From Research Center to Science Museum: Comparative Experiential Engagement Pathways in Informal STEM Learning Environments

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Abstract

This study is part of an ongoing doctoral research project exploring how students experience science when they encounter it outside formal school settings. More specifically, it compares how two informal STEM settings shape students' engagement, emotional response, and sense-making during science-related activities.
To address this research question, a comparative mixed-methods design was developed focusing on two informal STEM settings in Athens, Greece: the National Centre for Scientific Research "Demokritos" and the science and technology exhibition environment Aitherion.
The study combines quantitative data from structured questionnaires with qualitative observations, in order to examine the experience from more than one angle. The research instrument investigated constructs including active participation, experiential learning, emotional engagement, metacognitive awareness, autonomy, science skills, contextual interaction, and future STEM orientation.
A total of 150 secondary education students participated in the comparative phase of the study, including 75 students from Demokritos and 75 students from Aitherion.
Construct reliability analysis demonstrated satisfactory internal consistency for the main analytical constructs used in the comparative analysis, with Cronbach's alpha values ranging from .757 to .910.
Findings suggest that both environments supported highly positive STEM learning experiences, although through different experiential engagement pathways. Demokritos appeared to strengthen perceptions of scientific authenticity and direct engagement with scientific practice, whereas Aitherion appeared to enhance emotional engagement, accessibility, interactivity, and experiential immersion.
Descriptive and comparative analyses showed consistently positive evaluations across the main constructs. Emotional engagement emerged as a particularly important dimension, demonstrating a strong positive relationship with students' overall learning experience ($r = .783$, $p < .001$).
Independent-samples t-tests revealed statistically significant differences between the two environments regarding active participation, experiential learning, and emotional engagement, with higher scores reported in the Aitherion environment.
The findings suggest that informal STEM learning should be understood not only as exposure to scientific content, but as a broader experience involving participation, emotion, context, and students' developing relationship with science. The structure of the data may also allow future work to explore educational analytics approaches in a more systematic way.

Keywords: *Informal STEM learning, Experiential learning, Emotional engagement, Science museums, Research centers, Educational analytics, Science identity*

1. Introduction

In recent decades, informal STEM learning environments have received increasing attention within educational research due to their capacity to enrich students' relationships with science beyond traditional classroom settings. Museums, science exhibitions, research centers, and interactive STEM environments provide opportunities for students to engage with scientific concepts through participation, exploration, and experimentation.
Contemporary science education research increasingly recognizes that meaningful learning extends beyond cognitive achievement alone. Students do not only understand science cognitively, they also respond to it emotionally, socially, and personally.
Within this context, informal STEM learning environments appear particularly suitable for experiential engagement with science. Such environments allow students to interact with scientific ideas in authentic, participatory, and socially mediated ways that differ substantially from conventional classroom instruction.

The present study explores how different informal STEM ecosystems shape students' engagement with science, emotional involvement, experiential immersion, and future STEM orientation.
The comparative framework focuses on two distinct informal STEM environments in Athens, Greece:

- the National Centre for Scientific Research "Demokritos," representing an authentic research-centered scientific environment,
- and Aitherion, a science and technology exhibition environment emphasizing interactivity and immersive public engagement with science.

The purpose of the comparative design is not to evaluate which environment is "better," but rather to investigate how different informal STEM ecosystems activate different experiential pathways of engagement with science.
More broadly, the study contributes to current discussions on experiential learning, science identity, contextual engagement, and emotional involvement in STEM education. Rather than approaching informal STEM learning as a simple extension of formal instruction, the present research approaches these environments as spaces where students engage with science through experience, interaction, and participation.
The research is situated within a broader doctoral framework investigating how students experience science through informal and experiential educational settings and how these experiences may influence long-term engagement with STEM learning and their later interest in science and STEM-related studies or careers.

2. Theoretical Framework

2.1 Experiential Learning and Informal STEM Education

The study is theoretically grounded in experiential learning approaches, particularly Kolb's Experiential Learning Theory. According to Kolb (1984), learning develops through the transformation of experience via concrete experience, reflective observation, conceptualization, and active experimentation.
Informal STEM environments fit well with this view of learning because they allow students to participate actively, interact directly with scientific phenomena, and connect scientific ideas with personal experiences and meaning-making processes.
Within this perspective, learning is viewed as an active process shaped by experience, participation, and social interaction rather than passive reception of information.
Experiential learning approaches are particularly relevant within science education because scientific understanding is often strengthened when learners interact directly with scientific practices, experimentation, inquiry, and authentic scientific contexts. Informal STEM environments therefore provide important opportunities for students to experience science not only as something explained to them, but as something they can observe, question, and experience directly.

