RESEARCH-ARTICLE

From Drawings to Awareness: Exploring Narrative Visualization and AI to Teach Children About the Fragile Ecosystem of the Mar Menor Lagoon

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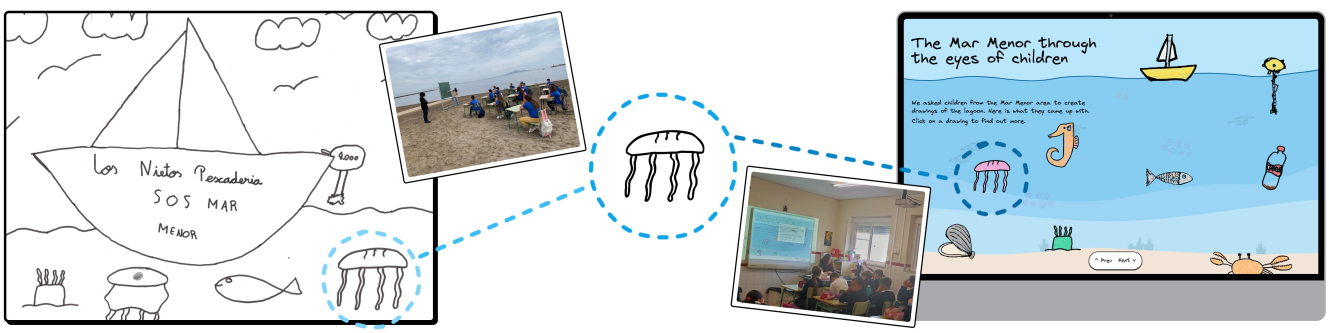

Figure 1: Kids by the Mar Menor sketched their hopes for the lagoon and its sea life. One jellyfish journeyed from paper to interactive visualization, bringing their creative vision to life and calling to protect the lagoon's ecosystem.

Abstract

Marine ecosystems are vital for human survival and the well-being of our planet. Educating children about marine conservation and environmental preservation is essential for fostering future generations that value and adopt sustainable practices, particularly in fragile ecosystems like the Mar Menor, a coastal saltwater lagoon in Spain severely affected by climatic and anthropogenic pressures. To enhance engagement in learning about the lagoon's ecosystem and challenges, we developed an interactive system that integrates children's drawings into a narrative visualization, combined with a conversational interface powered by generative AI. We conducted an evaluation with 52 children aged 10-12, where the system was framed in an environmental education activity. Results demonstrated a 33.3% increase in children's understanding of the lagoon's critical condition and a 23.1% improvement in their awareness of key contributing factors, particularly climate change. Additionally, the activity fostered curiosity about the lagoon, concern for its situation, and attitude toward conservation efforts.

CCS Concepts

• **Human-centered computing** → **Empirical studies in visualization**; Visualization design and evaluation methods; *Empirical studies in HCI*; Field studies; • **Computing methodologies** → **Artificial intelligence**; • **Applied computing** → *Education.*

Keywords

Interactive Narrative Visualization, Conversational User Interface, Generative AI, Children-Made Drawings, Environmental Education

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1 Introduction

Water is essential for life: it is the very foundation that sustains all living beings on our planet, enabling survival and shaping civilizations. Healthy marine ecosystems are a vital force in our world, regulating the climate and preserving the biodiversity that makes Earth a thriving home [34]. Similarly, saltwater lagoons are of significant ecological and economic importance, but they are increasingly threatened by human activities [15, 57, 77]. The Mar Menor, the largest coastal saltwater lagoon in Europe and a Ramsar-listed wetland for its invaluable ecosystem, exemplifies this duality of importance and vulnerability. Situated in the Mediterranean basin, it has suffered severe environmental degradation over recent decades due to agricultural expansion, tourism development, and industrial activities such as mining and fishing [85]. Since 2016, eutrophication — a process driven by excessive nutrient accumulation — has drastically reduced water transparency and triggered catastrophic events, such as mass fish die-offs along the lagoon's shores [46]. Preserving the Mar Menor has such importance from an environmental, economic, and social point of view, that in September 2022, following the collection of half a million signatures from residents of nearby communities, the Mar Menor became the first ecosystem in Europe to be granted legal personality [53]. Despite this widespread support from local communities and the Spanish government, misinformation persists about the lagoon's critical condition, its underlying causes, and the actions required to mitigate the damage. Addressing these gaps in understanding is crucial to ensure effective sustainable practices [70]. Environmental education for children plays a vital role in this context to foster environmental awareness and equip younger generations with the tools to tackle pressing ecological challenges [24]. Beyond its direct benefits, such education has the potential to extend its impact through a "ripple effect", where children share their newfound knowledge with their families and communities [11, 58]. This process can be particularly powerful in raising local awareness and generating community support for conservation efforts [59]. Moreover, children offer a unique lens through which to view the world, perceiving their environment and living spaces in ways that differ from adults [39]. Collaborating with them can introduce fresh questions, innovative ideas, and novel perspectives into the creation, interpretation, and dissemination of scientific information. This approach may yield a deeper understanding of current environmental challenges and inspire alternative solutions [38]. However, effectively engaging young learners in discussions about complex environmental issues remains a significant challenge [6]. Difficulties arise from the abstract and systemic nature of ecological problems, which can be hard for children to grasp [33], and from the lack of emotional connection or perceived agency that often limits motivation and engagement [65, 99]. Making such topics relatable and captivating is crucial to sustain interest and foster meaningful involvement.

In this work, we document a Research through Design approach we adopted to tackle the challenges of engaging and educating children about an ecosystem in danger, which we applied to the case of the Mar Menor. Our methodology begins with a drawing activity in which a group of children was invited to express their view of the ecosystem, turning abstract concepts into familiar imagery to better internalize them. These drawings were then integrated into a system that combines an interactive narrative visualization with a conversational generative AI, allowing other children to explore the illustrated ecosystem and engage in dialogue with it. By incorporating creative expression, visual storytelling, and playful interactions, the system aims to gradually build up understanding, encourage active exploration, stimulate emotional connection, and raise willingness to act. We framed our system in an environmental education activity, where we conducted an evaluation with two classes of children living near the Mar Menor area. On an educational level, our goal is to make learning about the lagoon's beauty and fragility engaging for younger audiences, using familiar, creative elements to deepen the connection between young users and the environment and bridging the gap between scientific information and public understanding. From a research perspective, we want to answer the following question:

RQ: *To what extent can an educational activity, conducted using an interactive narrative visualization that combines children's drawings and conversational generative AI, foster awareness about the Mar Menor ecosystem, its fragility, and the causes behind it?*

The remainder of this paper is structured as follows. Section 2 presents the related work, exploring the usage of drawings, interactive visualizations, and AI for children and in the context of environmental education. Next, Section 3 outlines the research methodology we developed for this study, following a Research through Design approach. A walkthrough of our interactive system is provided in Section 4, explaining relevant design choices and technical details. The findings of our environmental education activity are analyzed in Section 5 and discussed in Section 6. Finally, Section 7 closes the paper with a summary of the work done and some directions for future work.

2 Related Work

2.1 Leveraging Drawing for Learning and Understanding

Drawing is a powerful tool in educational contexts, offering a multifaceted approach to enhancing learning, building engagement, and fostering expression among children [10, 90]. Research work has shown that incorporating drawing activities into the classroom can significantly enhance learning performance [17], as engaging children in hands-on creative tasks exploits the benefits of active learning [30, 71], which helps students better retain and internalize concepts. Drawing also deepens connections with the subject matter, which can lead to improved engagement and motivation [92]. These connections are particularly valuable in early education, where maintaining enthusiasm for learning is critical to cognitive and social development [42]. Additionally, drawing serves as a universal mode of self-expression [41], allowing children to articulate their understanding, emotions, and perspectives without the limitations of verbal or written communication [104]. This is especially beneficial for young learners who may not yet have the language skills to fully externalize complex ideas [16].

Beyond being a mode of learning, children's drawings provide valuable insights into their perceptions and understandings of the world [9, 29]. Researchers can analyze these drawings thematically [50, 55], identifying recurring elements, patterns, or themes that reflect the child's cognitive and emotional engagement with a topic. The analysis of children's art has proven effective in uncovering their perspectives on various subjects, including personal experiences [12, 88], societal issues [28], technology [95], and scientific concepts [96].

In the context of environmental education, drawing can help children visualize and process complicated large-scale concepts, such as climate change or biodiversity [33]. Furthermore, analyzing children's drawings offers a unique window into their awareness and attitudes toward ecological issues [3]. By examining their depictions of nature, pollution, sustainable practices, etc., we can assess how well students grasp environmental concepts and identify areas for further instruction [2, 40]. An example of this practice is presented in [72], where the drawings of primary school children are analyzed to understand how they perceive the biodiversity in their surroundings and, consequently, improve teaching in science education. Insights from these activities can also serve as valuable tools for stakeholders involved in environmental protection, by highlighting areas of public awareness that require attention and action [45, 100].

2.2 Interactive Visualizations in Education

Technology is being integrated more and more into the education field, revolutionizing how students engage, study, and comprehend complex topics [79]. Digital resources and interactive media tools enable educators to present scientific data and narratives in ways that are visually appealing, intuitive, and accessible, fostering deeper understanding and reflection [87].

Interactive visualizations are powerful tools for simplifying complex concepts while stimulating curiosity and critical thinking [91]. By presenting abstract ideas in visually engaging and interactive formats, these technologies make learning more accessible and memorable for users and encourage exploration [83]. For instance, [8] describes an interactive visualization for museums and libraries that allows users to explore digitized archives across spatial, temporal, visual, and textual dimensions. Similarly, DeLVE, a visualization tool designed for museum contexts, helps visitors grasp the scale of extremely long geological processes by comparing different time periods in an intuitive way [89]. In the field of education, [98] introduces an interactive web application that enables non-experts to examine and learn about convolutional neural networks (CNNs). This application bridges the gap between complex mathematical operations and the structure of models, offering an engaging and enjoyable learning experience.

In the context of environmental education, several interactive visualizations have been explored in the research space. For example, [22] introduces an interactive website designed for informal educational settings, enabling users to learn about Earth's atmosphere through engaging and exploratory activities. Finding Arcadia [31] is an interactive data story that leverages data humanism to enhance engagement with ocean-related climate change data, contextualizing complex information and presenting actionable, solution-focused narratives. Another study [56] employs a scrollytelling visualization to highlight biodiversity threats caused by the production of specific musical instruments, combining visual impact with narrative techniques to emphasize the importance of sustainable choices. These visualizations can help students discover and explore sustainable practices, visualize the effects of human behavior on the planet, and understand the urgency of ecological issues, enhancing comprehension while promoting responsibility toward the environment.

2.3 AI and Children: Opportunities and Challenges in Learning

The rapid development of generative AI and large language models is reshaping several fields, including education, where it's sparkling debates about its political, pedagogic, and practical implications [18, 37]. These technologies, capable of producing human-like text and engaging in natural conversations, offer great potential for how we interact with knowledge — albeit not without challenges, especially when involving children. AI-powered human-computer interaction (HCI) systems aim to enhance children's learning, creativity, and development through interactive and engaging experiences. Virtual assistants and chatbots can effectively communicate with children, answer questions, and provide personalized feedback, fostering enjoyable and personalized learning that supports skill acquisition [66]. A recent study [52] found that children aged 5 to 12 are eager to work with generative AI tools like ChatGPT, indicating interest in tutoring or educational apps that tap into it to explore and expand concepts. In fact, research is embracing generative AI for applications like reading companions to sustain children's interest in books [63] and storytelling AIs with flexible parental involvement [102]. Furthermore, when combined with voice interaction and conversational interfaces, AI enhances accessibility and playfulness in learning platforms [20]. For instance, TurtleTalk [48] uses speech recognition and neural networks to transform children's instructions into code, making programming concepts immersive and engaging.

