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Exploring Visitor Engagement through Informal STEAM Learning in Museum Exhibits

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Abstract

The *Traveling Gallery of Fluid Motion* (TGFM) exhibits are a unique initiative designed to extend fluid dynamics education beyond academic and professional circles by integrating art and science. By curating visually captivating displays of fluid motion, these museum exhibits engage diverse audiences, fostering public understanding and appreciation of physics. This project demonstrates the educational potential of combining aesthetics with engineering principles, creating accessible pathways for learning. The first TGFM, *Chaosmosis: Assigning Rhythm to the Turbulent*, premiered in 2023 at the National Academy of Sciences museum in Washington, DC. It transformed fluid dynamics into an interactive and immersive experience through photographs, videos, sculptures, and sound installations. These works, created by both scientists and artists, challenge conventional teaching methods by sparking curiosity and encouraging interdisciplinary thinking. The second TGFM, *Spiraling Upwards*, was showcased at the Leonardo Museum in Salt Lake City, UT, in 2024. The initiative's main goal is to inspire creativity while promoting fluid dynamics to a broader audience. The traveling nature of the exhibit enables these insights to reach diverse geographic regions, broadening the educational impact of fluid dynamics across various platforms. This presentation discusses the innovative methods used in our exhibitions, the outcomes from the first two showcases, and the potential for future collaborations to enhance outreach efforts. We explore how interdisciplinary art and science exhibitions can reshape the narrative of engineering education by making technical subjects more approachable, engaging, and relatable to the public.

Overview

The science of fluid dynamics explores ordinary liquids and gases such as air, water, and oils, and extends to fluid-like materials including flowing plastics, mud, and plasmas. Fluid motion appears from nanometer to astrophysical scales in science, technology, engineering and math (STEM) fields such as physics, biology, geophysics, mechanical and chemical engineering, applied mathematics, and data and computer science. Everything flows, whether it is blood circulation in the body, ocean currents around the globe, atmospheric winds, or liquids through a diagnostic device. Advances in fluid dynamics are fundamental to addressing societal challenges such as energy production, pharmaceuticals, agriculture, and climate change.

To bridge the gap between technical expertise and the public's understanding and use of scientific concepts, science and engineering professional societies often use public engagement channels including lectures, publications, and educational materials. Such efforts often focus on highlighting technical phenomena or notable scientists to diverse public audiences. They are less frequently designed with input from diverse audiences and are rarely designed to solicit contextualized reflections on learning by such audiences[2]. In contrast, community-participatory exhibition design and curation, and participatory research, are more prevalent among museum professionals, particularly within institutions aiming to broaden visitation among individuals who have been historically marginalized or excluded from STEM careers[2-4]. For example, the *Race: Are We So Different?* exhibit at the Science Museum of Minnesota combines science and inclusivity, the Ohio Valley Museum of Discovery emphasizes STEM and rural communities, and the Natural History Museum's London Touring Exhibition Program highlights museums and traveling exhibits.[5] However, no exhibition fully integrates STEM and art in museums for both public and professional audiences while traveling to broaden participation, promote inclusivity, and connect with local communities and their cultures in each city it visits.

Effective informal STEM learning environments present technical information in ways that allow diverse public and professional audiences to see the world and themselves in new ways[9]. This can be accomplished through the application of design elements such as organizing the exhibition that are linked with specific objects and displays. Simple, illustrative narratives and questions to the audience can be included prominently in plain language label text to prompt visitors to “re-see” the world and themselves[10-11]. Interactive activities can highlight and reinforce key STEM principles and their applications to everyday life[12-13].

The use of these elements is uncommon in professional society public engagement activities but has been used to promote diverse audiences’ informal STEM learning [14-16] We applied these design elements in the context of a collaborative curation-design process that will bring these and other exhibition design elements to life through an iterative, participatory process of multidisciplinary workshops, community engagement meetings, and prototype evaluation and research designed to improve the capacity of the team to work together to advance informal STEM learning. We anticipate sparking and documenting new ways of thinking about STEM content and exhibition design by the curatorial-design and community team members and among exhibition audiences as they explore literal, scientific and metaphorical, artistic instantiations of concepts such as fluids, motion, and scale.