2.2 Contextual Learning and Informal Environments

The research is additionally informed by the Contextual Model of Learning proposed by Falk and Dierking (2016). According to this model, learning in museums and informal environments emerges through the interaction of personal contexts, sociocultural interactions, and the physical environment.
This framework is highly relevant to the present study because Demokritos and Aitherion represent substantially different contextual and experiential learning environments.
Demokritos offers students direct exposure to authentic scientific practice and research culture, whereas Aitherion emphasizes immersive participation, interpretative interaction, accessibility, and visitor-centered experiential engagement.
The contextual dimension of learning is particularly important within informal STEM education because students' experiences are shaped not only by scientific content but also by the broader experiential atmosphere, social interactions, interpretative structures, and emotional dynamics of the learning environment itself.

2.3 Emotional Engagement and Science Identity

Recent STEM education research increasingly emphasizes the importance of emotional engagement and science identity formation. Students' relationships with science appear strongly influenced not only

by conceptual understanding but also by emotional involvement, participation, personal relevance, and feelings of belonging within scientific experiences.
In this study, emotion is treated as part of the learning process itself, not as something external to it. Science identity approaches additionally suggest that students' long-term engagement with science is influenced by whether they perceive themselves as capable participants within scientific practices and scientific culture. Informal STEM environments may therefore contribute to science identity formation by providing opportunities for authentic participation, experiential immersion, and socially meaningful interaction with science.
In the present study, informal STEM learning is approached as a multidimensional experiential process in which participation, emotional involvement, experiential immersion, contextual interaction, and science-related identity development function as interacting dimensions shaping students' relationships with science.
Within this framework, experiential engagement ecosystem refers to the interaction between cognitive, emotional, contextual, participatory, and identity-related dimensions that shape informal STEM experiences.
For this reason, the study does not treat the different dimensions of learning as separate outcomes, but as elements that influence one another during the experience.

3. Methodology

3.1 Research Design

The study adopts a comparative mixed-methods design combining quantitative and qualitative approaches.
The comparative framework focused on two informal STEM learning environments:

- the National Centre for Scientific Research "Demokritos",
- and the science and technology exhibition environment Aitherion.

A mixed-methods approach was used because the study needed both numerical comparison and observational interpretation.
The study combines descriptive statistical analysis, comparative analysis, and interpretative qualitative observations in order to examine how different informal STEM environments shape experiential engagement with science. Observations focused on students' visible participation, interaction with the activities, questions, hesitation, enthusiasm, and use of the physical space.

3.2 Participants

A total of 150 secondary education students participated in the comparative phase of the study.
The comparative sample included:

- 75 students participating in educational activities at Demokritos,
- and 75 students participating in activities at Aitherion.

Participants ranged primarily between 14 and 17 years of age and participated in organized educational visits to the two informal STEM environments.
The sample included students from both Gymnasium and Lyceum educational levels, with representation across both educational levels and genders.
Students completed structured questionnaires immediately following their participation in the activities. The same questionnaire structure was used across both environments in order to support the comparative framework of the study.
The balanced comparative design was selected in order to support more consistent comparison between the two experiential contexts while maintaining methodological coherence across the analytical sample.

3.3 Research Instrument

The quantitative instrument consisted of parallel structured questionnaires investigating multiple dimensions of informal STEM learning.
The questionnaire explored constructs including:

- active participation,
- experiential learning,

- metacognitive awareness,
- emotional engagement,
- informal learning and autonomy,
- school–museum relationship,
- scientific skills,
- social and cultural context,
- and future STEM orientation.

Example questionnaire items included:

- "I felt enthusiastic during the activity" (emotional engagement),
- "The activity helped me understand how science works in real life" (scientific authenticity) and
- "I would like to participate in similar STEM activities in the future" (future STEM orientation).

Responses were collected using Likert-type scales ranging from 0 to 10.
Construct reliability analysis demonstrated satisfactory internal consistency for the main analytical constructs used in the comparative analysis. Cronbach's alpha values ranged from .757 to .910 for the primary multi-item scales, including active participation (α = .850), experiential learning (α = .835), emotional engagement (α = .910), and future STEM orientation (α = .757).
Qualitative observations were additionally used to support the interpretation of students' experiential responses within the two environments.

3.4 Data Analysis

The analysis included:

- descriptive statistics,
- construct reliability analysis,
- independent-samples t-tests,
- effect size analysis using Cohen's d,
- correlation analysis among the main experiential constructs.