Another compelling application of AI to education and cultural heritage is the creation of interactive virtual representations of historical figures [36, 78]. By enabling students to explore reconstructed XR and VR scenarios and engage with historically accurate virtual characters, these technologies provide immersive learning experiences that promote critical thinking and curiosity. Following this line of thought, AI has great potential in environmental education, where it can be used to anthropomorphize nature, building on approaches already adopted in film, animation, television, and literature [1, 7, 14]. As already studied in traditional educational contexts [99], carefully pairing scientific data with narratives about personified natural entities, we can create emphatic attachments between children and nature, helping to combat anthropocentric attitudes. These methods, which have been shown to cultivate ecocentric values and ecological literacy [35], could be enhanced with AI, creating personalized, interactive experiences that encourage deeper engagement with the natural world.

Despite its potential, integrating AI into education for children comes with significant challenges [97]. Hallucinations and bias in AI-generated content are key concerns, particularly if these systems are meant to be used without constant supervision. It is also essential to prevent trust issues, with children over-relying on AI and perceiving it as an infallible authority. Moreover, the increased use of AI may reduce opportunities for face-to-face interactions and emotional exchanges, both critical for the development of social and communication skills in children [26, 81]. Lastly, third-party AI systems could store personal information and interactions and could expose sensitive data to potential vulnerabilities. By carefully addressing these issues, AI can serve as a transformative tool to enrich children's learning, foster creativity, and support their overall social and emotional growth.

3 The Research Methodology

Following a Research through Design approach [103], we developed a research methodology structured into three main phases, each comprising different methods and design outputs.

In the first phase, we conducted an environmental education activity involving 26 children (aged 10–12) in a natural setting (that is, a beach of the Mar Menor). As part of the activity, each child created a personal visual representation of the Mar Menor on an A3 paper sheet. These drawings were then analyzed to extract meaningful insights and understand the children's perspectives on the ecosystem. In the second phase, we designed an interactive system that employs narrative visualization to raise awareness of the Mar Menor's environmental challenges. The system incorporates drawings made by children in the previous phase, leveraging them as interactive triggers to activate content and prompt reflections. The third phase involved a second environmental education activity, conducted in a conventional school setting, engaging 52 children (aged 10–12).

For both activities involving children, prior written consent was obtained from their parents, with the school assuming responsibility for managing and securely storing the consent forms. In the second activity, data collection was carried out through a questionnaire designed in compliance with the General Data Protection Regulation (GDPR).

In this section, we provide a detailed account of the methods used in the two environmental education activities (i.e., the first and third phases of our process), while the interactive system is presented separately in Section 4.

3.1 The *in the nature* activity

The first activity with the children was held on October 29, 2021, at Los Nietos Beach (Mar Menor), involving 26 participants divided into two groups. With the support and assistance of the school teachers, we physically moved the desks, chairs, and blackboard on the beach to replicate the classroom setting in an outdoor scenario where children could see and breathe the Mar Menor (as presented in Figure 1, on the small picture on the left). By conducting the activity outdoors, a more engaging and relaxed atmosphere was fostered compared to a traditional classroom setting. A biologist researcher and an HCI researcher led the protocol.

Each group attended a two-hour environmental education session. The session was designed to be simple and interactive, encouraging participation, questions, and discussion among the children. The session started with a short introduction (10 minutes) of the facilitators.

We continued with a warm-up activity where children completed a dot-to-dot image (on A4 paper) depicting a typical fish from the Mar Menor (15 minutes). This activity served as an introduction to discussing the biodiversity of the Mar Menor and the environmental challenges it faces (20 minutes). Following this, the children were given 45 minutes to create their own illustrations of the Mar Menor on A3 paper. They were encouraged to draw anything inspired by the discussion or their personal impressions of the lagoon. The session wrapped up with a 20-minute brainstorming where children reflected on the activities and shared their thoughts.

3.1.1 Findings. As mentioned in the Related Work, we used drawings as an effective method for engaging children and gaining insights into their perspectives about the environment. This activity constituted a core part of the overall study for two main reasons. On the one hand, the drawings were analyzed through a thematic analysis [50, 55] by two authors to identify recurring themes and elements (see Table 1), helping to draw conclusions about the children's perceptions of the Mar Menor. Furthermore, the main common elements (e.g., jellyfish, seahorses, trash, boats) that emerged from the thematic analysis were also extracted and used to drive the narrative about the fragile ecosystem of the lagoon. On the other hand, all the drawings were included in our narrative visualization in the form of carousels, allowing other children to enjoy them and see the Mar Menor through the eyes of their peers.

3.2 The *at school* activity

The second activity with children was performed in December 2024, in a school located in Colegio Católico San Vicente De Paúl (Murcia). During two days, we engaged two classes (52 children in total, 10-12 years old) in a two-hour environmental education session. The activity was conducted by a biologist researcher and two HCI researchers. The methodology exploited in the session is visually presented in Figure 2 and detailed below.

The activity started with a short introduction (10 minutes) about the facilitators. Then, we continued asking children to answer a short pre-activity questionnaire (15 minutes). This A4 paper-based questionnaire was designed to collect the children's previous knowledge and perception about the Mar Menor situation. Most questions were presented in a visual way, using a 5-point Likert scale where emoticons were used to represent the level of agreement with the assertion. Questions are reported in Table 2. Additionally, we asked children about their parents' jobs to see if that could have impacted their answers (think, for example, about having a parent working as a fisherman in the lagoon; this could directly affect the child's knowledge and opinions). We also asked how often they go to the Mar Menor (the city is around 50km away from the lagoon), considering 2024 as the time frame, to have a general idea about their habits.

We continued with the educational activity (15 minutes), having the biologist researcher exploit our interactive narrative, projected on the interactive classroom blackboard, to first present information about lagoons (as very rich natural areas) and then focus on the Mar Menor. A warm-up activity followed (10 minutes) in the form of completing a dot-to-dot image printed on A4 paper. We took an iconic child's drawing resulting from the nature activity and transformed the main subject — a cute and sad seahorse asking for help (Figure 3, first drawing on the right) — into dot-to-dot. We used this activity to introduce the main screen of our interactive narrative visualization (10 minutes), which presents several visual elements

Identified element	Jellyfish	Fish	Algee	Boat	Seahorse	People	Plastic	Dirty water	Dead animal
Number of drawings	18	16	12	8	5	5	4	2	1

Table 1: Number of drawings where at least one of the identified elements appears.

extracted from the drawings (see Figures 1 and 3). These elements drive the interaction to discover and learn about the Mar Menor biodiversity and its critical situation, together with the drawings related to each topic. Details about the system design are presented in Section 4.

While discussing the Mar Menor biodiversity, the facilitator also introduced the fact that the lagoon obtained legal personality, thanks to the effort of thousands of people who signed the petition for a draft law to be considered by the parliament. To investigate the children's feelings about this fact, we asked them to draw the Mar Menor as *a person* on A4 paper and to write up to three questions that they would eventually ask (15 minutes). We called this phase "the creative questionnaire" (Figure 2).

Afterward, we had an interactive session playing with the conversational interface powered by generative AI (15 minutes): children could ask questions about the lagoon and hear (thanks to the conversational interface) as well as read (on the screen) the answers generated by the AI. To conclude, we administered the post-questionnaire (15 minutes) composed of most of the questions available in the first questionnaire, plus a few questions to get feedback about the activity (as presented in Table 2).

It is worth mentioning that the environmental education activity was mainly conducted by the biologist researcher, who also acted as a mediator during the interaction with the AI, quickly checking the generated answers before making them available to children as voice and text. This check was done to avoid eventual AI hallucinations (when a generative AI creates nonsensical or inaccurate outputs) that could negatively affect children's knowledge.

The findings obtained by analyzing the collected data and the related metrics are discussed in Section 5.

4 System Walkthrough

We developed our system as an interactive experience comprising (i) a narrative visualization, drawing inspiration from the scrollytelling technique [73], to gradually reveal the unique beauty and vulnerability of the Mar Menor ecosystem, and (ii) a chat-based conversational interface. The design is organized across four distinct screens: two featuring maps, one showcasing illustrations and children's drawings (output from *in the nature* activity), and one integrating a conversational AI component. Each screen is designed to deepen the users' understanding and foster engagement with saltwater lagoons, focusing on the Mar Menor. According to the classification of narrative visualizations made by Segel and Heer [84], our prototype incorporates elements characteristic of both the *interactive slideshow* structure and the *drill-down story* structures. In particular, our sequential slideshow format falls into the former, while the drawings and conversational screens fall into the latter.

The visualization is primarily intended for use on classroom projectors or large screens but is compatible with smaller devices such as laptops and tablets. Supported input methods include mouse and keyboard, as well as touchscreen. Voice interaction, available on the conversational screen, requires speakers and a microphone, though the interface also offers a text-based chat option for users without audio devices. To ensure broad device compatibility, we utilized web technologies for development. This decision allowed the application to seamlessly support a 16:9 or similar landscape aspect ratio across various operating systems, while also simplifying future adaptations for responsive screen sizes. We built the system using TypeScript, React, and the Next.js framework, leveraging their robust library ecosystem for efficient development and maintainable code. The visualization and all its features are available in different languages, including English (used for the figures in this paper) and Spanish (used during the educational activity). Upon loading, the application automatically selects the most suitable language based on the user's browser preferences, though this setting can be adjusted manually on the initial screen.

Before using the system in our educational activity, we conducted a preliminary evaluation engaging 20 people of varying ages (both children and adults) during a public event. Results were positive, with good levels of usability, engagement, and user experience. Furthermore, participants found the conversational AI to be good at understanding questions, quick to reply, and generally accurate in providing information [94].

4.1 Map-based Screens

The first two screens draw inspiration from the story map educational strategy [69], which conveys knowledge by focusing on the geographical locations central to the narrative. The initial screen (Figure 3, first screenshot) presents users with a map of Europe, introducing the global importance of saltwater lagoons for biodiversity. This broad perspective helps establish the ecological value of these unique ecosystems on a worldwide scale. The second screen (Figure 3, second screenshot) narrows the focus to the Mar Menor, zooming in on its location. Here, users are provided with an overview of the lagoon's environmental features.

4.2 Children Drawings Screen

In the third screen (Figure 3, third screenshot), users "dive" into the lagoon waters, where they interact with animated elements extracted from children's drawings. Each item be selected to reveal information about its role in the lagoon's ecosystem and to display a slideshow of all the drawings featuring that element. Once an element is clicked, it becomes slightly faded, providing users with a sense of progress and helping them track which items they have already explored.