Science learning occurs in diverse informal contexts, including museums, community spaces, and online platforms, and can range from fleeting, unplanned moments of wonder to structured, educator-led activities. These experiences have immense potential to inspire curiosity, challenge ideas, and foster connections with science, but our understanding of their impact remains limited. Factors such as varied outcomes, individual differences, and the difficulty of assessing long-term effects make fully tapping into this potential a significant challenge. Despite these limitations, informal science learning plays a critical role in reaching audiences beyond formal education settings.

Research indicates that learning activities in informal contexts yield diverse outcomes, often categorized as cognitive (knowledge and understanding), affective (attitudes and feelings), social/interpersonal (empathy and communication skills), and physical/behavioral. A review by Rickinson[1] and colleagues highlights that outdoor adventure programs significantly enhance young people's attitudes, beliefs, and self-perceptions—fostering independence, confidence, self-esteem, and coping strategies—while also improving interpersonal and social skills such as communication, teamwork, and group cohesion .

Identity as a learning outcome in informal settings represents a complex and multifaceted area of study, encompassing dispositions that range from transient feelings to stable beliefs. Researchers agree that identity is a significant affective outcome tied to personal psychological development, social skills, and context-specific experiences [2-5]. Furthermore, identity formation is intricately connected to cognitive and skill development, underscoring the interdependence of affective and intellectual outcomes.

Identity is often described as both positional and interactional, evolving through individuals' interactions within communities such as museums, zoos, or field expeditions. These interactions prompt participants to redefine themselves through internal and external discourse, effectively becoming new versions of themselves.

In museum contexts, visitors engage with roughly one-third of exhibit elements, yet even limited interaction enables what he calls "identity work"[5]. This reflexive activity allows individuals to construct, maintain, and adapt their sense of self while persuading others to recognize this evolving identity. Informal settings like museums provide unique opportunities for identity exploration and transformation, even without deep cognitive engagement in specific domains.

Gallery of Fluid Motion1 (GFM)[17] at the annual American Physical Society (APS), Division of Fluid Dynamics (DFD) conference showcases scientist-generated images and videos of fluid dynamics, emphasizing both aesthetic appeal and new discoveries. Building on GFM's 40-year legacy, the Traveling Gallery of Fluid Motion (TGFM) is an iterative, community-participatory exhibition that highlights fluid motion as an organic blend of science and art. TGFM aims to expand public access to GFM content by connecting to local cultures, promoting inclusivity, and employing innovative visitor engagement strategies.

In TGFM, artifacts and digital displays (Figs 1a, 1c, 1d, and 2a) present applications of fluid dynamics to blood flow, respiration, cloud simulation, pipe flow, and flight. Thematically-oriented prompts in labels and interactives invite literal and metaphorical connections between scientific phenomena and the audience (Fig. 1b, 1d, 2b, and 2c). For example, in the first TGFM[18], *Chaosmosis*, a video shed lights on the airflow of an opera singer during singing (Fig. 1a), while a 3D-printed sculpture reveals the cloud-shape of human speech (Fig. 1c). *Chaosmosis* was featured in the *Washington Post*[20] and other local news outlets, earning recognition as one of DC's "Two Notable Photo-Adjacent Exhibits" of 2024[21].

(a) **(b)** **(c)** **(d)**

Figure 1. Selected exhibit items and audience engagement with *Chaosmosis: Assigning Rhythm to the Turbulent*.

The second TGFM exhibition[19], *Spiraling Upwards*, focused on the intersection of Leonardo da Vinci's studies on fluid dynamics and flight, and the curatorial mission expanded to include artists' selected works through an open, international call as well as the GFM archive. A website[22] was also created with educational materials including physics articles, hands-on concept-reinforcement activities, and interviews and panel discussions featuring contributing scientists and artists. The final partnership model for *Spiraling Upwards* included APS, museum, GFM Coordinator (PI), curators, local universities, and industries such as Utah State University, University of Utah, Brigham Young University, Utah Valley University, Weber State University, and Reaction Engineering International (REI). The partners sponsored portions of the exhibition costs and marketed it to their audiences[23], and the universities brought undergraduate students so that emerging STEM professionals could recognize classroom concepts in real-world phenomena through informal learning.

