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Telling tales: the use of narratives in informal STEM settings

Neta Shaby[a], Justin Dillon[b], Ran Peleg[a], Orit Ben-Zvi Assaraf[c], Scott Pattison[d], Palmyre Pierroux[e], Maya Barzilay[f], Muriel Grenon[g], Rolf Steier[h], Gina N. Svarovsky[i], Smirla Ramos-Montanez[d], Catherine Wagner[i], María Quijano[j], Amy Corbett[j], Viviana López Burgos[d] and Diana Contreras[j]

[a]Southampton Education School, University of Southampton, Southampton, UK; [b]IOE, UCL's Faculty of Education & Society, University College London, London, UK; [c]Program of Science and Technology Education, Ben Gurion University of the Negev, Beersheba, Israel; [d]TERC, Massachusetts, USA; [e]University of Oslo, Oslo, Norway; [f]Ben Gurion University of the Negev, Beersheba, Israel; [g]University of Galway, Galway, Ireland; [h]Oslo Metropolitan University, Oslo, Norway; [i]University of Notre Dame, Indiana, USA; [j]Metropolitan Family Service, Portland, Oregon, USA

ABSTRACT

Background: For decades, narrative has had a prominent place in educational studies, both as a focus of research and pedagogy. However, most research was done with school (or pre-school) students in formal settings.

Purpose: This paper emerged from a conference symposium that brought together five studies by researchers from across the world to discuss, debate and generate insights about the use of narrative in informal environments. The purpose of this paper is to synthesize the findings to form design conjectures that can serve informal researchers and practitioners.

Sample: We examine the use of narrative in five informal STEM environments: a science museum, a zoo, a virtual exhibition, an escape room, and home-based engineering activities.

Design and methods: The five studies look at a variety of participants, including elementary and high school students, free-choice visitors, and preschool-aged children and their families. We describe the use of narrative in these learning environments and explore the ways narratives can potentially support and facilitate STEM teaching, engagement, and understanding. All studies use qualitative research approaches, utilizing interviews and observations, following interpretivist data analysis approaches.

Results: The findings from the five studies were synthesized to form five design conjectures of how narrative support learning in informal STEM environments. The significance of this collection of studies is to showcase the varied use of narratives in informal STEM learning environments.

KEYWORDS

Stories; narrative-based pedagogy; informal learning environments; stem education

CONTACT Neta Shaby N.Shaby@soton.ac.uk Southampton Education School, University of Southampton, Highfield Campus, Southampton SO17 1BJ, UK

Introduction

Stories form a key part of our culture and our personal experience. The most influential introductions to our world and others are through the stories that we are told as children (Bruner 1991). Before writing existed, stories were the main means by which a civilization passed down its values and experiences from generation to generation. However, while stories can be used to report what happened, what was said and what is of importance, they can also distort and conceal. As stories, or narratives, are considered one of our main forms of communication, they have been studied in a number of disciplines, such as education, sociology, psychology, philosophy, history, fiction and film (Avraamidou and Osborne 2009). In science education, Avraamidou and Osborne (2009) argue for the use of narratives, which they describe as 'fictional written text' in school science to make it 'meaningful, relevant, and accessible to the public' (p. 1683). In this paper, we extend this discussion into STEM education in informal settings. This paper emerged from a symposium presented at the NARST science education research conference (Shaby et al., 2023). The purpose of the paper is to synthesize the findings emerged from five studies presented at the symposium to form design conjectures that can serve informal researchers and practitioners.

Defining narratives

The relationship between stories and narratives is convoluted and the two are hard to distinguish in everyday language. Some view narrative as a way of interpreting the story: Narrative is the choice of which events to relate and in what order to relate them – so it is a representation or specific manifestation of the story, rather than the story itself. The easy way to remember the difference between story and narrative is to reshuffle the order of events. A new event order means you have a new narrative of the same story (Bemgee n.d.). Others view narrative as 'not just an unresolved story, but a system of stories, some resolved and some not' (CSC n.d.). If that is not confusing enough, Bruner (1991) writes: 'narrative comprises an ensemble of ways of constructing and representing the sequential, diachronic order of human events, of which the sequencing of clauses in spoken or written "stories" is only one device' (p. 6). Avraamidou and Osborne draw on Ricoeur's (Ricoeur 1981) ideas when they state that 'Stories are essentially a subset of the narrative genre and describe a series of actions and experiences made by a number of real or imaginary characters' (pp. 1686–1687).

Despite this complicated relationship between narratives and stories, in the literature on science education and science communication, it seems that these two terms are used almost interchangeably (e.g. Norris et al. 2005; Prins, Avraamidou, and Goedhart 2017; Walan and Enochsson 2019; Yang and Hobbs 2020). When arguing for the use of narrative in science education, Avraamidou and Osborne (2009) describe narrative as 'fictional written text'. In this paper, we follow this approach and focus on the narrative as a 'sequencing of clauses in spoken or written "stories"' (Bruner 1991, 6).

