

Multimodal Visitor Analytics:

Investigating Naturalistic Engagement with
Interactive Tabletop Science Exhibits

Final Evaluation Report

Cathy Ringstaff and Burr Tyler

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Introduction

The external evaluation for this project, led by Dr. Cathy Ringstaff at WestEd, was a mixed-methods study that used a developmental approach. Specifically, the evaluators worked closely with the researchers as thought partners, rather than as an external team who primarily served to monitor progress of grant implementation. In the final year of the project, evaluators continued to provide feedback, share guidance, and prompt reflection on the project's progress and major activities during project meetings. For example, in sub-team meetings with developers, the evaluators provided input on development of the interactive exhibit about the narrative presented to visitors and the science content and its accessibility (e.g., reading level; vocabulary); and offered suggestions about how to improve visitor engagement, given the typically short exhibit dwell times in informal science education settings. In whole-group meetings, evaluators provided feedback about various features of the interface, data collection strategies, and dissemination opportunities.

WestEd also assisted by conducting several site visits where evaluators observed students using the multimodal platform, conducted interviews of research participants, and analyzed observational and interview data. Finally, evaluators interviewed key project staff in the final stages of the project about successes, barriers, and lessons learned over the course of the project.

Project Team Dynamics

In the final year of the project, staff (including software developers, experts in CS, educational researchers, graphic artists) continued to work well together. Project meetings were well organized and took place regularly over the course of the project, giving the group the opportunity to problem solve together and make decisions informed by the perspectives of different team members. The coordination of this multidisciplinary team required skillful

facilitation, which was evident throughout the project, not only in the meetings of project leaders, but also in meetings of each subgroup. One project staff member described how the teams distributed responsibilities in an interview:

It's like a large team, it's a multidisciplinary team.... There's a technology team, there's a science education team, there's a museum team... [My role involved] kind of getting the teams able to have kind of a concrete, clear research direction and cohesion and be driving their respective areas of the project forward.

The structure of the project and its use of different subgroups promoted forward momentum, despite the challenges associated with the pandemic, which prevented ongoing user testing that had been planned. Subgroups met regularly via Zoom, and continued to make significant decisions, even when the team was unsure of when they would be able to test their platform with students. For example, in meetings of the science education subgroup charged with making decisions about the educational aspects of Future Worlds, discussions were held about topics such as the challenges associated with enhancing the educational value of the platform, maximizing readability of text, and supporting interactivity, while at the same time offering environmental science content that was interesting and accessible. The following quote illustrates some challenges related to enhancing the user experience:

Supporting the kind of interaction we wanted students to have with the software was challenging, and I think related to that, understanding that level of sophistication...of the science concepts that we wanted....and helping to communicate some of these requirements to the [educational research] team.

Challenges associated with clearly communicating between subgroups was exacerbated in part by changes in staff over the course of the project, and a bit of uncertainty about the extent to which remaining staff members could actually make decisions and delegate tasks. As one staff member said,

When [one staff member] left someone had to step up ... in that role. I continued on the path that [the staff member who left] was leading us down and additionally kind of pushed out in some directions that I thought were interesting and beneficial...At some point I was maybe able to ... say, "This is the direction we need to go" ... but I was never sure if I was in that position to delegate, to know like, "Hey, this is your role. You have responsibility but also you have power

(sounds like power is an aggressive word) but also the power within our structure to make decisions.”

The project was able to quickly overcome challenges with communication due to staffing changes, and once their museum partner reopened their exhibits, project staff were ready to conduct a series of user studies. Overall, this project benefitted greatly from the skill of each staff member, the trust they had for one another with regard to decision making about the project, and the ease with which they were able to adapt to challenges such as the pandemic.

User Experience

In the final year of the study, when schools and informal education settings reopened after the pandemic, project staff were able to collect user data in an informal, naturalistic setting—the North Carolina Museum of Natural Science. (User data had been collected early in the project, but in a controlled study.) Before the site visits, team members discussed how to modify data collection strategies given changes in how the platform would be used at the museum to ensure that data would effectively be collected in the field. The team also carefully considered how to meet Human Subjects requirements.

In November 2022, students from Wake Young Women's Leadership Academy were invited to participate in a user study at the museum. Another study was conducted in December 2022, which included students from Exploris Middle School. A final study was conducted in January 2023, which included students from Wake Young Men's Leadership Academy. All three schools are located in Raleigh, NC, and the students were all sixth graders. To conduct these studies, the team worked closely with museum staff to identify a viable location within the museum. Ultimately, the Visual World Investigate Lab, located in the NCMNS Nature Research Center was chosen. This Lab focuses on scientific visualization, augmented reality, and other specialized computing technologies. In addition to housing two computers with Future Worlds for students to use, the Lab had other activities and exhibits, such as a three-D printer and staff members who talked to the students about how to use the printer.

