Multimodal Visitor Analytics: Investigating Naturalistic Engagement with Interactive Tabletop Science Exhibits

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Abstract

The overarching goal of this Research in Service to Practice project is to leverage multimodal learning analytics to develop an enriched understanding of visitor engagement in science museums. The project centers on data-rich investigations of visitor engagement with interactive tabletop exhibits about environmental science and sustainability. During free-choice learning in museums and science centers, visitor engagement shapes how learners interact with exhibits, move around the exhibit space, and form attitudes, interests, and understanding of science. Multimodal visitor analytics integrates the rich multichannel data streams produced by fully-instrumented exhibit spaces with the data-driven modeling functionalities afforded by recent advances in machine learning and educational data mining.

Research Question

How can we utilize multimodal visitor analytics to devise data-rich models of meaningful visitor engagement that address challenges faced by museum educators and exhibit designers?

Research Thrusts

Building on the Future Worlds digital interactive exhibit project and the multimodal analytics research infrastructure, this project has two central thrusts:

- Conduct a series of visitor studies on naturalistic engagement in solo, dyad, and group visitor interactions with multimodal visitor analytics
- Create learning analytic models of visitors' cognitive, affective, and behavioral engagement with interactive tabletop science exhibits

Engagement Theory

We adopt a conceptualization of engagement that is organized in terms of three core components (Fredricks, Blumenfeld, & Paris, 2004):

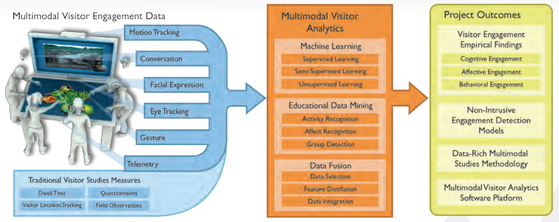
- Cognitive engagement (e.g., asking questions, generating explanations, recalling knowledge)
- Affective engagement (e.g., flow, joy, confusion, surprise)
- Behavioral engagement (e.g., dwell time, gesture)

Science Museum

- Multimodal visitor studies at the North Carolina Museum of Natural Sciences
- Largest museum of its kind in the Southeastern United States
- 1.2 million visitors annually

Multimodal Visitor Analytics

Utilizing machine learning and data fusion techniques from educational data mining, we will focus on devising runtime models of visitor engagement using nonintrusive data streams, operationalizing cognitive, affective, and behavioral engagement in terms of variables triangulated from multichannel data.



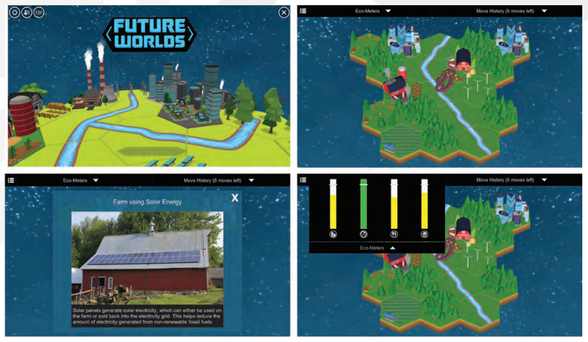
Future Worlds Learning Environment

Subject Matter: Sustainability
Environmental Themes: Energy, Food, Water
Objective: Enable learners to better appreciate the following:

- Rapid increases in human population and consumption of natural resources impacts Earth's systems.
- Human activities in agriculture, industry, and everyday life have major effects on the land, air, vegetation, streams, oceans, and biodiversity.
- Individuals and communities can do things to minimize humans' impact on the environment and help protect Earth's resources and environments.

Visitors learn about sustainable farming practices, renewable energy sources, and sustainable cities as they try to mitigate humans' deleterious impacts on the environment.