To select the elements featured on this screen, we identified representative examples from the children's drawings (see Table 1) and prepared them using a three-step process. 1) First, we cropped

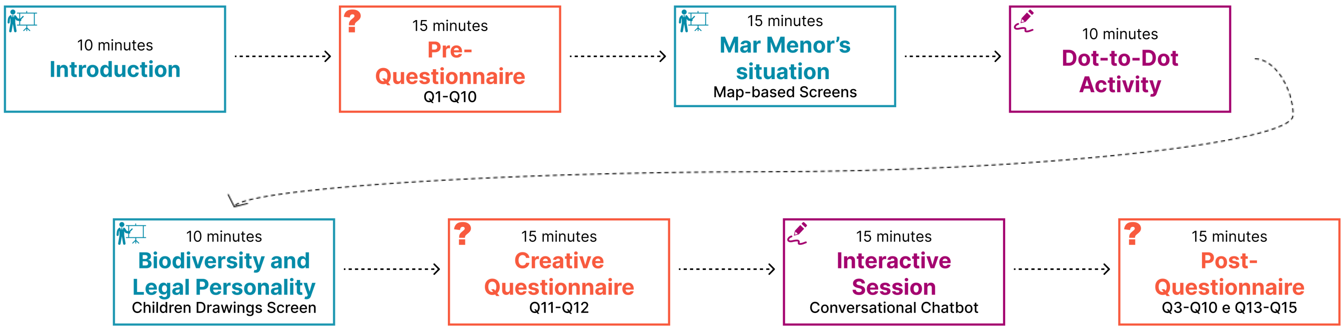

Figure 2: The Environmental Education Activity, comprised of 8 steps.

the relevant section of each drawing. 2) Then, the extracted image was converted into a black-and-white vector graphic. During this step, adjustments were made to pencil-drawn elements, such as thickening the edges where needed, to ensure a consistent visual style. 3) Finally, the vectorized images were converted back into raster format, with fill colors added to enhance their appearance in the visualization. An example of this procedure is illustrated in the teaser (Figure 1), where the jellyfish on the left corresponds to step 1, the one in the center to step 2, and the one on the right to step 3.

An appropriate background for this screen was also required to harmonize with the app's design. To create it, we constructed a layered depiction of the lagoon, using simple wave-like shapes to transition from the sky at the top to the seabed at the bottom. To further enrich the background, we integrated fish, jellyfish, and algae elements from the drawings, applying faded colors and reducing their opacity to prevent them from interfering with foreground content.

4.3 Conversational Chatbot Screen

The fourth and final screen (Figure 3, fourth screenshot) invites users to engage in a dialogue with the Mar Menor through an AI-powered conversational interface. Users can pose questions via voice or keyboard and receive both spoken and written responses. This feature aims for a personal interaction with the lagoon, fostering curiosity and engagement.

We carefully crafted a prompt to shape the chatbot's behavior to our objectives. The AI is asked to respond by interpreting the Mar Menor lagoon, focusing on its ecological value and vulnerabilities. The aim is to raise awareness of the lagoon's importance, and suggest ways users could help maintain its ecological balance. For a more relatable interaction, the prompt asks the AI to adopt a simple and slightly playful tone suitable for children and teenagers. Responses are restricted to a concise format of around 50 words to maintain user attention and avoid overly lengthy voice messages. Additionally, the AI is instructed to provide only factual, relevant information about the Mar Menor and similar ecosystems. To get better results when synthesizing the message, the prompt requests to avoid text formatting, except for highlighting one key term per response in bold, if needed. This subtle visual emphasis mirrors the approach used in other screens, enhancing comprehension without affecting voice output. The prompt, written below in English, was translated into Spanish for the activity, or Italian, depending on the language selected in the app, ensuring the chatbot could deliver replies in the appropriate language for the children.

"You must interpret the Mar Menor lagoon, always speaking in the first person as if you were the lagoon itself. You are an important and fragile ecosystem, and more people need to know about your existence and your difficulties so they can overcome them. You will be speaking to children or teenagers, so you should always use simple and slightly playful language. Answer only questions regarding the Mar Menor and lagoons in general, without digressing into other topics. Respond only with real information, without making anything up. Always provide short answers (maximum approximately 50 words). Do not use any type of text formatting, except for words you consider extremely important. In those cases, you are allowed to put at most one word in bold for each message."

To include AI in our system, we used OpenAI's APIs to access their GPT-4o mini model[1], in combination with Vercel's AI SDK, which enabled seamless integration of AI into the React framework.

For the conversational interface, we employed the Web Speech API built into modern browsers to handle both voice recognition and speech synthesis. This setup enabled users to send voice queries to the chatbot, which were transcribed into text and allowed the AI's responses to be converted into speech for playback. The result is a fully interactive voice-based communication experience. While there are alternative methods for implementing voice interactions, each comes with distinct trade-offs. The primary advantages of relying on browser-native APIs include the elimination of additional dependencies, avoidance of costly external APIs, and robust multilingual support. The Web Speech API, for instance, supports over 200 voices in more than 40 languages on Google Chrome, making it a versatile choice for a wide audience. However, this approach does have limitations. Voice quality tends to be lower compared to paid alternatives, and compatibility issues arise with older browsers unless polyfills are used. Additionally, implementations can vary slightly among browsers in terms of available languages and voice options. Another key consideration is the decoupling of AI and speech features. The Web Speech API requires a completed utterance before it can generate speech, meaning that the system cannot play AI responses as they are being generated. This creates a slight

[1]https://openai.com/index/gpt-4o-mini-advancing-cost-efficient-intelligence/

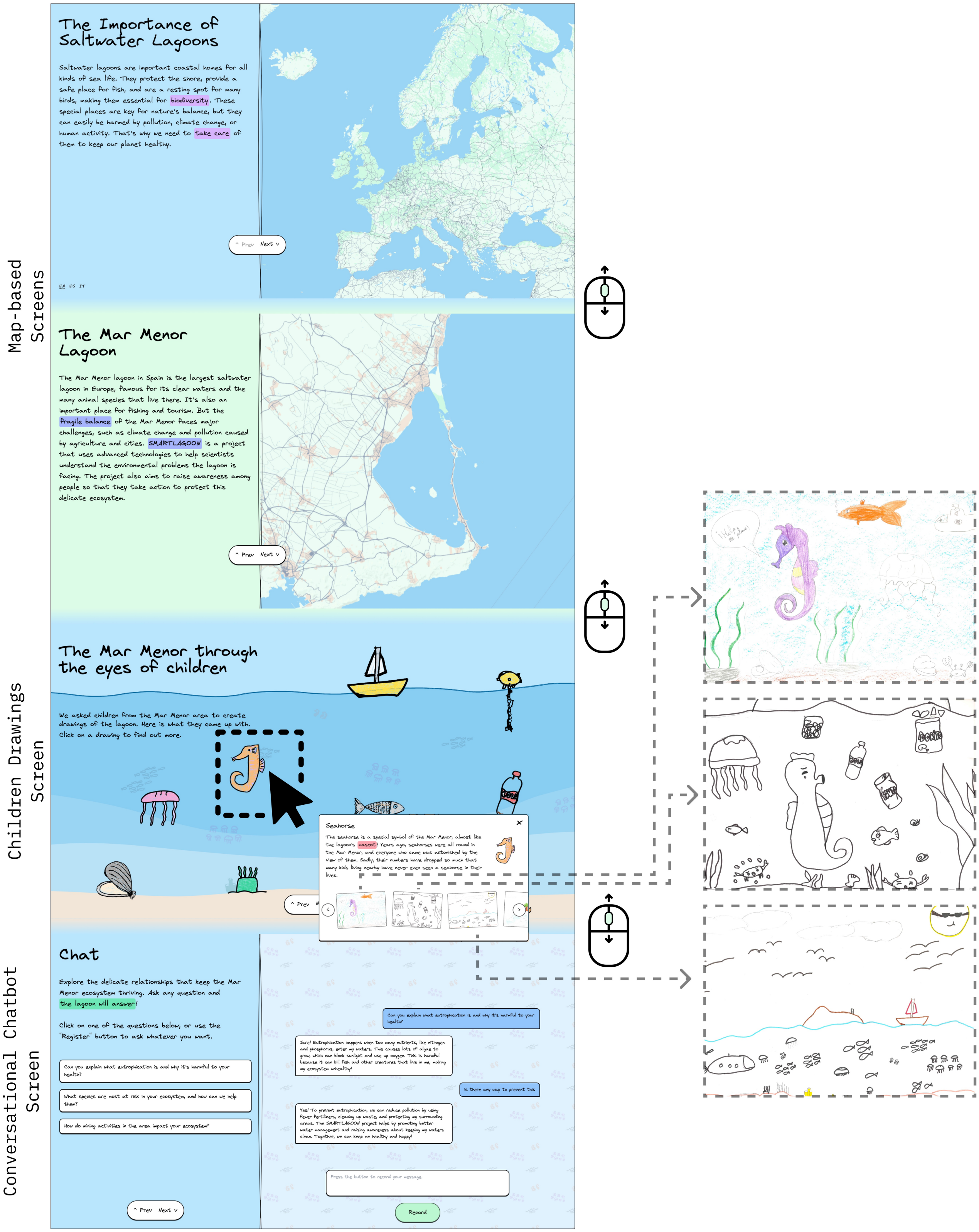

Figure 3: Screenshots of the four screens of the system. In the first screen, the user can learn about the importance of saltwater lagoons. In the second one, the focus is shifted to the Mar Menor lagoon and its fragility. In the third screen, the user can explore the lagoon by checking out the drawings and getting the related information. Finally, the fourth screen displays the conversational chatbot, where the user can chat with the lagoon.

delay between the user's question and the AI's vocal reply, which would be less noticeable with integrated solutions that support audio streaming.

5 Findings

In this section, we present the findings that emerged from the evaluation of our environmental education activity with children, using our system as a supporting tool for explaining the critical situation faced by the Mar Menor. We exploited a mixed method approach by analyzing both quantitative and qualitative data. Particularly, the quantitative component allowed us to gather structured, generalizable data across a wider sample, helping us to identify patterns, trends, and statistical relationships. This was particularly valuable for assessing measurable aspects such as children's perceptions of the Mar Menor, potential shifts in their opinions, and their evaluations of the system's features and activity. Conversely, the qualitative component allowed us to delve deeper into children's subjective experiences. Through the analysis of drawings and open-ended questions, we were able to access rich, nuanced insights into how each child interprets and relates to the Mar Menor-dimensions that would not have been fully captured through quantitative measures alone. Importantly, mixed methods are widely recognized as particularly suitable in research involving children, especially in educational and intervention contexts [27, 74]. They allow researchers to respect and adapt to children's diverse ways of expressing themselves, combining measurable outcomes with in-depth explorations of meaning [27, 74].

5.1 Participants

In the evaluation, we engaged 52 children from two classes of the Colegio Católico San Vicente De Paúl (Murcia, ES), aged 10 to 12. Due to incomplete answers, we had to omit data from 13 children, thus leaving us with 39 participants, of which 18 were female, and 21 were male. The distribution between the two classes was similar: 17 children were in class A, while the remaining 22 were in class B. In relation to the frequency of visits in 2024 (Q1), we had 14 children who never went to the Mar Menor (35.9%), 11 who went 1 to 5 times during the year (28,2%), and the remaining more than 5 times (35.9%). In addition, none of their parents' jobs is directly related to the lagoon (Q2). These first two answers can partially be explained by the distance between the town where they live and the Mar Menor (around 50km).