Visitors gave positive feedback on both *Chaosmosis* and *Spiraling Upwards*. On a 10-point scale, *Chaosmosis* received an average rating of 8.0 for enhancing understanding of the art-science connection and 7.3 for fluid dynamics in art. *Spiraling Upwards* garnered average ratings of 3.0 and 3.12 on a 5-point scale for increasing appreciation and interest in the material. Survey responses emphasized enjoyment of the art and a desire for more in-depth exploration of science, highlighting the importance of culturally relevant and inclusive elements for greater visitor engagement.

(a) **(b)** **(c)** **(d)**

Figure 2. (a-c) Selected exhibit items and audience engagement with *Spiraling Upwards*. (d) Example questions reflected the big idea of observation of phenomena presented on labels: How much can we learn about the world by observing it closely? How do observations lead to new ideas and innovations? Audience affirmations, such as "I am an Observer," and questions like "How has the exhibit sparked your curiosity?" are inspired by Leonardo da Vinci.

Assessment in Informal Science Learning Environments

Traditional assessment methods work well in structured settings but present challenges in informal environments where learners have greater autonomy. Developing normative data for informal learning venues, such as museums and nature centers, is difficult due to the lack of representative sampling[5]. While funding agencies often require quantitative methods like fixed-choice surveys, these can narrowly focus outcomes and fail to address the complexity of informal learning contexts.

Models and Dimensions of Assessment

Assessment in informal science settings spans several dimensions:

- **Outcomes Measured**: Knowledge, behaviors, feelings, attitudes, and values.
- **Purpose**: Ranges from individual empowerment (micro-level) to national policy-making (macro-level).
- **Learning Models**: Includes behaviorism, constructivism, and experiential/free-choice learning (Hein, 1998).
- **Methods**: Questionnaires, interviews, observations, and mixed-method approaches.

Challenges and Mixed-Methods Approaches

Qualitative methods such as open-ended interviews and observations are critical for understanding the nuanced interplay of variables in informal environments[26]. Mixed-methods research is increasingly advocated, blending quantitative rigor with qualitative depth to better evaluate program outcomes. Case studies and discourse analysis are also widely used to assess cognitive processes during free-choice learning experiences [3,4].

For example, Lebeau et al. (2001) studied the effects of goal-setting on middle school students at a science center, finding modest improvements in goal-setting behaviors [29-33]. They used confirmatory factor analysis and structural equation modeling to demonstrate that informal science resources have a small but significant impact on understanding scientific concepts. Other case studies, exploration of constructivist learning models, provide insights into the complex transformations resulting from informal learning experiences.

Visitor Engagement

We examined the impact of our exhibits on visitors from diverse public (families, K-12 students)**,** emerging professional (undergraduate engineering, art, and science students), and professional (Scientific Organization members) audiences. The research questions are aligned with design and development research that seeks to improve knowledge of learning related phenomena in a particular context, while contributing to theory and practice more broadly[24-27]. The research questions are:

1. How do focal audiences engage with exhibition content?
2. To what extent do the focal audiences use science concepts when describing their lives?
3. What similarities and differences are apparent in focal audiences' STEM learning?

Evaluation and Results

This evaluation framework emphasizes the importance of integrating diverse perspectives and iterative feedback to ensure the project remains responsive and aligned with its stated goals. The evaluation uses mixed methods, combining qualitative and quantitative data collection approaches, to comprehensively assess project outcomes and processes[28]. Evaluation outputs included: post-opening visitor experience evaluation surveys.

In our exhibits, artifacts and digital displays present concepts such as aerodynamics, hydrodynamics, and applications of fluid dynamics to blood flow, respiration, and cellular processes. Thematically-oriented prompts in labels and interactives invite literal and metaphorical connections between scientific phenomena and the audience A website was also created with educational materials including physics articles, hands-on concept-reinforcement activities, and interviews and panel discussions featuring contributing scientists and artists. The partners sponsored portions of the exhibition costs and marketed it to their audiences, and the universities brought undergraduate students so that STEM students could recognize classroom concepts in real-world phenomena through art.

The following results present a quick analysis of the survey data obtained during Exhibit 1. Each question/section from the survey is presented, along with tables and graphs, and a bit of lite commentary where applicable. There were 55 reported surveys, 43 were reported complete by Qualtrics, however the questions were optional, so not all questions have 43 complete responses. Overall, participants responded positively to the exhibit, however they also demonstrated a desire for more interpretation of the exhibit works, and more interactive exhibit materials.