Using narratives in science education

Norris et al. (2005), among others, suggest that narratives are thought to enhance information processing and memory by generating more interest, relevance, and attention. Educational research has long incorporated narratives, with Avraamidou and Osborne (2009) highlighting their significance. They argue that 'this picture of science, mysterious and opaque, estranges students because it is disconnected from their everyday experiences' (p. 1684). They go on to argue that: 'It portrays science as a set of objective truths and absolute realities to be approached – abstracted, disembodied, and decontextualized'. In discussing 'whether and how can stories [. . .] be used in science education', the authors wonder 'how can the complex grammar of science reliant on distinctive genres and a highly nominalized vocabulary adopt any of the features of the narrative – a highly interpretive account with its actors, agents, scene and motives?' (p. 1687). However, they focus more on the role of stories in simplifying complex, often abstract, ideas but do not address aspects of storytelling that explain its appeal to young people. Na and Song (2014), emphasizing the importance of utilizing everyday experiences as a starting point for elementary school students' science education, also advocate for integrating storytelling techniques to make science more relatable and engaging.

Research on the use of narratives addressed a range of topics and contexts and identified several potentially useful pedagogical approaches. Yang and Hobbs (2020) conducted a study that showcased the influence of stories by examining the variations in consumer attitudes and behaviors when information about agricultural biotechnology (specifically gene editing) was presented in two different ways: through a narrative format and through a logical-scientific framing. While a logical-scientific approach usually emphasizes rigorous scientific research, the study revealed that narrative formats are inherently more accessible, captivating, and persuasive. As a result, consumers responded more positively to the information when presented in a narrative form compared to the logical-scientific framing.

In their research on teaching about viral infections to young children, Walan and Enochsson (2019) employed a storytelling approach, using a narrative about a girl who contracted a cold from a rhinovirus. The results indicated that this storytelling method effectively enhanced students' comprehension of immunity concepts. The engaging structure and flow of the story also stimulated the students' imaginations, leading to a more effective learning experience. Similarly, Prins, Avraamidou, and Goedhart (2017) demonstrated that students better understand the scientific principles of natural selection when presented with a narrative compared to traditional textbook methods. The use of storytelling, when combined with hands-on activities, emerged as a valuable tool for offering students diverse perspectives on relevant scientific concepts, as noted by Walan and Enochsson (2019). Güler and Ünal (2023) used historical science stories at a university level physics course, indicating increases in motivation and academic achievement. Overall, incorporating narratives into science education has been shown to lead to better understanding and increased interest among students.

Using narratives in informal STEM education environments

As described above, narrative-based pedagogy in science education has been widely studied, but most research has primarily focused on school or pre-school children in formal educational settings. Additionally, research has mainly explored science education in these formal settings, rather than the broader STEM education which is more common in informal settings. Although the use of narratives and stories is relatively common in informal environments such as museums and science centers, there is a need to examine the use of narrative-based pedagogy in these settings and the outcomes.

Murmann and Avraamidou (2014) report on a study where they used a story to enhance students' engagement and interaction with an exhibit focused on human and other animal senses at a science center. The use of stories proved to be highly beneficial, as it fostered motivation, deepened immersion, and instilled a sense of agency among the visitors. The story provided a meaningful context for their learning activities, giving them a clear understanding of why they should participate in the educational experience. The effectiveness of the stories was attributed to the strong and evident connections between the narrative and the scientific concepts presented in the exhibit, making the learning process more engaging and relevant.

Other studies have highlighted the cognitive advantages of narrative-based pedagogy in informal educational settings. For instance, Glick and Samarapungavan (2008) conducted research with fourth-grade students at a nature center, where they engaged in a narrative-based exploration of natural phenomena, focusing on the biology and conservation of wolves. The study demonstrated that this narrative approach led to the development of a more sophisticated understanding of the subject among the students.

In a study by Hu et al. (2021), mystery-type stories were utilized to great effect in a science center. These stories proved to be highly effective in evoking interest, promoting interactivity, and facilitating the learning process. Moreover, the use of anthropomorphism in the stories played a significant role in enabling children to access and comprehend complex concepts. By connecting unfamiliar scientific phenomena with their own experiences, the students gained a deeper understanding of the subject matter. The researchers employed the stories to explore the concept of a star's death, which acted as a rich stimulus, resulting in a substantial improvement in the children's comprehension of astronomy-related concepts.

Designed informal settings such as museums often use narratives in the way mentioned above (i.e. a historical account or scientific phenomena). However, other ways of engaging learners through narrative have also been used. For example, rich stories or narratives can be used to promote engagement with engineering learning experiences. These allow design decisions to be made based on specific elements, characters, or plot points in the narrative and thus situate learners' design, testing, evaluation and improvement process in a concrete, understandable context (Milto et al. 2020). Moreover, digital media, tools and platforms have introduced multiple modalities in narrative designs, inviting new forms of participation, engagement and personalization (Coll and Coll 2018; Pierroux 2019).