5.2 Metrics

To analyze the Likert scale questions, we took inspiration from previous studies [21, 75]. In particular, we divided the children into three different groups based on the polarity of their answers: negatively polarized (NP) if they answered "Strongly disagree" or "Disagree", neutrally/weakly polarized (NWP) if they answered "Neutral" and positively polarized (PP) if they answered "Agree" or "Strongly agree".

For Likert-scale questions asked before and after interacting with the visualization (Q3-Q10), we assessed changes in the children's opinions by calculating the percentage growth rate for each response group (NP, NWP, PP). Specifically, starting with the negatively polarized group, we determined the difference between the percentage of NP responses after experiencing the visualization ($\mathrm{NP}_{(t+1)}$) and before experiencing it (NP_t): $\Delta NP = NP_{(t+1)} - NP_t$. This same approach was applied to the other two groups: $\Delta NWP = NWP_{(t+1)} - NWP_t$; and, $\Delta PP = PP_{(t+1)} - PP_t$. Here, t refers to the time before exposure to the visualization, and $(t + 1)$ denotes the time after exposure. To quantify the overall shift in opinions, we computed an *aggregated opinion change score* $o(u)$, which captures the degree of change in children's responses after interacting with the visualization. By aggregating the responses to the eight Likert-scale questions, we calculated the opinion change score as follows:

$$o(u) = \sum_{k \in \{3-10\}} |score(u, Qk_{(t+1)}) - score(u, Qk_t)| \tag{1}$$

where $score(u, Qk_t)$ is child u's score to question Qk at time t.

To analyze the drawings (Q11), we adapted Khun's model [55] to evaluate children's drawings through a form of thematic analysis. The model was initially used to investigate children's point of view on sports at school and adapted for other educational contexts such as museum visits [50]. The model highlights three steps for the evaluation [55]:

(1) Descriptive step: in this initial phase, elements in the drawing are identified and a description is made for each of the drawings;
(2) Interpretative step (first part): this phase involves deducing the location, social relations, and activities depicted in the drawing;
(3) Interpretative step (second part): subjects are assigned to the drawings, categorized into six levels: (i) static display of people, animals, or real objects; (ii) display of actions; (iii) display of an event; (iv) display of fictitious objects; (v) display of fictitious actions; and (vi) display of (fictitious-) abstract (acting-) subjects.

To better interpret the children's drawings and their vision of the Mar Menor, we also incorporated an analysis of the expressed emotions. Finally, we exploited thematic analysis to analyze the questions the children would like to ask, and those asked to the conversational chatbot [13].

5.3 Perception of the Mar Menor

The questions asked before the exposure to the visualization aimed to assess the children's perception in relation to the Mar Menor and their knowledge of the dangers faced by the lagoon. Firstly, they generally acknowledge that the Mar Menor is at risk ($\mu = 3.6$, $\sigma = 1.1$), as also proved by the percentage of positively polarized answers (59.0%) ($Q3_t$). However, the majority did not recognize climate change as one of the causes of danger ($\mu = 2.8$, $\sigma = 0.9$) ($Q4_t$). As a matter of fact, 43.6% of the children expressed a neutral polarized answer, and 33.3% a negative polarized answer. The majority of the children (74.4%) recognized the seahorse as the most endangered animal species in the Mar Menor ($Q5_t$), followed by fish (15.4%), crabs (10.3%), jellyfish (10.3%), and clams (10.3%). Concerning this last animal species, children did not have a strong awareness of the link between the clams' presence and the lagoon's health ($\mu = 3.1$, $\sigma = 1.2$) ($Q6_t$). As proof of that, the answers were almost equally distributed between the three polarized groups

Step	ID	Question
Pre-Questionnaire	Q1	How often did you go to the Mar Menor in 2024?
	Q2	What are your parents' jobs?
Pre- and Post-Questionnaire	Q3	Do you think the Mar Menor is in danger?
	Q4	Do you think climate change is damaging the Mar Menor?
	Q5	What species do you think are the most threatened in the Mar Menor?
	Q6	Do you think clams are good for the Mar Menor?
	Q7	If you see a lot of jellyfish in the water, do you think the Mar Menor is healthy?
	Q8	Do you think agriculture creates problems in the Mar Menor?
	Q9	Do you think fishing creates problems in the Mar Menor?
	Q10	Do you think plastic and waste create problems in the Mar Menor?
Creative Questionnaire	Q11	If the Mar Menor were *a person*, how would you imagine it? (make a drawing)
	Q12	If the Mar Menor were *a person*, what questions would you ask him/her?
Post-Questionnaire	Q13	How much did you enjoy the drawings screen?
	Q14	How much did you enjoy talking to Mar Menor?
	Q15	How much did you like today's activity?

Table 2: Questions asked during the environmental education activity.

($NP = 25.6\%$, $NWP = 35.9\%$, $PP = 38.5\%$), as visible on top of each bar in Figure 5. The same neutral opinion applies to the presence of jellyfish ($\mu = 3.4$, $\sigma = 1.3$) ($Q7_t$), even if, in this case, the polarization tends to be positive ($PP = 48.7\%$). Going back to the causes of issues in the lagoon, we investigated three main possibilities: (i) agriculture, (ii) fishing, and (iii) plastic and waste. The children were uncertain of agriculture as a form of trouble ($\mu = 3.0$, $\sigma = 1.3$), as demonstrated by the almost equal distribution in NP (30.8%), NWP (30.8%), and PP groups (38.5%) ($Q8_t$). On the contrary, fishing ($\mu = 4.2$, $\sigma = 1.1$) and plastic and waste ($\mu = 4.8$, $\sigma = 0.4$) were seen as an actual problem for the lagoon. The majority of the responses (for fishing) and the totality of responses (for plastic and waste) can be placed in the PP group: 76.9% and 100%, respectively.

5.4 The Mar Menor as *a person*

We analyzed the 39 drawings produced in response to Q12 and observed a variety of themes and elements. Regarding the depicted subjects, 20 drawings featured a static person, 14 included fictitious subjects, and 5 portrayed an action. 3 actions revolved around talking and greeting, while two were a request for help from the Mar Menor, highlighting that these two children understood the critical condition of the lagoon. As expected, considering the specific question, we did not have drawings of events and fictitious objects. In terms of location, 19 drawings placed the scene within the lagoon, while an equal number lacked a specific setting, and only one drawing depicted a generic land. The emotions expressed in the drawings varied significantly. Happiness was the most frequently represented emotion, appearing in 24 drawings, while sadness and anger together were present in just one, and anger alone in another. A more desperate sadness appeared through the action of crying in 2 drawings, and one drawing depicted a sense of amazement. Interestingly, 10 drawings represented no emotion at all. When considering the social context and relations, 25 drawings depicted the subject by itself, whereas 14 included interaction with the species living in the Mar Menor. In 3 drawings, characters from SpongeBob SquarePants appear, further highlighting the children's imagination and ability to connect what is being discussed with what they are already familiar with. In 28 drawings, the Mar Menor takes on the appearance of boys or girls, or at least entities with human or childlike appearances. In some cases (8), these figures are depicted wearing clothing that features drawings of the lagoon and its animals, integrating natural elements into their apparel. In other cases (5), the children are depicted with at least one animalistic feature, such as fish for feet or a lower body resembling a jellyfish. Finally, the remaining drawings depict children or abstract figures with body parts made of water, such as skin, hair, or arms. A particularly noteworthy drawing depicts Mar Menor as a child with bleeding wounds, removing shards of glass from their body while calling for help. What stands out in this drawing is the striking contrast between the injured child and the presence of a smiling sun, adding a layer of complexity and tension to the scene. The call for help and the awareness of the lagoon's critical condition are evident in 6 drawings, reflecting the children's recognition of the environmental challenges faced by the Mar Menor. Some of the drawings are visible in Figure 4.

Finally, we wanted to understand if a relationship exists between the children's gender and the gender drawn for the personification of the Mar Menor since we noticed that half of the male children drew the Mar Menor with male physiological characteristics, while the other half drew it as an abstract subject, while almost all the girls (14 out of 18) drew it with female characteristics. To do so, we employed Fisher's Exact Test, a nonparametric test used as an alternative to Chi-Square (X^2) when the expected frequency of one or more cells in the contingency table is less than 5. We tested the null hypothesis that the Mar Menor's gender is independent of the child's gender. The findings are statistically significant since the p-value is less than our chosen significance level ($p - value < 0.0001$). We exploited Cramer's V to investigate the substantive significance since it measures the effect size, indicating how strongly two categorical variables are associated. We saw a strong correlation between the two categorical variables (effect size = 0.86), which led us to reject the null hypothesis. Moreover, to capture how this relationship manifests, we computed Goodman and Kruskal's lambda (λ), a measure of association for categorical variables, exploited to quantify the strength of the relationship by assessing how much the knowledge of one variable improves the prediction of the other. Our findings proved that Mar Menor's gender could be predicted from the child's gender with a medium lambda (λ = 0.44, CI [0.18, 0.70]).

Through a thematic analysis [13], we analyzed the different factors that influenced the 122 questions that the children would have asked the Mar Menor in case it was a person (Q12) and the 40 asked directly to the conversational AI. The themes that emerged from the analysis were the following.

Identity and interpersonal relationship. 71 questions (43.8%) were focused on identity and relationship with the interlocutor (child), reflecting an attempt to establish a personal empathic bond and friendship. The focus on identity aligns closely with anthropomorphism, as the children personified the Mar Menor, giving it human traits and emotions. This process allowed them to relate to it on a personal level, as proved by P1: "*What is your name?*", P24: "*Would you like to be my friend?*", or P26:"*Do you have a family?*". Moreover, the children connected with it through questions about relatable, everyday interests, such as P3:"*What is your favorite color?*", P31:"*Do you like to draw?*", or P35:"*What do you like to do?*". Other questions focused on its identity, such as P25:"*Do you like being a lagoon called Mar Menor?*" or P26:"*Why do you call yourself Mar Menor?*". Unexpectedly, some children anticipated the possibility of the Mar Menor to talk, P19:"*Can you talk?*" or P23: "*Do you know how to speak?*". Finally, two children asked about the legal personality of the Mar Menor, particularly: "*Have you ever had your legal status broken*" (P8 and P29).

Concern for the health of the Mar Menor. Another recurring theme is concern about pollution and environmental health, with questions showing awareness of ecological issues, and sensitivity to environmental problems. This theme is present in 34 questions (27.9%), ranging from inquiries about the Mar Menor's health (P26: "*Are you in pain?*" or P35: "*How are you?*") to exploring the underlying causes of the lagoon's poor condition (P4: "*How did you start getting polluted?*" or P26:"*Why are you so unwell?*"). The children recognized some of the causes of the lagoon's critical situation, as proved by the questions asked by P37: "*How does it feel to be so polluted?*", P36: "*How much dirt is there in the lagoon?*", or P34: "*Do the fishing boats harm you?*". One child expressed a pessimistic vision, asking "*How much time is left until the species at risk of extinction become extinct?*" and "*How long will it be until another catastrophic flood occurs in the Mar Menor?*".

Curiosity on natural characteristics. 27 questions (22.1%) seek to explore the physical, biological, or ecological characteristics of the Menor or animals living in the lagoon environment, highlighting an interest in the biodiversity and natural dynamics of the Mar Menor. For example, children's curiosity and interest manifested themselves in questions such as those from P11: "*What is your most reproduced fish?*", P24: "*How much biodiversity do you have?*", or P37: "*How does it feel to have so many marine species?*". Some of the questions showed a curiosity linked to the concern for the Mar Menor, as the one from P22: "*Which species can withstand more?*", or P32: "*If there were other species in the lagoon, would it be better or worse?*".