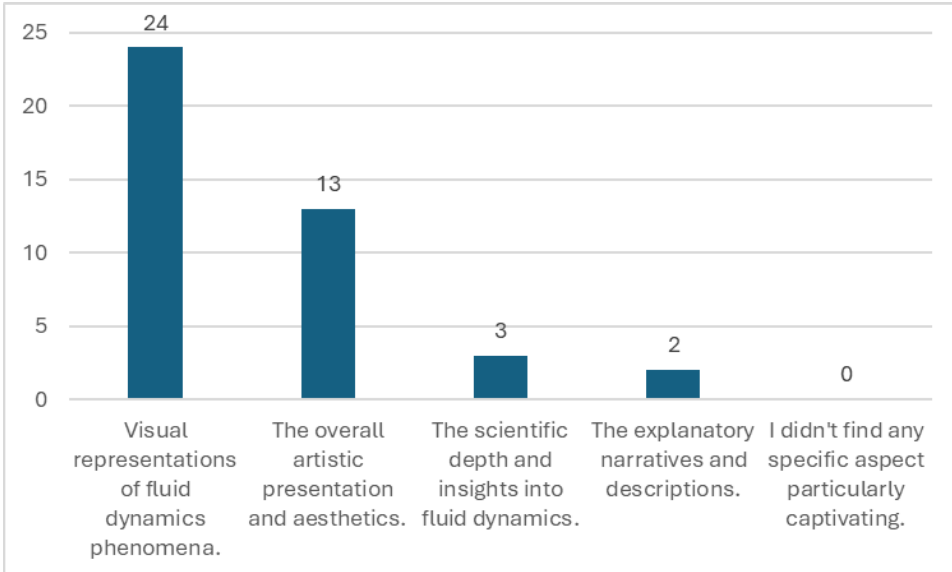

Figure 3. Which aspect of the exhibit did you find most captivating or informative?

Most respondents were captivated/informed by the visual representations of fluid dynamics phenomena, followed closely by the overall artistic presentation and aesthetics. The scientific depth and explanatory narratives were less informative to visitors. This may indicate that visitors would appreciate further insights and varying levels of information about the scientific exhibits, so that the exhibit text meets them where they are. At least 7 respondents indicated a desire for more information about the science, or more description in a variety of formats and content levels. Another Question asked guests to indicate to what extent the exhibit enhanced their understanding of 3 topics: “Fluid Dynamics in Art,” “Fluid Dynamics in Science,” and “the Connection Between Art and Science.” The table below indicates the average score and the most common (mode) score for each dimension.

Table 1. Indicate to what extent the exhibit enhanced their understanding of 3 topics: “Fluid Dynamics in Art,” “Fluid Dynamics in Science,” and “the Connection Between Art and Science.”

	Fluid Dynamics in Art	Fluid Dynamics in Science	Connection Between Art and Science
Average	7.28	5.88	8
Mode	8	6	10

This data indicates that, in general, this exhibit did enhance the respondents’ understanding of the of indicated topics, however the way these scores are distributed indicates that this effect is somewhat stronger for “Fluid Dynamics in Art” and “Connection between Art and Science” than it is for “Fluid Dynamics in Science,” because the responses for “Fluid Dynamics in Science” is peaked in the middle- fewer respondents reported higher scores, where as the other distributions are peaked on the high end, indicating most respondents felt the exhibit enhanced their understanding of these dimensions to a much greater extent. This is consistent with the results from Question 1, where guests indicated that they did not find the scientific depth or explanatory narratives as impactful as the visual representations and aesthetics on display.

