learning to generate museum-specific understandings of emotion that can be leveraged for real-time exhibit response

Affectively-designed museum experiences can help learners develop emotional knowledge and skills that are vital for STEM practice and engagement in ISL environments.

- As a part of efforts to align STEM education with 21st century skills, educational scholars and practitioners now consider learning to extend to the social and emotional domains [40]. ELEEE project outcomes demonstrate how systems that attend to emotion can support visitors in practicing, developing, and leveraging these social and emotional skills to enhance their STEM outcomes.

The brother described; *"It was fun working together." "It was enjoyable because we got to learn the information even if we got it wrong,"* his sister replied. Her brother expanded on this, *"We got to help each other figure it out."*

- For example, by designing exhibits that explicitly support productive struggle, visitors can feel motivated to persist through challenge. One pair of siblings in the Social Study illustrated this point.
- But, without the ability of exhibits to dynamically respond to emotion, designers can miss opportunities to engage visitors who might benefit from just-in-time supports or scaffolds.

Half of the visitors in the Productive Struggle Social Study did not experience, persist through, and resolve a struggle, suggesting that design could be better informed by the dynamic nature of visitors' emotional experiences.

Future directions for ISL research and development:

- Collaborate across STEM fields to explore and define STEM-critical social and emotional skills (such as collaboration, or grappling with uncertainty)
- Generate strategies to support the development of social and emotional skills through engagement with exhibits

Attending to emotion can help museum professionals develop more inclusive and equitable learning experiences.

- There are inherently emotional and affective components of designing a space where all people feel a sense of belonging. We engaged diverse groups of visitors whose experiences were deepened in ways that suggest the potential for affect-sensitive design to increase accessibility and inclusion by providing flexible experiences. For example, one visitor in the Butterfly Garden noted that by reflecting on her emotions, she was encouraged to engage with educators more deeply.

"It made me stop and think. I don't think I would have asked the volunteer about the broken butterfly wings." -Adult visitor

- Further, we found that visitors and museum professionals can become more aware of others' diverse perspectives, perhaps helping to build a more empathetic community – within the museum and beyond.
- Participants' quotes show that becoming more aware of others' subjective emotional experiences helped them to understand not just how others might feel, but also how the perceived emotions might impact how people treat each other.

"It was interesting to see some scary reaction. I think maybe he [my son] was too scared but [I thought he was] more like thrilled." After suggesting his son might have felt "thrilled," the son proceeded to explain that this was not the case, showing the group the specific bug that led to his negative feelings.
-Adult and youth duo

Future directions for ISL research and development:

- Develop culturally-inclusive affective systems that can identify barriers and pathways to engagement for diverse groups of learners
- Share visitors' affective data with educators as a way to demonstrate individual differences that could subsequently lead to the design of more equitable learning experiences
- Design systems to foster empathy by helping visitors reflect on multiple people's affective data

Final Reflections

Over the course of this project we have learned to think about emotion as a content-rich source of information about visitors' and our own assessments of the social, physical, and intellectual environment. Such information can be leveraged to deepen learning experiences, broaden participation, and support the development of critical STEM social and emotional skills that help visitors make decisions, navigate meaningful challenges, and adapt and learn in response to museum experiences.

To this end, the ELEEE project's design allowed us to experiment with a number of different ways of integrating affective technologies in our museum context. We have generated significant learning through this process, and have identified a number of promising directions for future research and development that could support the ISL field, and, in some cases, further advance the adjacent fields of affective computing, engineering, and science. Broadly, the potential of this work is in moving toward emotion-responsive museum spaces – spaces built through the expansion of innovative affective tools and support strategies that are available to designers and educators – yielding more inclusive and effective ISL experiences for a broader range of visitors, and thereby deepening the impact and value of museums.

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