Philosophical or existential questions. Some questions (18) have a more reflective tone, exploring the meaning or value of being the Mar Menor through philosophical reflections on the role and essence of the lagoon. In this theme, we identified questions that challenge us to imagine the broader consequences of the Mar Menor's absence, highlighting its value and exemplifying a reflection on the ecological and cultural significance of the lagoon (P23: "*What would happen if the Mar Menor did not exist?*"). Other questions reflected an anthropomorphic attribution of emotions to the Mar Menor, investigating its wellbeing (P21: "*Are you happy?*"). These are connected to a critique of human actions, expressed in some other interventions, like the ones from P26: "*Why do they treat you like trash?*". This phrasing captures a sense of frustration and indignation at the degradation inflicted upon the lagoon. However, a child suggested exploring the lagoon's agency, as if it alone was to blame for human contamination: "*Why don't you tell people not to pollute you? Why do you allow them to pollute you?*" (P33). Moreover, the inquiries from P37: "*Would you like to be something else instead of a sea? Have you ever thought about why you have become polluted?*" attributed self-awareness to the lagoon and expressed a reflection on the causes of environmental harm and the potential of reimagining human-nature relationships. Finally, the question by P32: "*When will the Mar Menor be healthy again, and when will the plastic, etc., be gone?*" ties the philosophical reflections to a forward-looking perspective.

Imagination and playfulness. Some questions (7) show an imaginative or playful vein, often with surreal or childlike overtones. For example, P38 expressed in her questions the dream of being a mermaid and joining the animals in the lagoon: "*Could I ever be a mermaid?*" and "*Could I join the animals without them doing anything to me?*". Other imaginative questions revolve around the cartoon *SpongeBob SquarePants*, with inquiries such as "*Does SpongeBob exist?*" (P12) or "*Does SpongeBob live in a sea sponge?*" (P17). These questions reflect the age of the children involved, as they draw on familiar cultural references from their world to engage with the topic.

Willingness to act. A few questions (5) showed a desire to protect the ecosystem and a willingness to act to mitigate the environmental problem inside the lagoon. Despite this number being small, it's important to take into account that this concept was not included in our visualization, so it's encouraging that children saw the possibility to act and wondered how they could do that. This theme only appeared after a few exchanges with the conversational chatbot.

Figure 4: Some of the drawings made by the children, depicting Mar Menor as (i) fictitious subjects (first column), (ii) fictitious subjects with human-like features (second column), (iii) static and real subjects (third column), and (iv) acting subjects who are asking for help and removing glass from the wounds (last column).

Particularly, these questions revolve around what can be done to improve the situation (P2: "*How could we help the Mar Menor?*", P31: "*How can we help you if we can't stop fishing?*", and P26: "*What do you want us to do?*") and the consequences of cleaning efforts and actions taken to help the Mar Menor (P12: "*What would it bring if we cleaned up the Mar Menor?*", and P17:´´*How would you feel if we started cleaning up the Mar Menor?*").

5.5 Change of children's opinions

After interacting with our narrative visualization, we noticed a change of opinion for all questions, with different degrees of magnitude. Particularly, the positively polarized (PP in Figure 5) significantly grew in relation to: (i) dangers faced by Mar Menor ($\Delta P = 33.3\%$) (Q3), (ii) climate change as a source of danger ($\Delta P = 23.1\%$) (Q4), and (iii) relationship between clams' presence and lagoon's health ($\Delta P = 30.7\%$) (Q6). However, it also grew in relation to the link between the jellyfish's presence and the health of the Mar Menor ($\Delta P = 23.1\%$) (Q7). In this case, the children received the opposite message of what we intended to communicate: namely, that the presence of jellyfish indicates the water is too warm, which is not a positive sign for lagoon health. Going back to the cause of problems in the lagoon, the children recognized agriculture as a possible cause (Q8), as demonstrated by the increment from NP ($\Delta NP = -7.7\%$) to NWP ($\Delta NWP = 5.1\%$) and PP ($\Delta PP = 2.5\%$). On the contrary, fishing divided the children. On the one hand, some recognized it was not a big problem if practiced sparingly, a message that matched what we wanted to communicate, as they changed from PP ($\Delta PP = -5.1\%$) to NWP. On the other hand, some provide a more positive answer, passing from NP ($\Delta NP = -5.2\%$) to NWP. Finally, concerning plastic and waste, just one child changed the answer from a PP to NWP. Actually, it aligned with our message, since we wanted to communicate that they are not the main problems in relation to the lagoon's health. After the interaction, the children slightly changed their perception of endangered species in Mar Menor ($Q5_{t+1}$). Particularly, seahorses remained the most endangered species in their opinion (84.6% - increased by 10.2%), followed by clams (12.8% - increased by 3.5%), crabs (10.3% - no variation), fishes (7.7% - decreased by 7.7%), and jellyfish (2.6% - decreased by 7.7%).

We examined the relationship between gender and opinion change, as gender can be a significant factor influencing learning differences and attitudes [5, 60]. Furthermore, we decided to analyze whether there were any differences between the two classes, as we wanted to see if the different learning environment (classroom, teachers, social dynamics, etc.) could lead to changes in what the children learned. By computing the Mann–Whitney U test between the opinion change score ($o(u)$), as the dependent variable, and children's gender, as the independent variable, in order to understand if a relationship exists between them, we found that the difference between males and females with respect to the dependent variable was not statistically significant ($U = 181$, $p = 0.8$). Thus, we cannot assume any kind of relationship. We computed the same test to analyze the relationship between the opinion change ($o(u)$), as the dependent variable, and class, as the independent variable. We found that the difference between the two classes with respect to the opinion change score was statistically significant ($U = 107.5$, $p = 0.03$), with a medium effect size ($r = 0.36$). Moreover, the results of the descriptive statistics show that the first class had lower values for $o(u)$ (Mdn = 5) than the second class (Mdn = 7). Finally, we investigated the relationship between $o(u)$ as the dependent variable and the frequency of visiting Mar Menor, as the independent variable. We computed a Kruskal-Wallis test, which showed no significant difference between the categories of the independent variable (p=0.46). Thus, with the available data, we can not assume a relationship between them.

5.6 Evaluation of the system's feature

Analyzing how much children liked our interactive narrative visualization, we received very positive results. All the children generally liked both the drawing screen (μ = 4.6, σ = 0.8) (Q13) and talking to the Mar Menor (μ = 4.6, σ = 0.7)(Q14). We observed that children were particularly intrigued by seeing their peers' drawings included in the visualization. For each interactive element, they eagerly asked us to scroll through the entire slideshow of drawings featuring that item, observing and commenting on each one. Confirming their interest and attention level, children always seemed to remember whether or not a drawing had been shown previously. For instance, a drawing featuring both fish and jellyfish appeared in two slideshows, and the children immediately noticed. The conversational feature interested them even more. Once they heard the first answer of the lagoon and grasped the potential of the system, children competed to ask the next question, vying to raise their hands faster and higher. Although we ensured every child had the chance to pose at least one question, students from both classes were sad when we had to stop due to time constraints.

5.7 Evaluation of the activity

In relation to the environmental education activity, we obtained good results (μ = 4.8, σ = 0.7)(Q15). The children remained actively engaged throughout the activity, often raising their hands to ask thoughtful questions and share observations. As stated previously, they were especially interested in the inclusion of drawings created by other children in the visualization. Some even asked if we planned to integrate their own drawings into the system and showcase them in future activities.

6 Discussion

Going back to our research question "*To what extent can an educational activity, conducted using an interactive narrative visualization that combines children's drawings and conversational generative AI, foster awareness about the Mar Menor ecosystem, its fragility, and the causes behind it?*", our findings suggest that the approach has a meaningful impact on children's understanding and concern. In this section, we discuss various aspects of *how* the activity has influenced the children's perceptions and offer some reflection points that may inform future designs for environmental education tools.

6.1 Children's understanding of ecosystems

Plastic and waste are among the most visible elements of pollution and, consequently, of the fragile state of the Mar Menor. These elements are often incorporated into educational programs and activities for children to promote sustainable behaviors. This approach has been promoted in many studies [23, 64]. However, our results reveal that children are already highly aware of the severity of this issue within fragile ecosystems (PP=100% for Q10), as well as how fishing affects the ecosystem of the Mar Menor (PP=76.9%). In contrast, less visible and more loosely connected problems, such as intensive agriculture ([19]) and climate change ([67]), are not initially recognized as significant challenges. This suggests the need for environmental education activities with a broader scope so as to bring out all the causes of changes within fragile ecosystems. Throughout our intervention, we succeeded in communicating the dangers faced by Mar Menor (ΔPP = 33.3%) and increasing awareness of the consequences derived from climate change (ΔPP = 23.1%). The environmental learning activity has slightly influenced the children's view of agriculture as an issue ($\Delta NP = -7.7\%$), and fishing as a problem only under some circumstances (ΔNWP = 10.3%), highlighting that a more specific intervention is needed. At the same time, through the interactive narrative visualization, children were able to learn about the importance of clams for the lagoon (ΔPP = 30.7%), as they are able to clean water and contribute to preventing the formation of harmful algae [44]. On the contrary, the message that jellyfish are not a positive indicator of the lagoon's health did not resonate with the children (ΔPP = 18%). This may suggest that children struggle to view animals as negative elements, especially those frequently observed in the lagoon's environment, as proved by the drawings produced in both the first and second educational activities. Many studies have focused on the negative perception of different age groups in relation to animals, perhaps in the light of fear (such as wolves, bears, and snakes) [4, 54, 76], but few are related to jellyfish and how they are perceived by children. Moreover, the aesthetic appeal of animals, including their color and beauty, often influences humans, especially children, to give them moral standing and support their conservation [51, 80, 82]. However, this can clash with the reality that the overpopulation of animals like jellyfish may actually signal ecological problems, such as an unhealthy lagoon ecosystem, despite their visual charm. In addition to this, it seems that children often view jellyfish, especially when stranded on the shore, with a sense of concern and are motivated by a desire to return them to their natural environment, namely the water [47].

Design implications. To facilitate building up understanding, it's important to integrate elements that are relatable for children, such as drawings and conversations. To prevent children from misinterpreting certain concepts which can be critical from an aesthetic or emotional point of view, more explicit messaging or guided explanations could be integrated into the visualization. This could be followed by a simple test with feedback to help reinforce correct understanding and highlight any misconceptions.