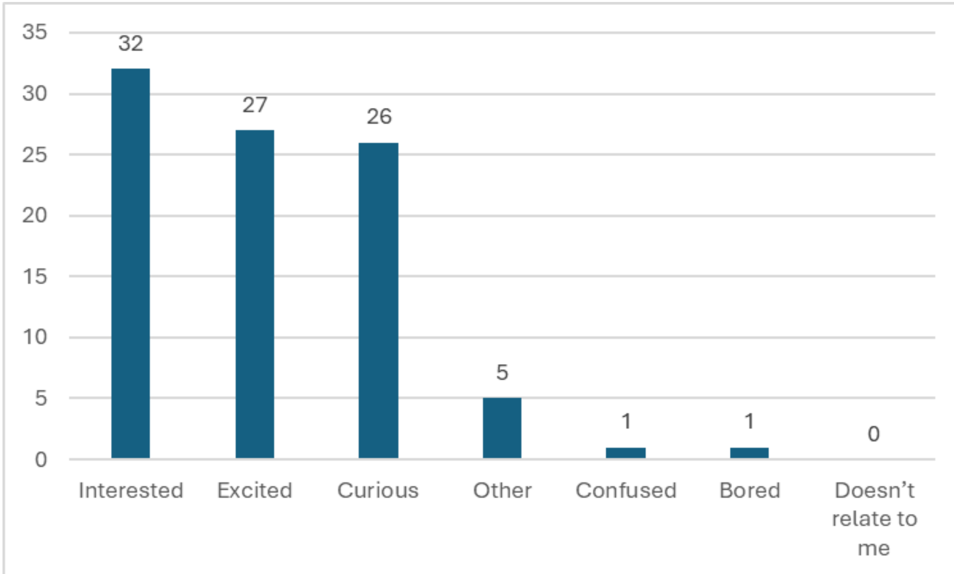

Figure 4. Select the words that best describe how this exhibit made you feel about the connection between art and science

Here, respondents were asked to select up to 3 words from a list that included: Interested, Excited, Curious, Confused, Bored, Doesn't relate to me, and Other. If a respondent selected "Other" they had the option of filling in their own word. 5 Guests selected other, and their inputs were: To be extended, Full of wonder/awe Captivated, and Appreciative (2x).

An overwhelming majority of guests chose from the list, and selected "Interested," "Excited," "Curious," or some combination of the three. It may be worthwhile to note that the single guest who chose "Confused" only selected that choice, and the guest who chose "Bored" also chose "Curious" and "Interested."

When asked, "Would you be interested in attending future exhibitions hosted by the Gallery of Fluid Motion?" none of the respondents selected "No." Instead, 30 responded "Yes," and 8 responded "Maybe."

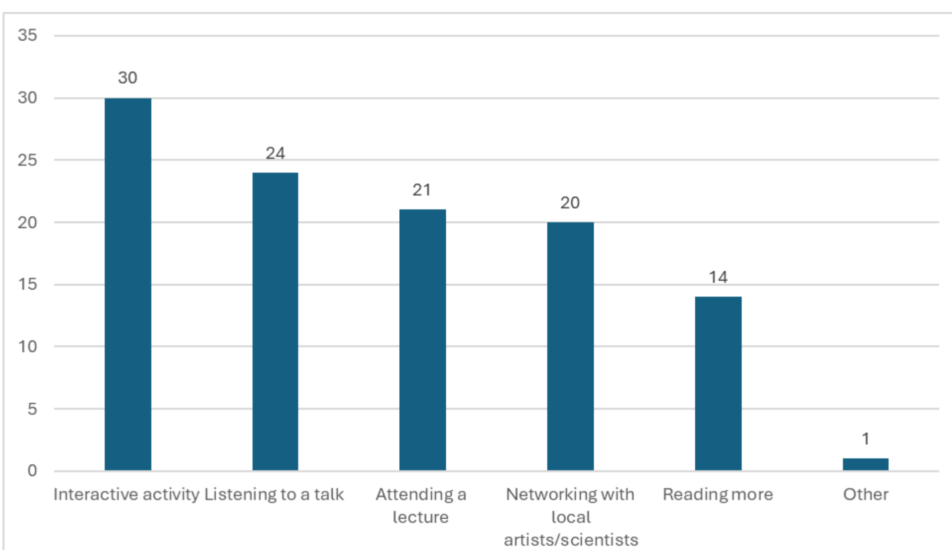

Figure 5. Would you be interested in any of the following? Select all that apply.

Guests were asked to select from a list of various activities but could also supply their own choice by selecting "other" and include their own text. The supplied list included: Listening to a talk about artworks in the gallery, attending a lecture about Fluid Dynamics, Engaging in an interactive activity within the gallery for deeper insights, Reading more about Fluid Dynamics, and Informal networking event with local artists/scientists.