Welch independent-samples t-tests were used due to variance differences observed between groups across some constructs.
Statistical analyses and reliability analyses were conducted using RStudio (R version 4.2.2).
The analysis also considers how different experiential dimensions relate to one another, which may inform future educational analytics work.
Although the present paper focuses primarily on descriptive and comparative analysis, the structure of the dataset may support future work on learner engagement profiles.

4. Findings

4.1 Overall Positive STEM Learning Experience

Findings indicated that both environments supported highly positive informal STEM learning experiences. Students in both Demokritos and Aitherion reported strong levels of participation, engagement, and experiential involvement.
Descriptive analysis showed consistently positive evaluations across the main constructs of the questionnaire. Emotional engagement and overall experience emerged among the strongest dimensions of the learning experience.
Overall, the results indicate that informal STEM environments may operate as meaningful complementary spaces for science learning beyond the classroom. The learning context itself therefore appears to matter.

4.2 Different Experiential Pathways

Although both environments produced positive learning experiences, important experiential differences emerged.
The Demokritos environment appeared to strengthen perceptions of scientific authenticity, direct exposure to scientific research, and students' understanding of science as a real research process.
In contrast, Aitherion appeared to emphasize emotional engagement, accessibility, interactivity, and experiential immersion.

Table 1 presents comparative descriptive statistics for the main experiential constructs across the two environments.

Construct	Demokritos (M ± SD)	Aitherion (M ± SD)	t(df)	p	Cohen's d
Active Participation	6.773333 ± 2.64	7.70 ± 1.83	-2.4911 (131.63)	.01398	0.4121
Experiential Learning	7.644444 ± 2.30	8.30 ± 1.55	-2.0499 (129.86)	.04238	0.3348
Emotional Engagement	7.448889 ± 2.58	8.34 ± 1.65	-2.5237 (126.06)	.01286	0.4121
Future STEM Orientation	7.302222 ± 2.25	7.56 ± 2.17	-0.7263 (147.82)	.46880	0.1200
Overall Experience	7.893333 ± 2.21	8.47 ± 1.77	-1.7528 (141.38)	.08181	0.2900

Table 1. Comparative descriptive statistics across the two informal STEM environments

The analysis revealed statistically significant differences regarding active participation, experiential learning, and emotional engagement, with students in the Aitherion environment reporting higher scores across these dimensions.
The effect sizes observed across these dimensions were small to moderate, suggesting meaningful experiential differences between the two environments without implying absolute superiority of one context over the other.
However, differences regarding future STEM orientation and overall experience did not reach statistical significance.