Storybooks are yet a further way in which narratives can stimulate, motivate, and engage children in conversations about STEM learning (Pattison et al. 2020). These storybooks can accompany an educational project, be distributed through schools or in various settings such as playgrounds or even laundromats (Pattison et al. 2020). From telling

preschool children's stories of teddy bears who have a STEM problem to solve, to STEM concepts being introduced in published story books, narratives have been found to effectively generate STEM talk and understanding. Plummer and Cho (2023), for example, took three different pre-school books, each with STEM themes about shadows, astronomy, and magnetism. They found variations in levels of STEM learning, though it was unclear whether the differences were about the experiment design or the nature of the narrative. While storybooks can be an effective catalyst for STEM learning, it is important to ensure diverse cultural groups are represented so that children see themselves in the narrative (Pattison et al. 2023).

Stories can be used to engage adults and not only children, in diverse informal settings such as zoos, planetariums, art and architecture museums. In these settings, narratives may be more implicit than explicit, functioning rather as 'prompts' that direct attention to connections between certain properties and features of objects or exhibition content. Narratives may convey stories through 'clauses' (Bruner 1986), for example, in the form of a specific arrangement of objects, sequencing of displays, or placement of analogue and multimodal texts and labels.

Conference symposia allow researchers from across the world to discuss and debate issues in ways that are generative and more immediate than engaging in publishing articles. The symposium on which this paper is based brought together five groups researching very different contexts but with one thing in common, the use of narrative approaches. The diversity of these contexts, we believe, strengthens the argument that we are making.

The studies

In this paper we draw on five studies that use different narrative approaches within informal STEM education (see Table 1). The studies were selected to provide a range in the way they approach narrative, in the age of the participants and in the research methodologies. Although each study is different, they all use qualitative interpretivist approaches. In this paper, we present each study, briefly describe the context, participants, methods and main findings. Then, we synthesized the findings from each study to develop practical insights in the form of design conjectures that can be used by both researchers and practitioners.

Table 1. The five studies.

Name	Settings	Participants	Method
The Life of Leonardo da Vinci	Fieldtrip to a Science Museum	Seventy-three 10-year-old students	Interviews
Luna the Hyena	Outreach program in a Zoo	Twenty-one children aged 6 to 10 years old	Interviews
Cell Explorer Escape Room	Schools and youth group	Thirty-seven 13–16 years old students	Interviews
The Forest in the House	Architecture exhibition	Thirty-five visitors (15 to 90 years old)	Video-recorded observations and questionnaires
Ready, Set, Go! Engineering	Home-based family activities	Sixteen Spanish- and English-speaking families with preschool-age children (ages 3 to 5)	Zoom-based video recordings and interviews

Study 1: 'the life of leonardo da vinci' – narrative-based pedagogy in a fieldtrip to a science museum *Neta Shaby and Orit Ben-Zvi Assaraf*

Science museums allow visitors to immerse themselves in the stories presented by their displays and objects, so that they might relate them to their own educational experiences (Hamilton and Margot 2020). The research, which aimed to explore the way narrative can promote science engagement, was part of a longitudinal study that tracked students from 4th to 6th grade (aged 10–12 years) during six visits to a science museum in Israel. The participants came from four different schools in the city of Be'er Sheva. All defined by the Ministry of Education as serving populations of low to medium socioeconomic status. This visit, to an exhibition entitled 'The Life of Leonardo da Vinci', was the second of the series and took place when students were in the 4th grade (aged 10 years).

The three-hour visit focused on the story of Leonardo da Vinci's life and students took part in three activities (Figure 1). The first occurred in the museum lab, where the educator introduced Leonardo da Vinci as a 'Renaissance man'. This was followed by a screening of an animated film centered around his life. The second activity involved a scavenger hunt in the Mechanics Exhibition Hall, where students searched for Leonardo da Vinci's inventions. The clues in the scavenger hunt were connected to elements from the animated film and the overall narrative. Upon completing the hunt, students received puzzle pieces, which, when put together, formed the image of the Mona Lisa. Moving on to the third activity, students engaged in a hands-on experience in the lab. The codex of da Vinci was reintroduced, and the students constructed model parachutes based on one of da Vinci's sketches (and took them home as a souvenir). In this study, the design of the entire visit used a narrative approach, with the story of Leonardo da Vinci serving as a thread throughout the day, in the various activities as described above.

In total, 73 students, from four different schools, participated in the visit. Following ethical guidelines, each student was interviewed in their school in the following two days (after the visit). Using a semi-structured interview that lasted 15–30 minutes, the students were asked to recall the story of Leonardo da Vinci. Several photos of the museum exhibits and images from the animated film were available to help the students construct their story, to promote various modes of communication (other than verbal) and to aid student to find their voice and express their views (Nind, Boorman, and Clarke 2012). We analyzed the stories told by students using thematic analysis (Braun and Clarke 2006).

Figure 1. Left – Students in Mechanics exhibition hall during scavenger hunt, Leonardo's codex and exhibits in the background; Right – Students building Leonardo parachute in the lab.

Four main aspects of how narratives can potentially support and facilitate science learning:

Remembering facts:
Between them, the 73 interviewees mentioned 217 facts about Leonardo da Vinci: he was born in Italy, painted the Mona Lisa, was a Renaissance Man, was an inventor, and was a researcher. However, some students remembered some of the fictional plot elements introduced in the animated film.