Two WestEd evaluators participated in the November museum implementation study to help collect data about how the platform was used, and one evaluator conducted interviews onsite during the December study.

Observations of Students

During the November 2022 user study, a member of the evaluation team and a member of the project research team observed students using Future Worlds. Both of these experienced researchers found observing students playing the game difficult, mostly because of where the computers were set up. Researchers could not clearly hear what the students were saying or see their facial expressions. One data point that was clear, however, was that most students spent much of the time allotted in the Lab playing the game (usually about 8 minutes), even though the students had the option of visiting other exhibits in the Lab, such as a 3D printer.

During the next user study in December, a modified observation form was created, and the positions of the computers were changed, but problems gathering reliable and valid observational data persisted. These less-than-ideal efforts to collect observational data reinforce the difficulties faced by informal educators and exhibit designers as they work to understand student engagement when using museum exhibits and reaffirm the goals of this study.

Interviews With Students

In interviews, students were asked about their level of enjoyment of the exhibit; the parts of Future Worlds that they liked best; what they learned about the environment and sustainability; if they plan to explore further about anything they learned with the Future Worlds exhibit; and if they had recommendations for improving Future Worlds.

Enjoyment Ratings

When asked to rate how much they enjoyed the Future Worlds exhibit, most students reported favorable ratings of 6 or higher on a scale of 1 to 10. (See Figure 1 and/or Table 1.) (Note that not all students were interviewed, and that students were interviewed informally, mostly in groups.)

Table 1. Analyses of student Future Worlds exhibit enjoyment during the three exhibit sessions

	November 2021	December 2021	January 2022	Total
# Students	35	54	31	120
Mean enjoyment rating (1 low -10 high)	7.81	7.25	8.3	7.8
Median	8	7	8.5	8
Mode	8	7	8	8

Standard Deviation

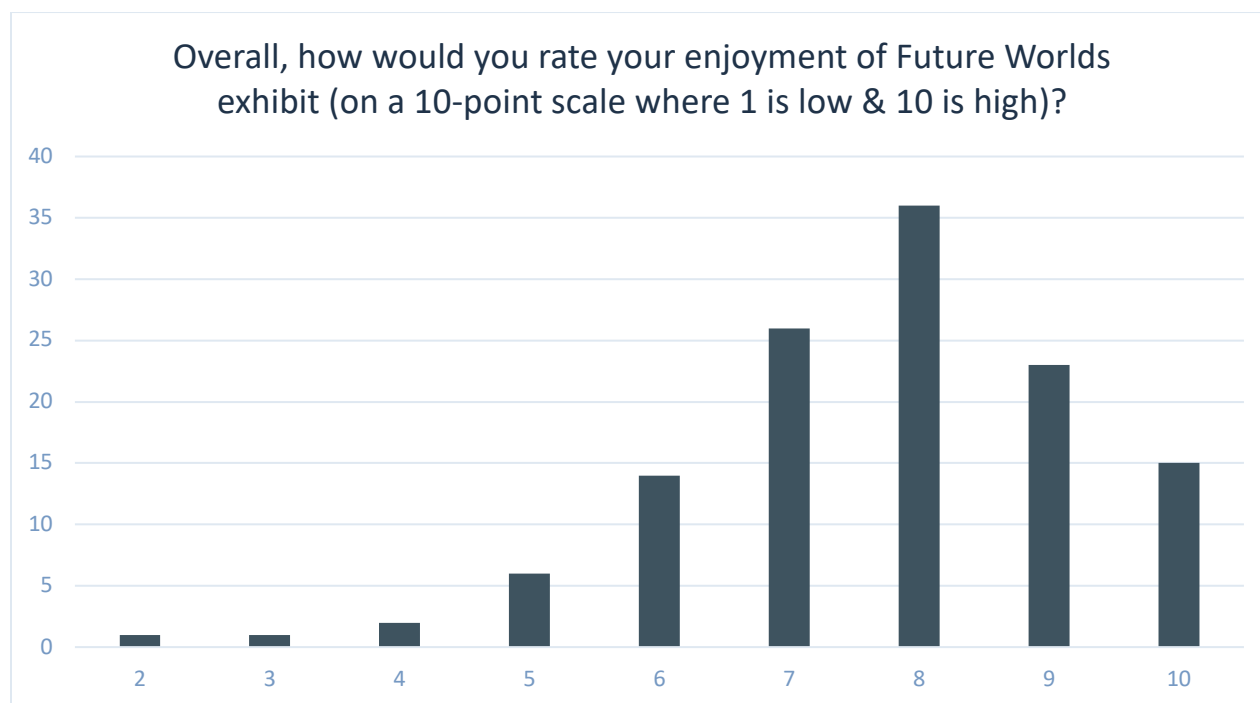
1.26

1.77

1.19

1.58

Figure 1. Frequency of all student enjoyment ratings (n=120)