The data collected here suggests all these options were well liked, however the most selected option was clearly "Interactive Activity." This is consistent with open ended feedback, where 11 respondents indicated that some form of interactive activity would improve their experience with the exhibit. Listening to a talk, attending a lecture, and networking with local scientists were all quite popular, and were also noted as possible improvements to the exhibit in the open-ended feedback. This is also consistent with the results from Question1. The single respondent who indicated "Other" supplied "Interested in participating in art exhibitions" as an activity that they would like to participate in.

This was an open ended question: **How do you think we could improve or enhance the exhibit?.** Responses cluster around a few key themes. The first of those themes is a desire for more explanation/interpretation. Of 23 responses, 11 participants suggested adding some interactive aspect to the exhibit, which is consistent with Question 4. 7 participants suggested that some sort of alternative interpretation, whether that was written in descriptions of different levels, or having a guide present to interpret the scientific information there. This was also consistent with Question 1. Other highlights included a suggestion for "Behind the Scenes" content about the production process behind the art in the exhibit.

The following charts break down the demographic information about guests who participated in the survey. Participants included representatives from all age groups, were mostly white or of Asian descent, and approximately half had graduate/professional degrees. While fewer than half of the participants indicated they were a Science Organization member, few of them properly indicated their unit. 17 participants indicated that they live somewhere in the state of Pennsylvania, USA, which was by far the most represented region in the survey data. Visitors came from as far away as Germany, Belgium, and the Netherlands. Various other US States were also represented (PA, NY, TN, NH, CA, VA, LA, MI, OK).

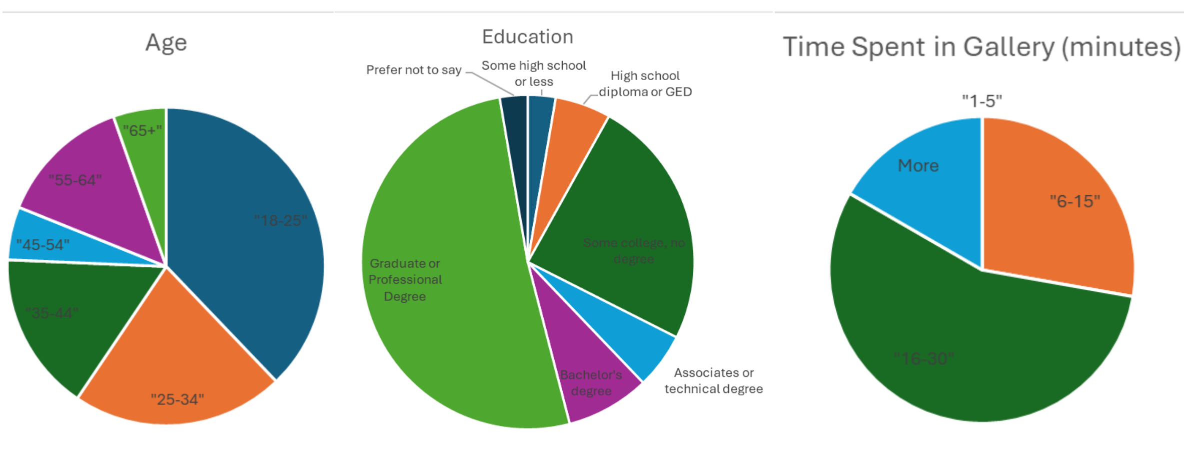

Figure 6. Demographic Data.

Visitors positively received both *exhibits*. On a 10-point Likert scale, for *the first exhibit* visitors rated an average of 8.0 for enhancing their understanding of the connection between art and science and 7.3 for deepening their understanding of fluid dynamics in art. For *the second exhibit*, visitors provided average ratings of 3.0 and 3.12 on a 5-point scale for developing a deeper appreciation and interest in learning more about the material, respectively. Visitor survey feedback emphasized enjoyment of the exhibitions and a desire for more opportunities to explore the science behind the displays, underscoring the importance of culturally relevant, inclusive components to enhance audience engagement and understanding further. Additional results will be presented in the final paper, including more detailed information with specific identifiers related to the exhibition content.