Vocabulary and nature of science:
More than half of the students used vocabulary that could be associated with the visit, for example using words not commonly occurring in daily contexts such as Renaissance Man, inventor, researcher and self-portrait. Additionally, the narrative presented aspects of the nature of science, which were mentioned by the students as traits that scientists possess ('talented scientist', 'a curious young man' who worked in many fields and 'kept on trying even if something didn't work at the beginning').

Creating a story:
Thirty-nine students mentioned the exhibits in their stories using the photograph presented, for example: 'Here we can see Leonardo's drum [points at a photo of the exhibit]. This was used to lift heavy weights at that time'. However, although students were very familiar with the elements of stories, it was surprising to see that only 12 students attempted to construct a true/full story. All other students merely listed facts.

Long-term effect:
After the sixth visit in the longitudinal study (i.e. two years after the Leonardo da Vinci themed visit) we asked students about their memories from the museum in general. All students mentioned Leonardo da Vinci, and most could repeat facts and elements from the visit, although two years had passed, and Leonardo da Vinci was only mentioned in the second visit.

As visits tend to be one-off events, museum educators are always pursuing more effective pedagogies to maximize experiences, learning processes and outcomes of the visit. Using narrative-based pedagogy proved to leave powerful impressions and lasting memories. Thus, narrative can be used by informal environments such as museums, in the following ways: creating a compelling narrative related directly to exhibits or activities in the environment; making explicit connections between the activities and exhibits and the narrative; introducing scientific vocabulary that is not commonly used in everyday lives but is used within the scientific community, in a non-threatening way; integrating elements of the nature of science in the narrative.

Study 2: the outreach program 'luna the hyena' *Maya Barzilay and Orit Ben-Zvi Assaraf*[

In the past few decades, many zoos have shifted their focus from a venue of entertainment to an educational platform for nature conservation (Barongi et al. 2015; Gusset and

Dick 2011; Patrick and Caplow 2018). As part of this change, zoos are seeking new ways to engage their visitors in nature conservation. This study focuses on one such educational outreach program. The study investigates the potential role of narrative-based-pedagogy in a nine-month-long outreach program in a zoo. It is part of a larger longitudinal research project that aimed to follow participating children's recalled experiences, knowledge expression and described emotions following participation in the program.

This qualitative study was conducted in a local zoo in the south of Israel that hosts over 100 different species, many of which are local desert species. The outreach program included a two-hour weekly session and was aimed at elementary school children. The program's syllabus included an introduction with specific characteristics of animals, different taxonomic classes and biological principles from the natural world (such as principles of flight, different roles in the beehive, and senses). Within the program, narrative-based pedagogy was implemented as a design element by the zoo staff using embedded stories about three specific animals (hyena, owl and jungle cat) as part of the overall program. These stories were created based on the animals' biographies and put in simple language through personification, including naming of the three animals. For example, Luna the hyena's story was presented as a personal crisis. She was injured in her wildlife habitat, moved to the zoo and subsequently rehabilitated. This was presented to the children as a personal crisis, a move from her natural habitat to the zoo and subsequent recovery. Other activities such as feeding the animals were interlinked with the narratives for each animal. Every week the children saw all three animals and learned about events that happened to them in the past week through stories (for example that Luna was to receive a new potential mate).

The research focused on 21 children aged 6–10 years-old who participated in the program. The children belong to upper-middle-class backgrounds and reside in Israel's peripheral region. At the end of the program, interviews were conducted with each child at their home asking about their thoughts, feelings, memories, and recalled experiences from the program. The interviews lasted 30–50 minutes and were audio-recorded and transcribed. Data were analyzed using thematic analysis (Braun and Clarke 2006). Specifically, the goal of the analysis was to find out how the narrative-based pedagogy affected the experiences and whether it made them memorable.

Three main themes emerged from the data: (1) narratives enabled children to create a personal context for learning, (2) physical activities (such as feeding), connected with the narrative, strengthened a personal, emotional connection with the animals, and (3) children expressed rich biology knowledge relating to the species of the three animals presented in the stories. To demonstrate these points, we will focus on the narrative of one animal – Luna the hyena. Of note, the findings around Luna's narrative also emerged around the stories of Alexandra the owl and Sandy the jungle cat. In the interviews, the children expressed great affection for Luna the hyena, including missing her whilst they were away from the zoo, a willingness to feed, play and care for her, and explicit expressions of love ('If I were a staff member of the zoo, I'd feed Luna [because] I love her'). The elements used in the stories (such as Luna's crisis, move to the zoo and rehabilitation) supported the children's personal connection to Luna. Furthermore, the experiences that combined physical activities with narratives were the ones children remembered the most, such as feeding and watching Luna's response after they threw

her a ball ('One day we went to Luna, and we had to throw her punctured ball, then she just tore it apart').

When asked what scientific information they had learnt, the children would cite aspects of the three specific (named) animals more often than about other (non-named) animals in the zoo. They could express specific knowledge about these animals – for example knowledge about hyenas including being a predator, having a very strong jaw and scavenging on bones. This knowledge was told through their acquaintance with Luna ('[Luna] is a strong animal in the jaw and she is also night-active, and she lives alone because she can eat people').