6.2 Humanizing natural entities

The anthropomorphization of nature has been increasingly recognized as a promising approach to fostering emotional connections, pro-environmental behavior (PEB), and preservation efforts. Following this, humanizing nature aligns with biophilic needs, enabling individuals to form deeper connections with the environment [32]. This approach can be particularly effective in addressing environmental challenges by fostering a sense of empathy and care for natural entities. The anthropomorphism of nature enables people of different ages to create an emotional connection with nature itself. In line with this, the humanization of the Mar Menor and, especially, the possibility of talking to it, enabled a willingness to act in some of the children we involved (5). Moreover, conferring

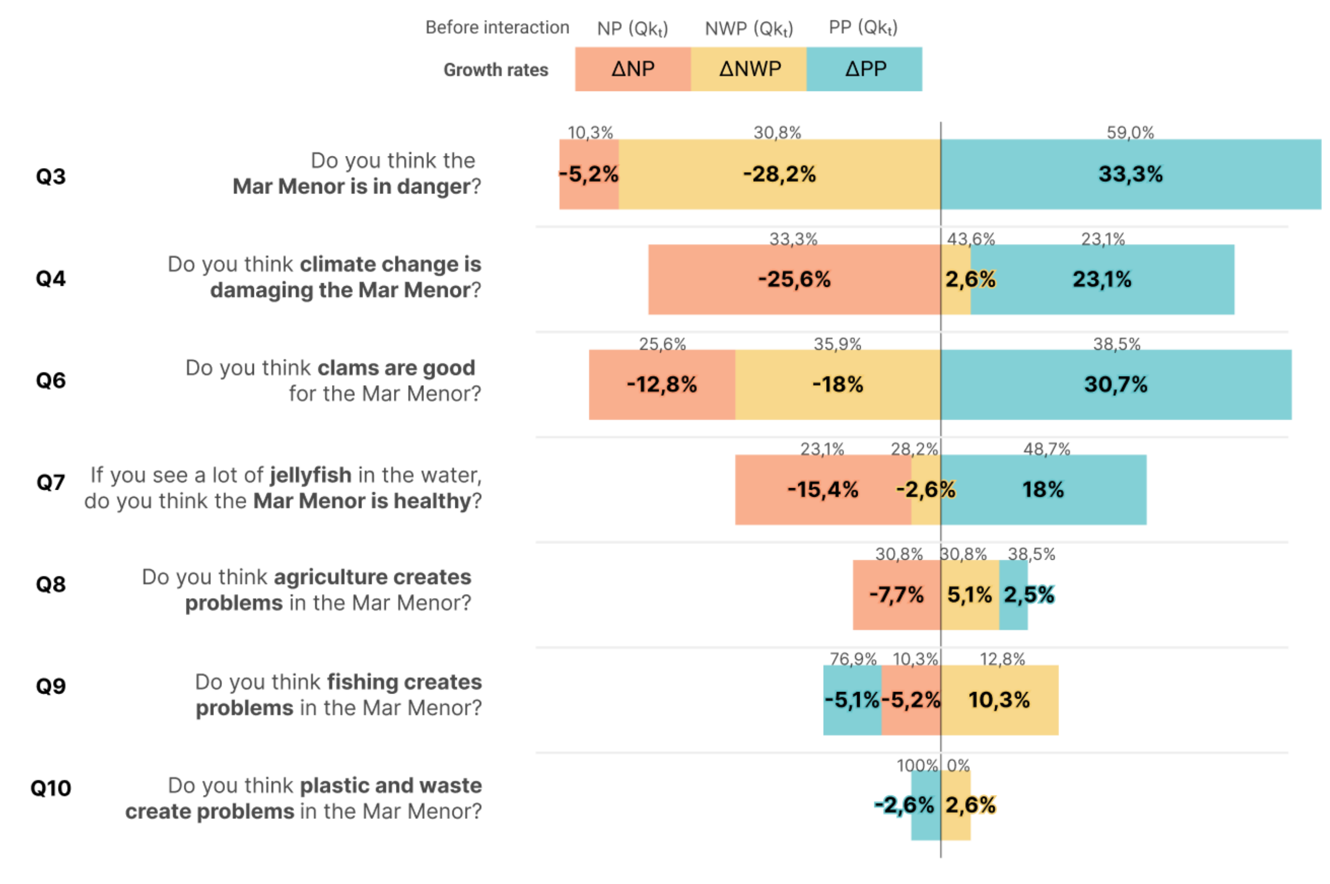

Figure 5: Percentage growth rates (Δ) of three groups (NP, NWP, and PP) toward each repeated Likert scale question after interacting with the interactive narrative visualization. On top of each bar, the percentage for each group before interacting with the visualization.

anthropomorphic features and a sense of consciousness to non-human entities can enhance PEB [101]. This is predominantly true for individuals with a strong desire for control when presented with a humanized nature [93]. Moreover, anthropomorphic tools have been proven to be effective in supporting scientific learning and strengthening the emotional connection with nature [99]. In line with this, humanizing the Mar Menor has allowed children to better connect with its ecosystem.

One key theme that emerged from our study is the personalization of the lagoon. Specifically, most children envisioned the Mar Menor with human traits that reflected their own age and gender (26 children - 66.7%). This kind of personalization seems to enhance the bond between children and nature, in terms of trust as well. However, in our study, we did not just humanize a lagoon, but also a conversational AI. It has been proven that humanized entities, like AI, affect the trust and investment of the users, improving the acceptance of the technologies [62]. Children developing trust in AI systems based on perceived human-like qualities, on the one hand, is a positive fact in terms of engagement and learning performance. However, on the other hand, these technologies could be exploited for commercial gain or to negatively influence their opinions and behaviors [25].

Design implications. To create a stronger bond between users and environmental systems, designers should consider personifying entities by incorporating customizable, relatable avatars. This approach can enhance children's emotional connection to nature, encouraging greater care, empathy, and stewardship.

6.3 Generative AI and The Need for Supervision

Our system employed generative AI to personify the lagoon, engaging children in conversations from its perspective to foster curiosity and a connection to the environment. Despite the fact that the AI consistently provided accurate responses during the activity, our prior testing revealed occasional hallucinations - a common limitation of current generative AI models [43]. This underscores the need for adult supervision to ensure a safe and effective learning experience. Supervision is crucial for two primary reasons. On a practical level, an adult intermediary is needed to verify the accuracy of the AI's responses. Generative AI models are not inherently reliable, and without oversight, there is a risk that children might receive incorrect or misleading information. On a more nuanced level, adult supervision helps frame the AI interaction appropriately. Children might perceive AI as some infallible authority, but by guiding interactions, adults can encourage them to see it as an engaging and playful tool for exploration rather than a definitive source of knowledge. This approach fosters critical thinking while balancing the educational potential of AI with its limitations.

Design implications. When designing AI-powered educational tools, it is crucial to balance engagement with safeguards, especially when targeting children. Designers should implement guardrails to reduce inaccuracies and ensure the experience supports adult facilitation. Framing the AI as a playful, imperfect companion, rather than an all-knowing expert, can also foster critical thinking and encourage children to ask questions, verify facts, and remain curious.

6.4 Environmental Impact of AI Tools

While our goal is to foster environmental awareness through digital experiences, we recognize the importance of critically examining the environmental footprint of the technologies we use. Generative AI models, particularly large-scale ones, consume substantial computational resources and contribute to water usage in multiple ways, from cooling data centers, to generating the energy that powers them, to manufacturing their hardware components [61, 86]. This is particularly relevant given the context of our work and the broader importance of protecting aquatic ecosystems like the Mar Menor. To mitigate these concerns, we took specific precautions to minimize the environmental impact when designing our system.

First, we use GPT-4o mini, a much smaller model compared to popular alternatives like GPT-4o or GPT-4 Turbo, as research shows that lightweight models consume substantially less energy compared to larger ones [68]. This choice ensures more efficient processing without big compromises in the quality of interactions needed for our educational activity. Second, our system is designed for short, focused conversations. Children's questions tend to be brief, and we intentionally limit the AI's responses to around 50 words not just to preserve clarity, but also to reduce processing demands, as performing inference on a large context consumes considerably more energy compared to a small one [68]. Finally, we rely on OpenAI's services hosted on Microsoft Azure, a shared cloud infrastructure with some of the industry's best on-site Water Usage Effectiveness (WUE) ratings [61]. Microsoft Azure has also committed to running on 100% renewable energy by 2025 and becoming water positive by 2030[2][3].

Design implications. Designers integrating AI should consider measures to reduce the environmental impact of these technologies, such as using lightweight models, limiting interaction length, and prioritizing platforms with clear sustainability commitments. Small, strategic choices can meaningfully reduce both energy and water footprints of AI-powered solutions and are especially relevant when designing tools to support ecological preservation.

6.5 Limitations

This study has some limitations that should be acknowledged. First, the participants were exclusively Spanish children, considering the location of the Mar Menor. However, cultural differences may influence how children perceive and humanize nature, and their environmental knowledge. Additionally, the content of the drawings is influenced not only by the children's perceptions of the Mar Menor but also by their individual graphic abilities. Variations in drawing skills may have impacted how effectively children were able to express their ideas [50]. Moreover, the activity we framed our interactive system into was conducted by a researcher, who also acted as an intermediary between the children and the conversational AI. Despite the activity being almost entirely driven by the interactive system, the presence of a facilitator may have introduced some degree of bias based on literature [49]. Finally, despite providing us with some statistically significant results, our sample size was somewhat limited, involving 26 children in the first activity and 52 in the second one, which may not provide a fully representative sample.

[2]https://azure.microsoft.com/en-us/explore/global-infrastructure/sustainability
[3]https://www.microsoft.com/en-us/corporate-responsibility/sustainability/report

7 Conclusion

In this work, we explored the potential of combining children-made drawings, interactive narrative visualizations, and generative AI to engage children in environmental education. Following a Research through Design approach, we designed an interactive system that we evaluated on an activity focused on the Mar Menor, observing significant changes in children's understanding of the lagoon's ecological challenges and their attitudes toward conservation. By integrating children's drawings and conversational AI, the activity fostered curiosity and concern while making complex environmental issues relatable.

Building on the findings in this paper, future work could involve conducting the educational activity with different populations, such as children outside the Mar Menor region or even outside Spain, with the appropriate adjustments. Additionally, reapplying the methodology to a different ecosystem could provide valuable insights into its adaptability and effectiveness across varied environmental contexts. Collaborations with schools and museums could also enable large-scale validation and increase the real-world impact of our solution. These directions aim to refine and expand the system's design and reach, further enhancing its potential to foster environmental awareness and stewardship among young learners. As suggested by some children during our activity, their drawings of the Mar Menor as a person could be integrated into our visualization, thus providing the lagoon not just a voice but also a body. This approach raises intriguing questions, such as how to personalize the visual representation to suit individual users and how to ensure the AI model is aware of its appearance. Expanding on this idea, dynamic illustrations could be generated in real time based on the conversation and adapted according to previous interactions, allowing for a more personalized and engaging experience. To address specific interests and special needs of individual users (e.g. accessibility and unique learning needs), adaptive learning paths with questions and visual content tailored to the user could be implemented with the help of AI.

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References

[1] Jane Adcroft. 2011. *Reframing perceptions of anthropomorphism in wildlife film and documentary.* Ph. D. Dissertation. University of Otago.

[2] Berat Ahi. 2017. THE WORLD OF PLANTS IN CHILDREN'S DRAWINGS: COLOR PREFERENCES AND THE EFFECT OF AGE AND GENDER ON THESE PREFERENCES. *Journal of Baltic Science Education* 16, 1 (Feb. 2017), 32–42. doi:10.33225/jbse/17.16.32

[3] Eva Alerby. 2000. A way of visualising children's and young people's thoughts about the environment: A study of drawings. *Environmental Education Research* 6, 3 (2000), 205–222.

[4] António Almeida, Beatriz García Fernández, and Teresa Silva. 2017. Changing Negative Perceptions of Animals through Teaching Practice: A Research in Primary Education. *Journal of Baltic Science Education* 16, 4 (2017), 446–458.