Conclusion

Informal science learning is influenced by complex interactions of internal and external variables, necessitating diverse and mixed-method approaches. The Traveling Gallery of Fluid Motion exhibits demonstrate the transformative potential of integrating art and science to make fluid dynamics accessible, engaging, and relevant to diverse audiences. By embracing participatory design, interdisciplinary collaboration, and innovative exhibition strategies, the project bridges gaps between technical expertise and public understanding. Visitors' positive feedback underscores the effectiveness of combining aesthetics with scientific principles to foster curiosity, deepen understanding, and inspire connections with STEM concepts.

Through iterative work, the project provides a model for rethinking public engagement with technical subjects, offering new ways to inspire interdisciplinary thinking and visitor engagement in STEAM. As future exhibits are developed and studied, the TGFM project will continue to contribute to the growing body of knowledge on informal STEAM learning, demonstrating how art and science can converge to reshape educational narratives and broaden participation in engineering and scientific fields.

References

[1] M. Rickinson et al., *A Review of Research on Outdoor Learning*, London: National Foundation for Educational Research, 2004.

[2] G. Hull and J. G. Greeno, "Identity and agency in nonschool and school worlds," in *Learning in Places: The Informal Education Reader*, Z. Bekerman, N. C. Burbules, and D. Silberman-Keller, Eds. New York: Peter Lang, 2006, pp. 77–97.

[3] M. Brody, "Learning in nature," *Environmental Education Research*, vol. 11, no. 5, pp. 603–621, 2005. [Online]. Available: https://doi.org/10.1080/13504620500169809.

[4] J. H. Falk and L. D. Dierking, *Learning from Museums: Visitor Experiences and the Making of Meaning*. Walnut Creek, CA: AltaMira Press, 2000.

[5] Simon Fraser University's Morris J. Wosk Centre for Dialogue, *Beyond Inclusion: Equity in Public Engagement*, 2020. [Online]. Available: https://www.sfu.ca/content/dam/sfu/dialogue/ImagesAndFiles/ProgramsPage/EDI/BeyondInclusion/Beyond%20Inclusion%20-%20Equity%20in%20Public%20Engagement.pdf.

[6] V. Golding and W. Modest, *Museums and Communities: Curators, Collections and Collaboration*. London: Bloomsbury, 2013.

[7] L. A. Jason, C. B. Keys, Y. Suarez-Balcazar, R. R. Taylor, and M. I. Davis, Eds., *Participatory Community Research: Theories and Methods in Action*. Washington, DC: American Psychological Association, 2004. [Online]. Available: https://doi.org/10.1037/10726-000.

[8] American Association for the Advancement of Science, "Many approaches to public engagement," *AAAS*, [Online]. Available: https://www.aaas.org/resources/communication-toolkit/many-approaches-public-engagement.

[9] Reimagining Equity and Values in Informal STEM Education, "About REVISE," *REVISE*, [Online]. Available: https://informalscience.org/about/about-revise/.

[10] National Informal STEM Network (NISE), *Museum and Community Partnerships: Collaboration Guide and Additional Resources*, [Online]. Available: https://www.nisenet.org/collaboration-guide.

[11] American Physical Society, "Code of Conduct for APS Meetings," *APS*, [Online]. Available: https://www.aps.org/about/governance/policies-procedures/code-of-conduct.

[12] J. K. Garner, A. Kaplan, and K. Pugh, "Museums as contexts for transformative experiences and identity exploration," *Journal of Museum Education*, vol. 41, no. 4, pp. 341–352, 2016. [Online]. Available: https://doi.org/10.1080/10598650.2016.1199343.

[13] K. Pugh, "Transformative experience: An integrative construct in the spirit of Deweyan pragmatism," *Educational Psychologist*, vol. 46, no. 2, pp. 107–121, 2011. [Online]. Available: https://doi.org/10.1080/00461520.2011.558817.

[14] B. Serrell and K. Whitney, *Exhibit Labels: An Interpretive Approach*. Lanham, MD: Rowman & Littlefield, 2024.

[15] P. Campos, M. Campos, J. Pestana, and J. Jorge, "Studying the role of interactivity in museums: Designing and comparing multimedia installations," in *Proc. 14th Int. Conf. Human-Computer Interaction: Towards Mobile and Intelligent Interaction Environments (HCII'11)*, Berlin, Heidelberg: Springer-Verlag, 2011, pp. 155–164.