In accordance with previous work, it was found that storytelling and personification can lead to positive emotions toward the animals (Caldwell and Henry 2020) as well as empathy (Myers and Saunders 2002). However, personification needs to be implemented in moderation so as not to jeopardize the understanding that these are wild animals and not pets (Schneider et al. 2019). In that respect, the zoo staff highlighted attributes relating to Luna, such as their natural habitat, their ecosystems and their predatory nature so as not to create an illusion that she could be a pet. This study demonstrates the importance of narratives and storytelling along with personification as part of the design elements in the zoo learning environment. The study emphasizes the need to explore children's point of view and the way they interpret the narratives that they are exposed to during a zoo outreach experience.

Study 3: Cell Explorer escape room: the role of the story in participants' experience *Ran Peleg and Muriel Grenon*

Escape games are a popular genre of games in which players solve puzzles to achieve a mission (Nicholson 2015). In recent years, escape games have made their way into a variety of educational settings (Veldkamp et al. 2020) and provide a game-based learning (GBL) approach that taps into an innate nature to play (Fotaris and Mastoras 2018).

Narrative has been suggested to be at the heart of the escape game experience, creating a feeling of immersion which promotes puzzle solving and staying on task (Fotaris and Mastoras 2018). However, the role of the narrative has not been researched and most reported adaptations to educational settings were driven by practical concerns rather than being research informed (Veldkamp et al. 2020).

This study investigates the role of the story in STEM education escape game from the participants' point of view. Escape games are viewed as designed informal environments (National Research Council, 2009) and this study focuses on an example implemented within a school and an afterschool youth club. The research questions guiding this specific study are: (1) What are participants' spontaneous and elicited recollections of the story? and (2) What is the role of the story in the game experience as perceived by participants?

The escape game was created to engage 13–24-year-olds with topics particularly in modern biology. It was designed with input from undergraduate students, experts in educational escape games and STEM communication experts. The resulting game includes several scientific puzzles in which players perform hands-on activities (Figure 2).

Figure 2. Left – scientific equipment used in the escape game including a centrifuge, a microscope and a DNA model; Right – participants conducting an experiment as part of the escape game.

Narrative-based design was used when the game begins with a video presenting the background story: a medical scientist visiting the school/club for educational purposes accidentally left a locked case with her patient files. It has become known that one of her patients was exposed to a contagious virus. Players need to identify this patient to prevent the whole country entering lockdown. This story was chosen since students knew about viruses and lockdowns. However, the virus mentioned in the story was a fictious one and COVID-19 was never mentioned in the story.

The activity was run in schools and in youth group settings. Participants played in teams of 4–6 players with up to four teams playing in parallel. Focus group interviews were conducted within a week after the activity and lasted 30–45 minutes. Since this study took place between December 2021 and May 2022, the focus group interviews were conducted either online or in-person, depending on COVID-19 restrictions. The data consisted of 11 focus group interviews with 37 students in six school classes from two schools and four after-school youth groups, from a mid-sized city in Ireland. Both schools are public, co-educational and serve students from diverse socio-economic backgrounds. The youth groups operate in the afternoons and are managed by an organization that provides specialized services for vulnerable youth.

This analysis was part of a larger study looking at the overall experience of playing the escape game. The focus group interviews had several questions relevant to the story. Thematic analysis was used to analyze the transcribed interviews (Braun and Clarke 2006).

The following insights were identified in the analysis of the data:

Spontaneous recall of the story:

When asked about their experience of the game, most participants mentioned the puzzles or the teamwork, but none mentioned the background story as an important factor of their experience.

Elicited recall of the story:

When explicitly asked to recall the story, all interviewed groups pieced together a narrative ranging from vague to detailed. Recall mainly included story details relevant to the mission they had to complete, for example 'we had to get the papers... or the whole world had to get shut down'. Some added information not mentioned in the story suggesting they used the story to scaffold their own meaning making, for example 'There was a very bad disease like the corona but not THE corona' (COVID-19 was never mentioned in the original story).

Importance of story:

When asked to reflect about the importance of the story, 10 groups claimed it was important to give an initial direction for solving the puzzles, but it was not otherwise mentioned as an important feature of their experience. Only one team thought the story had no importance at all. Also, none of the participants remembered thinking about the story or discussing it with their team members during the game.

These findings emphasize the significance of the story as an integral part of the escape game experience but in a nuanced way. They challenge the assumption that narrative is at the heart of escape rooms and its role is in assisting participants to *stay* on task (Fotaris and Mastoras 2018; Veldkamp et al. 2020). Instead, it seems that the story primarily serves to *start* players off on a mission, yet it is another motivation that keeps them on task. This suggests that an escape game narrative should only contain sufficient details to give participants their initial motivation, while the puzzles should sustain players' motivation throughout the game. One notable limitation of the study was its reliance on participants' recollection of the experience and future studies might focus on observing participants during the game to identify other components of their motivation.

Study 4: the forest in the house - embodied narratives in an architecture exhibition *Palmyre Pierroux and Rolf Steier*

In architecture museums, there is growing interest among curators and educators in the potential of new types of digital media and technologies to support visitor learning and engagement in exhibitions (Goodhouse 2017; Pierroux 2019). Virtual reality, a tool increasingly used by architects to model and communicate their designs, is an example of how digital technologies can deepen experiences and understandings of architecture. These developments served as the basis for a collaborative investigation of the design and use of Immersive Virtual Reality (IVR) in an architecture museum in Norway (Pierroux, Sauge, and Steier 2021).