What Students Liked Best

The second post-exhibit interview question asked students about their favorite parts of Future Worlds. Some students provided explanations for their answers, but most simply named what they liked. “Helping the environment” was the most common theme in students’ responses, followed by the exhibit’s problem-solving and game features. Some students mentioned various aspects of the layout of the exhibit, and a smaller number commented on the pig farm theme. A few vague responses included “All of it,” “No favorite part,” and, “It was really cool.” No students said they did not like anything about the exhibit, but one did say, “I got bored after the introduction.”

Learning About the Environment

A total of 40 students said they liked that the exhibit related to the environment. About two thirds of these students’ comments were quite general, but some were able to identify more specific aspects related to the environment that they liked about the game, and some

mentioned energy. Examples showing the range of specificity in responses are below. Note that these examples are paraphrases of student comments, since interviews were not recorded.

- *That we could see how to help the environment and how we can contribute.*
- *Learning more about sustainability and the environment.*
- *That all the parts were interconnected. If you cut down trees somewhere it impacted things elsewhere.*
- *I liked how we could use the solar panels because it made a lot of stuff better.*
- *You have to experiment with different power sources to make sure you have the best option.*

Playing a problem-solving game

Some students were drawn to the problem solving and the interactivity aspects of the exhibit. They liked seeing the impact of the choices they made, as well as the opportunity to work together with their peers to decide what to try. Several mentioned that it was a fun way to learn.

- *It was the fact you had a certain amount of moves you could make. Felt like a strategy game.*
- *The interactive part. It's not just a video. You get to actually do it and it keeps you engaged.*
- *Making the right decisions.*
- *Different options and what they did. Seeing what happens.*
- *With friends you can figure out more stuff.*
- *Even though you're playing a game, you're learning.*

Layout of the exhibit

Twenty students identified visual aspects of the exhibit when asked what they liked the best, including the tiles, the characters, the eco-meters, and just being able to see how their choices impacted the environment:

- *Liked to click around, explore tiles. Pictures helped me understand. I liked the animation.*
- *Tiles all meant something different; I liked the shapes.*
- *Being able to tell how the process is when the meter goes up. It felt satisfying.*
- *It was fun to see what makes things go up and down.*
- *That you can change the environment. How you could see pictures.*

Pig Farm

Seven students mentioned the context of the pig farm in their favorite things about the Future Worlds exhibit:

- *The farm part.*
- *Getting to grow pigs.*
- *Helping the pig farms.*

What Students Said They Learned

The third interview question asked students what they learned “about our environment and sustainability.” “Energy” was the most common theme among student responses to this question, followed by variations in the responsibility that humans have to take care of the environment. The other prevalent theme in students’ responses related to pig farming. A small number of students said they didn’t learn anything (“Nothing. I knew a lot of it already.”), and a couple of students offered responses so vague that it was hard to tell what they learned (“We’re always running out of food, water, and energy.” “About the environment: how it’s good & bad.”).

Students Learned about Energy

Thirty-eight students said they learned something about energy from the Future Worlds exhibit. About half of those students provided a range of reasons why solar and/or wind energy is good for the environment:

- *Solar-powered farms give better water quality.*
- *Wind farms are really good because they bring up everything. Air quality improves and CO2 decreases.*
- *Solar power wind helps the water source. The faster the wind the faster the water.*

An additional nine students stated that wind was better than solar energy, and eight articulated that fossil fuels were bad for the environment:

- *You really need wind energy even more than solar. Solar brings down some of your factors.*
- *I always thought solar panels were best, but the game showed me that wind power energy systems are better for the environment.*
- *I thought coal factories were good but then realized wind is the best.*
- *Different oil industries are no good, they pollute.*

Five students demonstrated slightly deeper comprehension of energy and the environment:

- *Things like proper energy use or soil can positively affect parts of the environment you wouldn't think they would.*
- *You have to make sure you experiment with power sources and make sure you have the best option.*
- *It's good to have diversity in energy sources.*
- *Have both solar & wind; don't rely on one source.*
- *Using non-sustainable energy sources is not good. Renewable energy sources are better.*

Only one student's response clearly demonstrated erroneous understanding:

- *Wind vanes affect the environment in a negative way.*

Students Learned about the Environment

About 26 students mentioned the environment, without reference to energy, when asked what they learned from the exhibit. Some responses were quite general, but most acknowledged the impacts of human behavior:

- *All different ways you can help environment.*
- *Sometimes the world can be polluted. Animals die.*
- *How different places can impact the environment.*
- *Too much of something is not always good. Even solar if you already have a lot.*
- *I learned that when they farm meat (cattle), it really affects the environment. If we have a cleaner environment, it is better.*
- *If you build a lot of suburban housing the water quality goes down. More houses equals more pollution.*
- *It reinforced that everything can affect the environment. I didn't know houses can affect the environment.*

Students Learned about Pig Farming

Twenty-three students said they learned about pig farming, including 14 who said pig farming is bad for the environment:

- *Don't pollute. Pig farms are a disaster.*
- *That pig farms can hurt the environment.*
- *I didn't realize pig farms were a big problem.*
- *Farms can do a lot of damage depending on the type.*
- *Organic farming, I didn't know it was a thing.*
- *I learned that spreading manure is better - organic pig farms.*

Other Things Students Learned

Seven students said they didn't learn anything, and some explained that they already knew all or most of the information in the exhibit. Four responses were so vague that they could not be included above.

- *Didn't learn much because I wasn't on there much.*
- *Not really. Knew a bit already. Inspired though.*
- *About the environment: how it's good and bad.*
- *We need more food and water availability. We have a poor environment, and I love how this game is going to make it better.*

- *We're always running out of food, water, and energy.*
- *About building neighborhoods.*

What Students Will Do Differently

Students were asked if there were any topics that they planned to learn more about or actions they planned to take because of what they learned from the exhibit. Twenty-five students said they did not plan to learn or do anything new. However, after experiencing the Future Worlds exhibit, sixteen students said they planned to learn more about: various aspects of energy, such as how renewable energy sources work; pollution and its effect on animals; how they can help the environment; and how to find more sustainable food sources. Students also reported that they wanted to start composting, be more aware of their recycling habits and use of electricity, reduce how much water they waste, be more involved in sustainability, help others understand the importance of sustainability, and participate in more neighborhood cleanups. Ten students reported wanting to look more into how farms operate, with a few mentioning their impact on the environment.

- *Different farms. How our world today will impact the future.*
- *Stuff that can help the environment and solar energy in farming*
- *I would research more about how we affect the environment and do my part to help stop it.*
- *Look up how to help the environment.*
- *How we can make solar and wind accessible to people who use coal.*
- *More about the science of wind energy.*
- *Researching solar panels and how they work.*
- *Why do people use coal if wind is more useful.*
- *Stuff that can help the environment & solar energy in farming.*
- *More about pig farms.*
- *Organic farming.*

For actions they planned to take, most students provided specific ideas, while some offered general ones:

- *Going to use compost recycling. All goes into oceans. Ocean full of trash, not cool.*
- *Recycle more.*
- *Trying to find different or more sustainable food sources.*
- *I will think about how I am using resources. How to save water and other important resources.*
- *Try to make the environment more healthy. Electricity use.*
- *I'll notice a lot more stuff that I saw in the game.*
- *Maybe later in the future I might help make changes.*

What Students Did Not Like

In November, students also mentioned things about the exhibit that they found confusing or that they didn't like, and some provided ideas for what could make the game better. Many students found that there were not enough instructions when they first started, saying they would have liked tips for certain parts and more information for some of the graphics. Recommendations included an option for difficulty level, more content, more options to incorporate in the game (i.e., seasons, expanding the map, more building options), adding a "skip" button, and more. In December, all students were asked if they had suggestions for the exhibit. Twenty referred to difficulty and variety, with fourteen suggesting that more levels be added to the exhibit. Four students said the game was too easy, and two said it was too hard.

- *I wish it had more variety of levels...levels for each category. Make it progressively harder. More choices.*
- *I would unlock more levels or ecosystems to get a better understanding of how to make different ecosystems better.*
- *Add more levels. Make it a little harder because it was kind of easy.*
- *Difficulty of level 2 - it was "impossible"*

Twenty-one students mentioned the introduction to Future Worlds in response to this question, with eight suggesting that the introduction be shortened, and seven saying they would have liked to be able to skip the introduction, especially after seeing it once.

Value of The Project

As was described above, trying to ascertain the engagement level of individuals or groups using museum exhibits is challenging. As one staff member explained, this project will shed light on the extent to which multimodal data and AI machine learning can contribute to a better understanding of user engagement:

This is a process [i.e., studying engagement] that, for a long time, museum researchers have done manually through observations and administering surveys and taking video recordings and analyzing them afterward. This project is an opportunity to explore how these AI machine learning techniques that have been emerging can augment and support and enhance that sort of investigation.