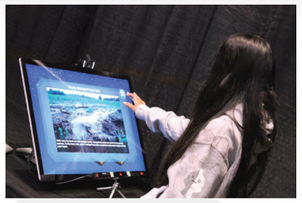
A key feature is a series of dynamic "eco-meters" that represent **Environmental Quality** (air, water, and biodiversity) and **Resource Availability** (food, housing, and energy). They visually represent the **cause-and-effect** relationships of learner decisions within Future World's modeled system.



Multimodal Data Collection

Data collection with three groups of school visitors have been conducted with Future Worlds at the North Carolina Museum of Natural Sciences.

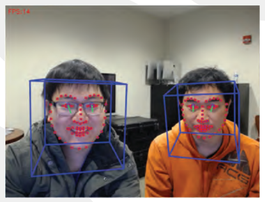
- Total of 116 learners, aged 10-11
- Learners explored Future Worlds up to maximum of 10 minutes



Visitor Informatics Platform

We are developing the Visitor Informatics Platform (VIP), an open-source software toolkit that supports multimodal data collection and analysis of learner interactions with digital exhibits.

Facial Behavior Analysis with Multiple Learners



VIP uses OpenFace 2.1, an open-source software toolkit for facial behavior analysis (Baltrušaitis et al., 2018). OpenFace supports facial landmark detection, head pose tracking, facial action unit recognition, and eye gaze estimation with one or more simultaneous learners. Facial expression data is collected by an externally mounted Logitech C920 USB webcam.

Motion and Gesture Analysis with Multiple Learners

Microsoft Kinect 2 for Windows utilizes dedicated motion-tracking hardware to capture learners' body movements, including gesture and posture, during interactions with interactive surface exhibits.

Eye Gaze Analysis

Mounted Tobii EyeX eye tracker enables VIP to capture targets of learner visual attention on an interactive surface exhibit's display. Supports one learner at a time.

Speech Analysis with Multiple Learners

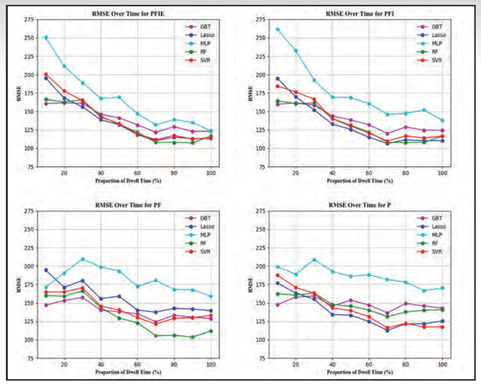
OpenSmile open-source toolkit enables automated extraction of acoustic features from learner conversations (Eyben et al. 2010).

Interaction Trace Log Data Analysis

Trace log data captures timestamped records of visitor interactions with the exhibit, including learner taps and multitouch gestures, as well as learning events and simulation states.

Visitor Engagement Results

- Multimodal Bayesian hierarchical models outperform competing non-hierarchical baselines for modeling museum visitor dwell time with Future Worlds (Emerson et al., 2020 in Proceedings of the International Conference on Artificial Intelligence in Education).
- Machine learning-based early prediction models of visitor dwell time benefit from additional modalities yielding improved accuracy and convergence rates (Emerson et al., 2020 in Proceedings of the International Conference on Multimodal Interaction).



- Multimodal adversarial domain adaptation techniques enhance early prediction of unimodal visitor engagement models (Henderson et al., 2021 in Proceedings of the International Conference on Educational Data Mining).
- Multimodal models of visitor visual attention treated with debiasing techniques mitigate patterns of encoded bias that arise across different modality combinations (Acosta et al., 2021 in Proceedings of the International Conference on Multimodal Interaction).

Current and Future Directions

- Conduct additional museum studies to capture multichannel sensor data on naturalistic patterns of visitor engagement
- Continue to iteratively design, develop, and refine the VIP multimodal visitor analytics platform
- Investigate multimodal learning analytic models of cognitive, affective, and behavioral engagement with groups of visitors

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