In a recent review of research on the use of IVRs for science learning (Matovu et al. 2023), narrative was identified as one of four key design elements, along with social, sensory and actional features. The narrative for this exhibition is indicated by its title, 'The Forest in the House', an intentional twist on a well-known setting in fairytales, a house in the forest. The narrative concept was grounded in the architect's belief that 'humans are driven by an unconscious drive to experience nature in architecture'. However, instead of reading or listening to an explicit story with a character, plot or challenge (Matovu et al. 2023), the narrative was intentionally implicit, open to visitors' own connections to 'The Forest in the House'. Visitors were invited to use their bodies and senses to observe, recognize and explore

'nature-architecture' relations, toggling between two different virtual settings: a forest terrain and a house designed to provide an architectural experience of this same terrain (Figure 3).

From a STEM perspective, exploring and experiencing nature-architecture connections was at the core of the approach to the exhibition design. Moreover, to support a shared exploration process, the exhibition was designed to be experienced in pairs (Steier 2020); as one visitor who wearing the headset moved through the exhibition, their companion was able to watch a large screen that showed what was being seen and heard in the virtual world (Figure 4). Each visitor spent about 15–20 minutes exploring and wearing the headset before switching roles, and it was possible for companions to converse the entire time. The aim of the study was to investigate how the narrative concept 'forest in the house' was made relevant in visitors' embodied experiences and conversations.

Figure 3. A view from the same physical place in the exhibition, showing how house (left) and nature (right) were correlated in the renderings of virtual environments.

Figure 4. Visitor pairs in 'The Forest in the House' exhibition.

To study visitors' embodied experiences and understandings of the narrative concept, we first recruited 17 pairs ($N = 34$) to visit the exhibition, participate in an interview and answer a questionnaire. Video recordings were made of their exhibition experiences (11 hours total) and interviews (17 hours total). General visitors ($N = 324$) were also recruited onsite as anonymous respondents to the same questionnaire, after their exhibition experience (see Steier 2020). Using interaction analysis (Jordan and Henderson 1995; Rusk et al. 2015), we identified in the video data two main types of talk and interaction when visitors made nature-architecture connections: 'presence' and 'inhabiting'. These themes were also identified in the questionnaire responses using thematic analysis (Braun and Clarke 2006).

Presence

The most frequent type of connection to the narrative concept was made through visitors' comparisons between the respective forest and house settings, as if they were present in these immersive virtual environments. The following excerpt from the video recordings illustrates how visitors made joint observations of nature-architecture relations.

Visitor 1: Look behind [viewing large screen as companion with headset turns]

Visitor 2: [wearing headset, leaning on railing, looks behind].

Visitor 2: And look a little farther to the left. No, no stop. And press to go into the house again.

Visitor 1: Yes.

Visitor 2: Do you see the column?

Visitor 1: Oh yes.

Visitor 1: Which is a tree . . . Which is a tree, yes, I see it.

Visitor 2: Mmm.

Visitor 1: [laughs].

Questionnaire responses confirmed visitors' observations of nature-architecture connections (Biuso 2020), with 85% of them agreeing/strongly agreeing that they noticed and experienced similarities. In the open comments, one visitor wrote that she 'appreciated the juxtaposition of the natural and designed context'. Another visitor explained that he 'frequently switched between the two scenes', which he believed gave him a 'greater experience of the design and the architect's craftsmanship'.

Inhabiting

In our analysis of the video data, we also found that nearly half of the visitors became narrators of their own stories about what it would be like to live in the environments. They created imagined and personal narratives of inhabiting the house, as the following excerpt illustrates.

Visitor 1: It would be comfortable here, right?

Visitor 2: I suppose so.

Visitor 1: Especially with the weather here.

Visitor 2: Yes.

Visitor 1: You can pick up a bottle of white wine.

Visitor 2: Yeah.

Visitor 1: Champagne, maybe, isn't that what one drinks?

Visitor 2: Some shrimp and a baguette.

Our study suggests that the lack of an explicit story-form in the IVR provided opportunities for visitors to orient their own observations and construct personal, embodied connections to the exhibition narrative through a sense of presence. Visitors also created shared imaginings of what it might be like to 'live here', a narrative mode of constructing reality inspired by their own life experiences (Bruner 1986). Finally, the study illustrates how narrative is intertwined with social, sensory and actional features in STEM IVR environments. We believe these findings might inform narrative designs for IVR educational experiences.

Study 5: the power of stuffies: how families use story and narrative to enrich home-based engineering engagement *Scott Pattison, Gina N. Svarovsky, Smirla Ramos-Montanez, Catherine Wagner, María Quijano, Amy Corbett, Viviana López Burgos and Diana Contreras*

The Ready, Set, Go! Engineering project focused on engineering learning experiences for young children and their families. Engineering involves engaging in an iterative and intentional process to develop technologies that solve specific problems or address specific design goals (NASEM, 2020). Stories can provide a powerful context for engaging young learners in the engineering design process and empowering them to help define the nature of the engineering problem being addressed (National Academies of Sciences 2021). They also allow learners to situate their testing, evaluation, and improvement process in a concrete, understandable context and make design decisions based on specific elements, characters, or plot points.