[16] T. Dancstep and L. Sindorf, "Exhibit Designs for Girls' Engagement (EDGE)," *Curator*, vol. 61, no. 3, pp. 485–506, 2018. [Online]. Available: https://doi.org/10.1111/cura.12267.

[17] American Physical Society. (n.d.). Gallery of Fluid Motion. Retrieved from https://gfm.aps.org/about

[18] National Academy of Sciences. (2023, February 23). Chaosmosis: Assigning rhythm to the turbulent. Retrieved from https://www.cpnas.org/news/art-exhibition-inspired-by-fluid-dynamics-to-open-at-nas/

[19] Leonardo Museum. (2024). Spiraling Upwards. Retrieved from https://theleonardo.org/exhibits/current-exhibits/spiraling/

[20] The Washington Post. (2024, February 2). Art gallery shows in the DC area. Retrieved from https://www.washingtonpost.com/entertainment/art/2024/02/02/art-gallery-shows-dc-area/

[21] Washington City Paper. (2024, January 5). 2024's eight best local photo exhibits. Retrieved from https://washingtoncitypaper.com/article/755051/2024s-eight-best-local-photo-exhibits/

[22] American Physical Society, Division of Fluid Dynamics. (n.d.). Traveling Gallery of Fluid Motion: Spiraling Upwards. Retrieved from https://engage.aps.org/dfd/resources/traveling-gallery-resources

[23] Utah State University. (2024, February 1). USU engineering sponsors traveling exhibition Spiraling Upwards at The Leonardo. Retrieved from https://www.usu.edu/today/story/usu-engineering-sponsors-traveling-exhibition-spiraling-upwards-at-the-leonardo

[24] J. K. Garner, J.-A. Page, A. Carver, and A. Inwood, "A commitment to art education and outreach: Forming a researcher-practitioner partnership to support diversity and inclusion at a university art museum," *The Museum Review*, vol. 4, no. 1, 2019. [Online]. Available: https://themuseumreviewjournal.wordpress.com/2019/05/23/tmr_vol4no1_garner/.

[25] A. Kaplan, J. K. Garner, M. Smith, and A. Rush, "Designing for diverse museum visitors' identity exploration around inventiveness," *Frontiers in Education*, vol. 8, 2023. [Online]. Available: https://doi.org/10.3389/feduc.2023.1078001.

[26] National Science Foundation, *Common Guidelines for Education Research and Development*, NSF 12-126. [Online]. Available: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf13126.

[27] J. K. Garner and A. Kaplan, *Museum Visitors' Engagement, Learning, and Identity Exploration Around Inventiveness in Change Your Game | Cambia tu juego*. Unpublished technical report, NSF award #2005404, 2024.

[28] A. Kaplan and J. K. Garner, *Dynamic Systems Model of Role Identity (DSMRI): Analysis Guide and Codebook*, Version 6, Temple University & Old Dominion University, Jul. 2022.

[29] Center for Advancement of Informal Science Education, *Principal Investigator's Guide: Managing Evaluation in Informal STEM Education Projects*, Washington, DC, 2011. [Online]. Available: https://informalscience.org/research/principal-investigators-guide-managing-evaluation-informal-stem-education-projects-pi-guide/.

[30] M. E. Loverude, C. H. Kautz, and P. R. L. Heron, "Helping students develop an understanding of Archimedes' principle. I. Research on student understanding," *American Journal of Physics*, vol. 71, no. 11, pp. 1178–1187, 2003. [Online]. Available: https://doi.org/10.1119/1.1607335.

[31] J. Martin, J. Mitchell, and T. Newell, "Development of a concept inventory for fluid mechanics," in *Proc. 33rd ASEE/IEEE Frontiers in Education Conf.*, Boulder, CO, 2003. [Online]. Available: https://www.academia.edu/7368689/Development_of_a_concept_inventory_for_fluid_mechanics?source=swp_share.

[32] A. J. Petrosino and M. J. Mann, "The challenges of understanding fluid in fluid density," *Journal of Continuing Education and Professional Development*, vol. 4, no. 1, pp. 28–38, 2017. [Online]. Available: https://doi.org/10.7726/jcepd.2017.1003.

[33] Lebeau, R. B., Davis, L. A., & Wolf, P. G., "The effects of goal-setting on middle school students at a science center," Journal of Research in Science Teaching, vol. 38, no. 10, pp. 1149–1168, 2001.