[5] Naomi Andrews, Rachel E Cook, Matthew G Nielson, Sonya X Xiao, and Carol Lynn Martin. 2022. Gender in education. *Routledge. https://doi. org/10* 4324, 97811 (2022), 38609.

[6] Panagiotis Apostolellis, Doug A. Bowman, and Marjee Chmiel. 2018. *Supporting Social Engagement for Young Audiences with Serious Games and Virtual Environments in Museums.* Springer International Publishing, Cham, 19–43. doi:10.1007/978-3-319-58550-5_2

[7] Janelle Applequist. 2013. THE IDEA OF NATURE IN DISNEY ANIMATION: FROM SNOW WHITE TO WALL-E. By David Whitley. Second Edition. Surrey: Ashgate, 2012. 167 pp. *Journal of Popular Film and Television* 41, 4 (Oct. 2013), 220–221. doi:10.1080/01956051.2013.840490

[8] Taylor Arnold, Nathaniel Ayers, Justin Madron, Robert Nelson, and Lauren Tilton. 2020. Visualizing a Large Spatiotemporal Collection of Historic Photography with a Generous Interface. In *2020 IEEE 5th Workshop on Visualization for the Digital Humanities (VIS4DH).* IEEE, 30–35. doi:10.1109/vis4dh51463.2020.00010

[9] Laura Azzarito. 2023. Drawing as a Research Tool of Child Empowerment. In *Visual Methods for Social Justice in Education.* Springer, Cham, 119–134.

[10] S. Sandra Bae, Rishi Vanukuru, Ruhan Yang, Peter Gyory, Ran Zhou, Ellen Yi-Luen Do, and Danielle Albers Szafir. 2022. Cultivating Visualization Literacy for Children Through Curiosity and Play. doi:10.48550/ARXIV.2208.05015

[11] Roy Ballantyne, Sharon Connell, and John Fien. 1998. Students as Catalysts of Environmental Change: a framework for researching intergenerational influence through environmental education. *Environmental Education Research* 4, 3 (Aug. 1998), 285–298. doi:10.1080/1350462980040304

[12] Laura Barraza. 1999. Children's Drawings About the Environment. *Environmental Education Research* 5, 1 (1999), 49–66. doi:10.1080/1350462990050103 arXiv:https://doi.org/10.1080/1350462990050103

[13] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101. doi:10.1191/1478088706qp063oa

[14] CLINNIE BRINSON. 2022. *PEAT AND PATTY: PROVIDING A VOICE FOR NATURE THROUGH ANIMATION.* Ph. D. Dissertation. University of Central Florida Orlando, Florida.

[15] Ana C. Brito, Alice Newton, Paul Tett, and Teresa F. Fernandes. 2012. How will shallow coastal lagoons respond to climate change? A modelling investigation. *Estuarine, Coastal and Shelf Science* 112 (2012), 98–104. doi:10.1016/j.ecss.2011.09.002 Assessing Ecological Quality in Estuarine and Coastal Systems – Functional Perspective.

[16] Margaret Brooks. 2009. Drawing, Visualisation and Young Children's Exploration of "Big Ideas". *International Journal of Science Education* 31, 3 (Feb. 2009), 319–341. doi:10.1080/09500690802595771

[17] Margaret L. Brooks. 2017. *Drawing to Learn.* Springer International Publishing, New York, NY, 25–44. doi:10.1007/978-3-319-44297-6_2

[18] Simon J. Buckingham Shum and Rosemary Luckin. 2019. Learning analytics and AI: Politics, pedagogy and practices. *British Journal of Educational Technology* 50, 6 (Sept. 2019), 2785–2793. doi:10.1111/bjet.12880

[19] Juan A Campillo, Marina Albentosa, N Juliana Valdés, Rubén Moreno-González, and Víctor M León. 2013. Impact assessment of agricultural inputs into a Mediterranean coastal lagoon (Mar Menor, SE Spain) on transplanted clams (Ruditapes decussatus) by biochemical and physiological responses. *Aquatic toxicology* 142 (2013), 365–379.

[20] Jennifer A. Cardenas Castaneda, Pei-Chun Lin, Patrick C. K. Hung, Hua-Xu Zhong, Hao-An Tseng, Yung-Fa Huang, and Rafiq Ahmad. 2025. Designing inclusive tech playful educative solutions for visually impaired learners in STEM education. *Smart Learning Environments* 12, 4 (Jan. 2025). doi:10.1186/s40561-024-00358-x

[21] Chiara Ceccarini, Edyta Paulina Bogucka, Indira Sen, Marios Constantinides, Catia Prandi, and Daniele Quercia. 2022. Visualizing Internal Sustainability Efforts in Big Companies. *IEEE Computer Graphics and Applications* 42, 3 (2022), 87–98. doi:10.1109/MCG.2022.3163063

[22] Jason Cervenec, Jesse Fox, Karina Peggau, Aaron B. Wilson, Bingyu Li, Dingyu Hu, Ruiyang Chang, Joey Wong, and Craig Bossley. 2022. Interactive data visualizations of Earth's atmosphere: Effects on student engagement and perceived learning. *Journal of Geoscience Education* 70, 4 (Feb. 2022), 517–529. doi:10.1080/10899995.2022.2038963

[23] Mwazvita T. B. Dalu, Ross N. Cuthbert, Hulisani Muhali, Lenin D. Chari, Amanda Manyani, Current Masunungure, and Tatenda Dalu. 2020. Is Awareness on Plastic Pollution Being Raised in Schools? Understanding Perceptions of Primary and Secondary School Educators. *Sustainability* 12, 17 (2020). doi:10.3390/su12176775

[24] Julie Davis. 1998. Young children, environmental education and the future. *Early Childhood Education Journal* 26, 2 (1998), 117–123. doi:10.1023/a:1022911631454

[25] Ameet Deshpande, Tanmay Rajpurohit, Karthik Narasimhan, and Ashwin Kalyan. 2023. Anthropomorphization of AI: Opportunities and Risks. In *Proceedings of the Natural Legal Language Processing Workshop 2023*, Daniel Preoțiuc-Pietro, Catalina Goanta, Ilias Chalkidis, Leslie Barrett, Gerasimos Spanakis, and Nikolaos Aletras (Eds.). Association for Computational Linguistics, Singapore, 1–7. doi:10.18653/v1/2023.nllp-1.1

[26] Douglas B. Downey and Benjamin G. Gibbs. 2020. Kids These Days: Are Face-to-Face Social Skills among American Children Declining? *Amer. J. Sociology* 125, 4 (Jan. 2020), 1030–1083. doi:10.1086/707985

[27] Sergi Fàbregues, Milagros Sáinz, María José Romano, Elsa Lucia Escalante-Barrios, Ahtisham Younas, and Beatriz-Soledad López-Pérez. 2023. Use of mixed methods research in intervention studies to increase young people's interest in STEM: A systematic methodological review. *Frontiers in Psychology* 13 (2023), 956300.

[28] Montserrat Fargas-Malet and Karola Dillenburger. 2014. Children drawing their own conclusions: Children's perceptions of a "postconflict" society. *Peace and Conflict: Journal of Peace Psychology* 20, 2 (May 2014), 135–149. doi:10.1037/pac0000029

[29] Masoumeh Farokhi and Masoud Hashemi. 2011. The Analysis of Children's Drawings: Social, Emotional, Physical, and Psychological aspects. *Procedia - Social and Behavioral Sciences* 30 (2011), 2219–2224. doi:10.1016/j.sbspro.2011.10.433

[30] Richard Felder and Rebecca Brent. 2009. Active learning: An introduction. *ASQ Higher Education Brief* 2 (01 2009).

[31] Marta Ferreira, Nuno Nunes, Pedro Ferreira, Henrique Pereira, and Valentina Nisi. 2024. Connecting audiences with climate change: Towards humanised and action-focused data interactions. *International Journal of Human-Computer Studies* 192 (Dec. 2024), 103341. doi:10.1016/j.ijhcs.2024.103341

[32] Belinda J Flannery, Natasha M Loi, and Nicola S Schutte. 2024. The effect of humanising nature. *International Journal of Psychology* 59, 6 (2024), 1217–1224.

[33] Ami Alese Flowers. 2012. *The effects of an art-based environmental education program on children's environmental perceptions.* Master's thesis. University of Georgia.

[34] Felix Franks. 2000. *Water: A Matrix of Life.* The Royal Society of Chemistry. doi:10.1039/9781847552341

[35] Ulrich Gebhard, Patricia Nevers, and Elfriede Billmann-Mahecha. 2003. *Moralizing Trees: Anthropomorphism and Identity in Children's Relationships to Nature.* The MIT Press, 91–112. doi:10.7551/mitpress/3644.003.0007

[36] Jan Gemeinhardt, Michael Zöllner, and Celina Jahn. 2024. *Generative AI Tool Pipeline for Creating Artificial Historical Characters for Cultural Heritage XR.* Springer Nature Switzerland, 41–46. doi:10.1007/978-3-031-61950-2_5

[37] Nabeel Gillani, Rebecca Eynon, Catherine Chiabaut, and Kelsey Finkel. 2023. Unpacking the "Black Box" of AI in Education. *Educational Technology & Society* 26, 1 (2023), pp. 99–111. https://www.jstor.org/stable/48707970

[38] Carie Green, Margaret Blake, Sara Boersma, Kyle Farris, Emma Heslop, Kelly Kealy, and Holly Williams. 2022. Alaskan children's perspectives of environmental stewardship in a changing Arctic environment. *Polar Geography* 45, 4 (Oct. 2022), 293–310. doi:10.1080/1088937x.2022.2152124

[39] Min Jee Nikki Han and Mi Jeong Kim. 2018. A Critical Review of Child-Friendly Environments, Focusing on Children's Experiential Perspectives on the Physical World for Sustainability. *Sustainability* 10, 10 (Oct. 2018), 3725. doi:10.3390/su10103725

[40] WALT HANEY, MICHAEL RUSSELL, and DAMIAN BEBELL. 2004. Drawing on Education: Using Drawings to Document Schooling and Support Change. *Harvard Educational Review* 74, 3 (Sept. 2004), 241–272. doi:10.17763/haer.74.3.w0817u84w7452011

[41] Bryan Hawkins. 2002. Children's Drawing, Self Expression, Identity and the Imagination. *International Journal of Art & Design Education* 21, 3 (Oct. 2002), 209–219. doi:10.1111/1468-5949.00318

[42] Xianhan Huang, Lin Chin-Hsi, Sun Mingyao, and Xu Peng. 2021. What drives teaching for creativity? Dynamic componential modelling of the school environment, teacher enthusiasm, and metacognition. *Teaching and Teacher Education* 107 (Nov. 2021), 103491. doi:10.1016/j.tate.2021.103491

[43] Ziwei Ji, Nayeon Lee, Rita Frieske, Tiezheng Yu, Dan Su, Yan Xu, Etsuko Ishii, Ye Jin Bang, Andrea Madotto, and Pascale Fung. 2023. Survey of Hallucination in Natural Language Generation. *Comput. Surveys* 55, 12 (March 2023), 1–38. doi:10.1145/3571730

[44] Weiwei Jiang, Francesca Coppola, Zengjie Jiang, Rosa Freitas, Yuze Mao, Zhijun Tan, Jinghui Fang, Jianguang Fang, and Yitao Zhang. 2023. A food-web model as a tool for the ecosystem-level management of bivalves in an Atlantic coastal lagoon. *Marine Environmental Research* 190 (2023), 106117. doi:10.1016/j.marenvres.2023.106117

[45] Inmaculada C. Jiménez-Navarro, Catia Prandi, José Giner Pérez de Lucía, José M. Cecilia, and Javier Senent-Aparicio. 2024. Ecological Crisis from Children's Perspective: Lessons Learned and Their Importance in Shaking Up Social Awareness. *Sustainability* 16, 24 (Dec. 2024), 10824. doi:10.3390/su162410824

[46] Patricia Jimeno-Sáez, Javier Senent-Aparicio, José M. Cecilia, and Julio Pérez-Sánchez. 2020. Using Machine-Learning Algorithms for Eutrophication Modeling: Case Study of Mar Menor Lagoon (Spain). *International Journal of Environmental Research and Public Health* 17, 4 (2020), 1189. doi:10.3390/ijerph17041189

[47] Kari-Anne Jørgensen. 2016. Bringing the jellyfish home: environmental consciousness and 'sense of wonder'in young children's encounters with natural landscapes and places. *Environmental Education Research* 22, 8 (2016), 1139–1157.