In this study, the team partnered with Metropolitan Family Service (MFS) – an early childhood and family support organization – to develop and iteratively test a series of home-based, narrative-rich engineering activities with English- and Spanish-speaking families from low-income communities. The study was situated within a sociocultural perspective on learning, emphasizing the knowledge and assets families bring to STEM learning experiences, centering the ways that children and their families engage with engineering design practices through social interactions, and highlighting the importance of narrative and storytelling to support learning (Pattison and Ramos Montañez 2023; Rogoff 2003).

In partnership with MFS, the team conducted a design-based research study (Brown 1992; Cobb and Koeno 2008) to (a) iteratively develop home-based, engineering design activities for families and (b) advance theory about strategies that support engineering design engagement in these contexts. The team worked with MFS to recruit 16 Spanish- and English-speaking families from low-income backgrounds with preschool-age children (ages 3 to 5), balanced by their primary home language (Spanish and English). The team

then collaborated with these families to iteratively test three engineering activities over the course of approximately 5 months. Drawing from narrative-based pedagogy, each activity placed the engineering design challenge in an imaginative, story-based context, such as a children's book or song, and used a variety of strategies for integrating these narratives into families' engineering design process. For example, the *Pollitos* activity (Spanish for 'baby chicks') included a picture book with the words from a song popular in many Spanish-speaking countries about a mother hen taking care of her baby chicks. The activity invited families to use wooden blocks and small pieces of cardboard to build a structure to keep a nest of baby chicks safe and cozy (Figure 5).

During each round of testing, families received the current version of one of the three activities and recorded themselves engaging with it using a Zoom-based video recording system (Pattison et al., 2023). A bilingual member of the team then conducted a virtual 30–45 minute interview with one adult caregiver from each family to gather their perspectives and feedback. The data were analyzed using quantitative and qualitative techniques to identify improvements to the activities and inform theory development.

The analysis suggested that the narrative contexts and support elements sparked playful and imaginative engagement for families and helped deepen and extend the engineering design learning. In particular, the study pointed to the importance of the stuffed animals that were included in two of the three activities. These activity elements provided a fun way to engage families with the activities, immediately catching children's attention and motivating play. As physical manifestations of the narrative context, both as presented in the activities and as imagined by children and families, the stuffed animals appeared to influence engineering engagement in several ways:

Figure 5. A family engaging with the [project name] *Pollitos* activity © [organization] 2023.

Connecting narratives and design challenges

By directly connecting with the characters in the stories and the design challenges, the stuffed animals motivated children and adults to bring those stories to life and expand the narrative context as they engaged in play and design.

Motivating user-centered design

The strong connection to the narrative and the use of the stuffed animals appeared to motivate user-centered design, encouraging families to discuss the needs of the characters in the stories while also incorporating both physical success criteria (e.g. size) and imaginative criteria (e.g. comfort) into the design challenges (Pattison et al., 2023).

Empowering families to modify the design space

The affordances of the stuffed animals also appeared to help families creatively modify the design goals and constraints (e.g. making a playground instead of a coop for chicks), which in turn allowed children to take ownership over the design process and empowered families to tailor the challenges to individual interests and ability levels.

This work has provided key insights into the extensive capacity of young children and their families to engage in rich and sophisticated engineering practices when meaningful and flexible supports are made available – and particularly those that consider the central roles of family learning and narrative context for early learners. These insights can guide ongoing research on engineering engagement in early childhood and enhance the impact of programs and activities designed for children and their families at this age.

Towards design conjectures

We have presented five studies of the use of narrative informal environments in different aspects of STEM education. The studies covered a range of uses of narratives, in different settings, with varied participants and using various methodologies, providing various findings that emerged from each study. Study 1 described how a narrative-based pedagogy was used to enhance a visit to a science museum and explored what 10-year-old students remembered from the story and whether they could form a story of their own. Study 2 used a narrative-based pedagogy in a long-term outreach program for children in a zoo, as a way to promote positive feelings toward animals and support remembering facts about them. Study 3 demonstrated the use of a narrative embedded in a game to examine the role of the background story in an escape room experience. Study 4 used implicit narrative in an immersive virtual reality architecture exhibition and examined its role in visitors' meaning making. Study 5 employed narratives through songs and storybooks and analyzed the ways in which families with preschool-age children used these to deepen their engagement with the engineering design process.

Whilst the research literature on using narratives at large is rich, their use in informal STEM settings is limited. The contribution of this paper is to discuss the manifestation of narrative specifically in designed STEM informal environments and activities. In this section, we synthesize the findings from the five studies to raise four design conjectures that focus on the use of narrative in informal settings. Conjectures are provisional ideas about how design concepts can affect learning processes and outcomes; they are a step in the way and lead to theory building through further testing and refining (Sandoval 2014).

These design conjectures are meant to provide an anchor for researchers and practitioners alike: researchers might want to further investigate and refine each conjecture in further informal contexts; practitioners might want to use them to design new narrative-rich activities in informal settings.