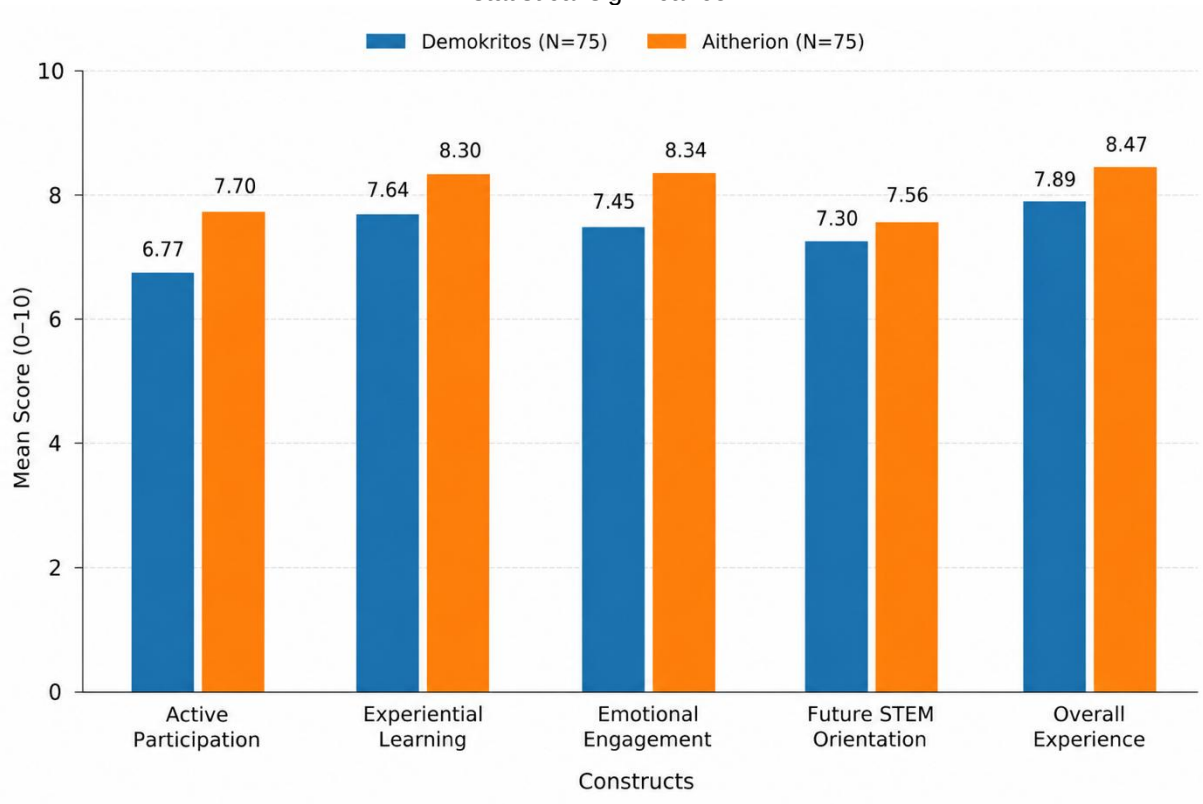

Fig. 1. Comparative experiential profiles of Demokritos and Aitherion across the main constructs of informal STEM learning.

The comparative findings suggest that the two environments supported engagement in different ways. These findings suggest that informal STEM environments may operate through different experiential mechanisms, with some environments emphasizing scientific authenticity and research culture, while others emphasize immersion, accessibility, and emotional participation.

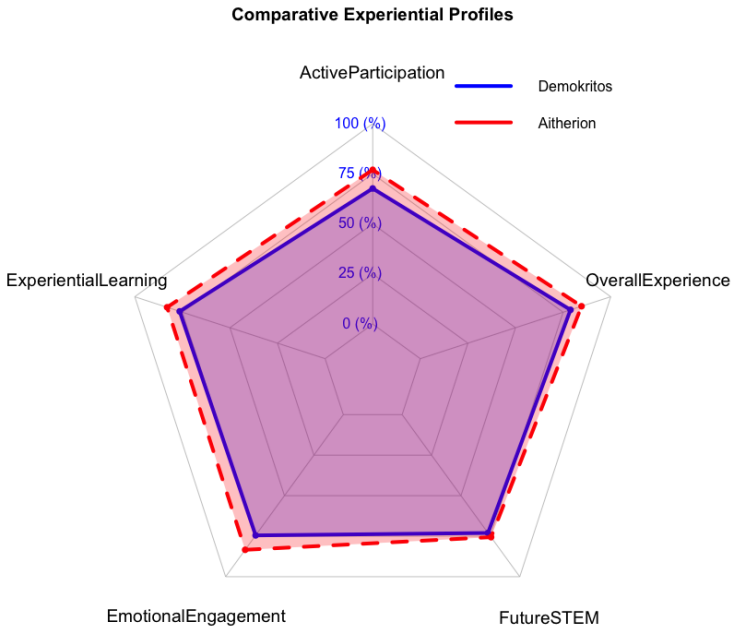

Fig. 2. Comparative experiential engagement profiles across the two informal STEM learning environments.

4.3 Emotional Engagement as a Central Experiential Mechanism

One of the most important findings of the study concerns the role of emotional engagement.
Students reporting higher levels of enthusiasm, personal involvement, and emotional connection with the activities also tended to report more positive overall learning experiences.
Correlation analysis demonstrated a strong positive relationship between emotional engagement and overall learning experience ($r = .783$, $p < .001$), suggesting that emotional involvement functions as one of the main ways through which students came to value the experience.
Taken together, the results highlight the importance of participation and emotional involvement within informal STEM learning experiences, rather than viewing learning simply as knowledge transmission.
The strength of the observed relationship additionally suggests that students' emotional experiences within informal STEM environments may play a particularly important role in shaping how students evaluate, remember, and relate to science experiences more broadly.
The comparative results show that informal STEM learning cannot be reduced to a single model of student engagement.