Project staff are optimistic that the work they have conducted will be generalizable to other museums, to formal educational settings, across disciplines, and in different contexts:

I think that the general concept of taking an exhibit or an exhibition space and setting up a set of video sensors or audio sensors, of taking existing digital interactive exhibits and ensuring that they are designed so that some log data or telemetry is available for those exhibits, that these data sources are available and those can be directed and fed into a machine learning-based system to produce some analytics for understanding patterns of learner engagement. There's nothing about it that would restrict it to only being able to be used in a particular museum or ... exhibit that we've created, that it wouldn't be able to be used for other exhibits now.

I don't think it's limited to the informal setting. Probably the informal setting is the most challenging setting because it's usually free choice learning, which means the visitor groups can dynamically change even within one session.... We were tackling probably one of the most challenging scenarios to build a system, but definitely [the system] can support individual users and formal learning contexts as well.

Project staff were particularly pleased that the Future World software performed well during the three user studies at the museum. As one project staff member said: “One additional thing about this software is robustness. It should run robustly and reliably across the multiple sessions without system or software failure.” Moreover, project staff discussed that they were able to overcome the significant challenges associated with synchronizing data:

One of the things I think is really powerful about the software that we've created ... is solving the synchronization problem. You have these different data sources, you have video data and audio data and log data, and getting them all synchronized in a single format, and ... capturing these different data streams at different frequencies and kind of different grain sizes...[is] a huge amount of effort....It can then be, with relatively little effort ... transformed into a format that can then be analyzed using standard statistical ... techniques as well as then machine learning techniques.

Lessons Learned

At the time this evaluation report was written, data analysis from the three site visits had not been completed, but looked promising in terms of reaching project goals:

We had a number of positive results from that type of analysis specifically for using machine learning to kind of process input from these different sensor-based data streams, and to make early predictions about how long visitors will spend at an exhibit, which is a useful indicator of learner engagement....You can train that model using multiple different data sources. Then you can use it effectively to ... adapt and transfer it to a setting where you don't have all of those data sources available... You create your initial model using those kind of rich multimodal data sources, and then you ... leverage that ... to create a model that can be able to perform the same task of predicting how long someone will spend at the exhibit

but in a setting where you don't have all those data source., where you don't have the video and you don't have the eye tracking, just have the log data.

Another lesson the team learned was how challenging it was to set up and use multimodal sensors to collect data. Challenges included having the “right hardware setup; having the section [of the museum] that you're actually using ... sequestered off so that you don't accidentally collect data you don't want to collect; [and] managing that data so if I have five students in this area walking between multiple machines [that we can understand the data we collected].” Preliminary data analysis indicate that the project staff were successful in setting up the software and managing data collection despite these challenges, and what the team learned will be shared with others with similar research interests.

Dissemination

The NCSU team has made significant efforts to disseminate information about their work by doing presentations at relevant conferences and working on articles for publications (see Project Staff's Final report for details). The evaluation team is currently preparing an article for submission to the Educational Technology Research and Development journal. The audience for the article will be museum practitioners and will focus on practical aspects of using multimodal data collection for understanding visitor engagement.

Implications for the Future

Recent articles in popular media indicate that there is increasing concern about the loss of personal privacy since video cameras and other technology are ubiquitous. The extent to which researchers, museum staff, and teachers will be able to take advantage of the capabilities of the multimodal system developed by project staff depend to a great extent on the level of comfort people feel about having their actions, voices, gestures, etc. recorded. In the museum, participants gave their consent to be recorded after the project went through a Human

Subjects review and approval process. This would be a challenge for researchers in the future who want to use the multimodal system, as these quotes illustrate:

There's a whole rich kind of ethical AI conversation that is really important to figure out. What are the standards and practices for being able to capture this type of data from the public or ... in a space like a museum.... Under what conditions is it desirable or OK to collect this type of data?

How do the people who are having data collected on them, how do they give consent or have ownership over that data? Those are really important questions that I think will be important to be considering and answering and mapping out in thinking about the generalizability of these technologies.

Conclusion

Overall, this project was well run, with highly qualified and motivated staff who conducted excellent research despite the challenges brought about by the pandemic and the complexity of the research. Project staff met their goals, and their findings will no doubt contribute to knowledge about multimodal measurement, AI machine learning, and student engagement. They successfully disseminated their work in a variety of venues, and they plan to continue to engage in analysis and dissemination activities.