Design conjecture 1: narratives engage and motivate learners

In all five studies, narrative was used to foster engagement and attract learners into the activity. In a sense, this design conjecture was seen by the researchers as an assumed affordance of narrative that needed no further investigation and instead they focused on the following three conjectures. Indeed, this conjecture is well documented in other informal science education contexts (e.g. Glick and Samarapungavan 2008; Hu et al. 2021; Murmann and Avraamidou 2014).

Design conjecture 2: narratives help people make sense of the learning activity and content

A strong theme that comes out of all studies is that narratives helped learners make sense of their learning. Narrative helps people structure information into a form that is clearly understandable and makes sense (Avraamidou and Osborne 2009; Bruner 1986, 1991). In the science museum and zoo (which used narrative-based pedagogy), narrative helped the learners make sense of the learning content directly. In the other three studies, narrative helped learners understand and engage with the activities or STEM learning process (understand the mission at hand in the escape game, understand what the design challenge was and create a context for learning in architecture exhibition). Extrapolating from this idea, narrative can be developed to help learners' meaning making of different domains but also different aspects of the activity. Future work can consider framing other aspects of learning through a narrative – for example framing an entire museum visit as a story or introducing metacognitive reflections on an activity using a narrative.

Design conjecture 3: using narratives gives people a common language for communication

Using narratives opens the door for learners to talk using the language of stories. This outcome was seen across most of the studies in different manifestations. Having such a shared language allowed visitors to discuss what they learnt and communicate with fellow participants in the activity. Creating an opportunity to use the language of stories also provided researchers with a tool with which to communicate with the research participants.

Bruner (1986; Bruner, 1991) suggests two modes of thought: a paradigmatic one which refers to organizing thoughts in a logico-scientific way and a narrative one which refers to organizing ideas and information into a story. Introducing narrative into activities not only allows meaning making of the learning activity but gives learners the tools to contextualize and extrapolate from this activity. An exception to this observation was in the escape room in which the participants were only able to recall pieces of the story. This limitation is probably due to the small role the story played in the actual activity.

Design Conjecture 4: stories help learners recall content

Finally, across all studies, narrative helped learners recall content, probably as a result of the previous design conjectures. This is perhaps the least surprising conjecture – we expect people to remember stories and we know intuitively that people remember stories. This point is, of course, backed by adequate research evidence (Avraamidou and Osborne 2009; Bruner 1986). But *what* information do stories help people recall? Again, the answer to this question varied between the five studies. It included scientific or historical information explicitly delivered in the activities (science museum and zoo), or simply information that was necessary for the learner to conduct the activity (escape room and engineering storybooks). In the narrative for the immersive virtual exhibition, 'nature-architecture relations' was the conceptual content. It would be interesting to research whether the story created by the participants would help them recall their journey at a later stage.

Concluding remarks

In presenting five studies of the use of narratives in informal settings, we aimed to illustrate that the approach is commonly found and potentially powerful but not well understood in terms of strengths and limitations. In our experience this is true of other aspects of informal education such as the use of models, simulations and visualizations. Looking across diverse examples of the use of pedagogy in informal settings can provide design conjectures that might allow exhibit and exhibition designers ways into thinking about the use of narrative approaches. They are, though, conjectures, and lack some of the rigor of large-scale, in-depth research but, for many practitioners, they may be a good next step. They also provide tools for researchers in the area to think about what research might be fruitful in informal settings. Because the use of narratives in formal settings has been relatively well researched, there is already a firm theoretical and empirical foundation for future studies. We believe that this paper opens up new avenues for research and practice in learning in informal settings.

As with other pedagogies, these design elements need to consider the context and the culture in which they are embedded. The narrative of a house in the forest can work well in Norway, a country with vast forests and a cultural heritage of folk stories about houses in them but might not work well in a different context such as Israel for example, where such a folklore does not exist (neither do forests). Yet, we believe that synthesizing the cases from diverse contexts in this paper is a strength by providing universal principles. Future applications need to take into account and will require adjustments to local contexts and cultures.

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ORCID

Neta Shaby http://orcid.org/0000-0002-3788-6613
Justin Dillon http://orcid.org/0000-0001-5154-8306
Ran Peleg http://orcid.org/0000-0002-9184-6030
Orit Ben-Zvi Assaraf http://orcid.org/0000-0002-4194-9998
Scott Pattison http://orcid.org/0000-0001-9296-7814
Palmyre Pierroux http://orcid.org/0000-0003-4018-6885
Maya Barzilay http://orcid.org/0000-0003-0789-1531
Muriel Grenon http://orcid.org/0000-0002-9910-5974
Rolf Steier http://orcid.org/0000-0001-9809-3169
Gina N. Svarovsky http://orcid.org/0000-0002-8939-3132
Smirla Ramos-Montanez http://orcid.org/0000-0002-0799-0073
Catherine Wagner http://orcid.org/0009-0007-9036-2775
María Quijano http://orcid.org/0009-0001-3922-1359
Amy Corbett http://orcid.org/0000-0002-3645-6734
Diana Contreras http://orcid.org/0009-0005-4570-4903

Ethics statement

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