5. Discussion

The findings contribute to current discussions concerning experiential learning and student engagement within informal STEM education.
A central observation from the comparative analysis is that the two environments supported engagement through different mechanisms. In this sense, different environments appear to activate different experiential pathways of engagement with science.
Demokritos emphasizes scientific authenticity and direct interaction with research culture, whereas Aitherion strengthens emotional engagement, immersive participation, and interpretative interaction with scientific ideas.
Importantly, however, both environments appear capable of supporting meaningful science engagement.
These observations align closely with experiential learning approaches and the Contextual Model of Learning proposed by Falk and Dierking. Learning appears to emerge not only through cognitive

processing but also through emotional involvement, participation, contextual interaction, and experiential immersion.
Perhaps the most notable finding concerns the role of emotional engagement. Students' relationships with science appear strongly influenced by whether they experience science as emotionally meaningful, participatory, and personally relevant.
Emotional engagement also appeared to connect participation, contextual immersion, and students' future orientation toward STEM learning.
The findings suggest that students' informal STEM experiences are shaped by multiple interacting dimensions. These include understanding, participation, emotional involvement, the structure of the setting, and students' sense of belonging within science-related activities.
In practice, this means that informal STEM environments may influence students not only cognitively, but also emotionally and socially through participation, immersion, and identity-related experiences.

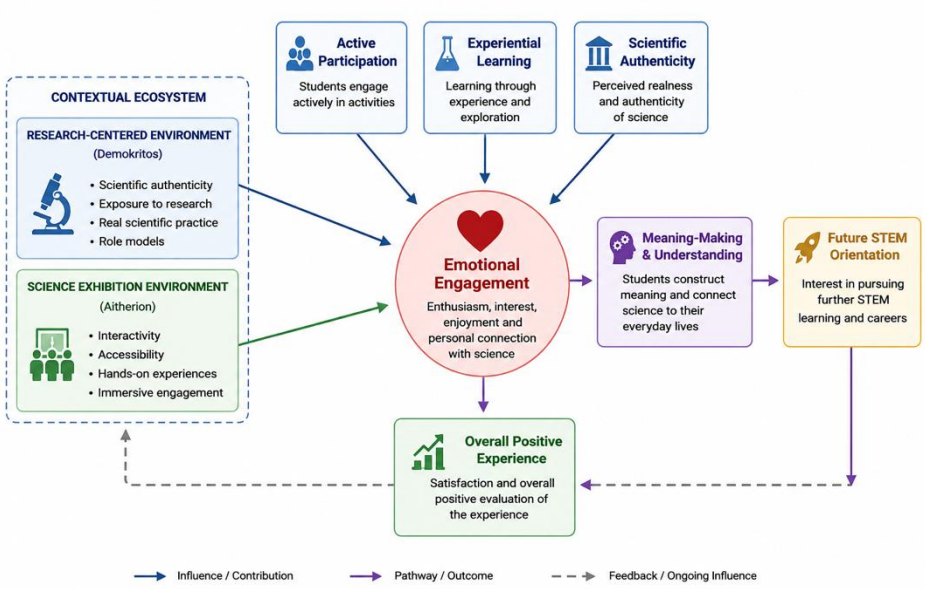

Fig. 3. Conceptual model of experiential engagement pathways in informal STEM learning environments.

At the same time, several methodological limitations should be acknowledged. First, the study relies primarily on self-report questionnaires completed immediately following participation in the activities, which may increase the influence of recency effects and social desirability bias. Second, the study did not include pre-visit measurements, limiting the possibility of examining changes in students' attitudes before and after participation. In addition, the research focuses primarily on short-term experiential responses and does not investigate the long-term sustainability of STEM engagement over time.
Finally, the comparative framework is based on two informal STEM environments located in Athens, Greece, limiting broader generalizability.
Future studies may additionally explore explainable predictive approaches, such as learner engagement profiling and decision-tree modeling, in order to investigate how experiential dimensions predict future STEM orientation across different informal learning environments.
The multidimensional structure of the present findings may additionally support future applications of educational analytics and explainable predictive modeling within informal STEM education research.
The findings may additionally support educators, museum designers, and informal STEM learning practitioners in designing experiential science activities that strengthen emotional engagement, participation, contextual immersion, and students' long-term relationships with science.
Despite these limitations, the study provides an important exploratory framework for understanding experiential engagement within informal STEM education.

6. Conclusions

The present study investigated how students experience science across two different informal STEM learning environments: a research-centered scientific environment and a science exhibition environment.

The findings suggest that both environments support meaningful STEM learning experiences, although through different experiential mechanisms.
Demokritos appears to strengthen perceptions of scientific authenticity and direct interaction with research culture, whereas Aitherion enhances emotional engagement, immersive participation, and experiential accessibility.
The study additionally highlights the central role of emotional engagement within informal STEM learning. Students seem to value these experiences more strongly when they feel involved, not only informed.
Overall, the findings highlight the multidimensional nature of informal STEM learning, where cognitive, emotional, contextual, and participatory dimensions continuously interact during the learning experience.
The study therefore offers a comparative framework for understanding how different informal STEM settings can support students' relationship with science in distinct but complementary ways.

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