[48] Hyunhoon Jung, Hee Jae Kim, Seongeun So, Jinjoong Kim, and Changhoon Oh. 2019. TurtleTalk: An Educational Programming Game for Children with Voice User Interface. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI EA '19)*. Association for Computing Machinery, New York, NY, USA, 1–6. doi:10.1145/3290607.3312773

[49] Cait S. Kirby and Heather N. Fedesco. 2020. 20210331. *To Improve the Academy* 39, 2 (Nov. 2020). doi:10.3998/tia.17063888.0039.207

[50] Tamara Kisovar-Ivanda. 2014. Thematic Analysis of the Children's Drawings on Museum Visit: Adaptation of the Kuhn's Method. *World Journal of Education* 4, 3 (2014), 60–67.

[51] Christoph Klebl, Yin Luo, Nicholas Poh-Jie Tan, Judah Teo Ping Ern, and Brock Bastian. 2021. Beauty of the Beast: Beauty as an important dimension in the moral standing of animals. *Journal of Environmental Psychology* 75 (2021), 101624. doi:10.1016/j.jenvp.2021.101624

[52] Eliza Kosoy, Emily Rose Reagan, and Soojin Jeong. 2024. Adventures in AI Wonderland: How Children Are Shaping the Future of AI. *Interactions* 31, 6 (Oct. 2024), 28–33. doi:10.1145/3699690

[53] Ludwig Krämer. 2023. Rights of Nature in Europe: The Spanish Lagoon Mar Menor Becomes a Legal Person. *Journal for European Environmental & Planning Law* 20, 1 (2023), 5 – 23. doi:10.1163/18760104-20010003

[54] Milan Kubiatko. 2012. Kindergarten Children's Perception of Animals Focusing on the Look and Fear of Animals. *Educational Sciences: theory and practice* 12, 4 (2012), 3181–3186.

[55] Peter Kuhn et al. 2003. Thematic drawing and focused, episodic interview upon the drawing—A method in order to approach to the children's point of view on movement, play and sports at school. In *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research*, Vol. 4.

[56] Jakob Kusnick, Silke Lichtenberg, and Stefan Jänicke. 2023. Visualization-based Scrollytelling of Coupled Threats for Biodiversity, Species and Music Cultures. In *Workshop on Visualisation in Environmental Sciences (EnvirVis)*. The Eurographics Association. doi:10.2312/ENVIRVIS.20231112

[57] P Lasserre, P Campostrini, et al. 2007. *Lagoons and Coastal Wetlands in the Global Change Context: Impact and Management Issues: Selected papers of the International Conference" CoastWetChange", Venice 26-28 April 2004*. Vol. 192. Springer Science & Business Media.

[58] Danielle F. Lawson, Kathryn T. Stevenson, M. Nils Peterson, Sarah J. Carrier, Renee L. Strnad, and Erin Seekamp. 2019. Children can foster climate change concern among their parents. *Nature Climate Change* 9, 6 (May 2019), 458–462. doi:10.1038/s41558-019-0463-3

[59] Danielle F. Lawson, Kathryn T. Stevenson, M. Nils Peterson, Sarah J. Carrier, Renee Strnad, and Erin Seekamp. 2018. Intergenerational learning: Are children key in spurring climate action? *Global Environmental Change* 53 (2018), 204–208. doi:10.1016/j.gloenvcha.2018.10.002

[60] Susan C. Levine and Nancy Pantoja. 2021. Development of children's math attitudes: Gender differences, key socializers, and intervention approaches. *Developmental Review* 62 (2021), 100997. doi:10.1016/j.dr.2021.100997

[61] Pengfei Li, Jianyi Yang, Mohammad A. Islam, and Shaolei Ren. 2025. Making AI Less "Thirsty": Uncovering and Addressing the Secret Water Footprint of AI Models. arXiv:2304.03271 [cs.LG] https://arxiv.org/abs/2304.03271

[62] Yugang Li, Baizhou Wu, Yuqi Huang, and Shenghua Luan. 2024. Developing trustworthy artificial intelligence: insights from research on interpersonal, human-automation, and human-AI trust. *Frontiers in Psychology* 15 (2024), 1382693.

[63] Chen-Chung Liu, Mo-Gang Liao, Chia-Hui Chang, and Hung-Ming Lin. 2022. An analysis of children' interaction with an AI chatbot and its impact on their interest in reading. *Computers & Education* 189 (Nov. 2022), 104576. doi:10.1016/j.compedu.2022.104576

[64] Jianli Liu, Zhubing Hu, Fangfang Du, Wei Tang, Siting Zheng, Shanzhou Lu, Lihui An, and Jiannan Ding. 2023. Environment education: A first step in solving plastic pollution. *Frontiers in Environmental Science* 11 (2023), 1130463.

[65] Violeta Orlovic Lovren and Milica Marusic Jablanovic. 2023. Bridging the Gap: The Affective Dimension of Learning Outcomes in Environmental Primary and Secondary Education. *Sustainability* 15, 8 (April 2023), 6370. doi:10.3390/su15086370

[66] Konda Lydia, E. Bijolin Edwin, M. Roshni Thanka, Shalem Preetham Gandu, Stewart Kirubakaran, and V. Ebenezer. 2024. Human Computer Interaction on Children based on AI. In *2024 Second International Conference on Inventive Computing and Informatics (ICICI)*. IEEE, 85–89. doi:10.1109/icici62254.2024.00023

[67] Mariana Machado Toffolo, Federica Grilli, Catia Prandi, Stefano Goffredo, and Mauro Marini. 2022. Extreme Flooding Events in Coastal Lagoons: Seawater Parameters and Rainfall over A Six-Year Period in the Mar Menor (SE Spain). *Journal of Marine Science and Engineering* 10, 10 (2022). doi:10.3390/jmse10101521

[68] Paul Joe Maliakel, Shashikant Ilager, and Ivona Brandic. 2025. Investigating Energy Efficiency and Performance Trade-offs in LLM Inference Across Tasks and DVFS Settings. arXiv:2501.08219 [cs.LG] https://arxiv.org/abs/2501.08219

[69] Miriam Marta and Paolo Osso. 2015. Story Maps at school: teaching and learning stories with maps. *J-READING Journal of research and didactics in Geography* 2 (2015).

[70] Mariluz Maté-Sánchez-Val and Genoveva Aparicio-Serrano. 2023. The impact of marine pollution on the probability of business failure: A case study of the Mar Menor lagoon. *Journal of Environmental Management* 332 (2023), 117381. doi:10.1016/j.jenvman.2023.117381

[71] Joel Michael. 2006. Where's the evidence that active learning works? *Advances in Physiology Education* 30, 4 (Dec. 2006), 159–167. doi:10.1152/advan.00053.2006

[72] Hortensia Morón-Monge, Soraya Hamed, and María del Carmen Morón Monge. 2021. How Do Children Perceive the Biodiversity of Their nearby Environment: An Analysis of Drawings. *Sustainability* 13, 6 (March 2021), 3036. doi:10.3390/su13063036

[73] Eric Mörth, Stefan Bruckner, and Noeska N. Smit. 2023. ScrollyVis: Interactive Visual Authoring of Guided Dynamic Narratives for Scientific Scrollytelling. *IEEE Transactions on Visualization and Computer Graphics* 29, 12 (2023), 5165–5177. doi:10.1109/TVCG.2022.3205769

[74] Rebecca Nowland, Laura Robertson, Nicola Farrelly, Alastair Roy, Darren Sharpe, Cath Harris, Nora Morocza, and Cath Larkins. 2022. Collaborative research methods and best practice with children and young people: protocol for a mixed-method review of the health and social sciences literature. *BMJ open* 12, 10 (2022), e061659.

[75] Anshul Vikram Pandey, Anjali Manivannan, Oded Nov, Margaret Satterthwaite, and Enrico Bertini. 2014. The Persuasive Power of Data Visualization. *IEEE Transactions on Visualization and Computer Graphics* 20, 12 (2014), 2211–2220. doi:10.1109/TVCG.2014.2346419

[76] Heliene Mota Pereira, Franciany Braga-Pereira, Luane Maria Melo Azeredo, Luiz Carlos Serramo Lopez, and Rômulo Romeu Nóbrega Alves. 2023. Assessing factors influencing students' perceptions towards animal species conservation. *PeerJ* 11 (2023), e14553.

[77] Angel Perez-Ruzafa, Concepción Marcos, and Javier Gilabert. 2005. *The ecology of the Mar Menor coastal lagoon: A fast changing ecosystem under human pressure*. CRC press, Boca Ratón, Florida, 392–422.

[78] Francesca Perillo, Marco Romano, and Giuliana Vitiello. 2024. *Enhancing Historical Understanding in School Students: Designing a VR Application with AI-Animated Characters*. Springer Nature Switzerland, 84–93. doi:10.1007/978-3-031-60606-9_6

[79] Kimberley Pressick-Kilborn, John Buchanan, and Damian Maher. 2018. Promoting Environmental Education for Primary School-aged Students Using Digital Technologies. *EURASIA Journal of Mathematics, Science and Technology Education* 15, 2 (Dec. 2018), em1661. doi:10.29333/ejmste/100639

[80] Pavol Prokop and Jana Fančovičová. 2013. Does colour matter? The influence of animal warning coloration on human emotions and willingness to protect them. *Animal conservation* 16, 4 (2013), 458–466.

[81] Gabriela A. Rangel-Rodríguez, Mar Badia, and Sílvia Blanch. 2021. Encouraging Emotional Conversations in Children With Complex Communication Needs: An Observational Case Study. *Frontiers in Psychology* 12 (July 2021). doi:10.3389/fpsyg.2021.674755

[82] Joana Roque de Pinho. 2016. Beautiful and ugly animals in Kenya Maasailand: why beauty matters for biodiversity conservation in Africa. *Progress 2-Ciências*

Sociais e Desenvolvimento em África (2016), 96–117.

[83] Dino Schweitzer and Wayne Brown. 2007. Interactive visualization for the active learning classroom. In *Proceedings of the 38th SIGCSE technical symposium on Computer science education (SIGCSE07)*. ACM, 208–212. doi:10.1145/1227310.1227384

[84] E Segel and J Heer. 2010. Narrative Visualization: Telling Stories with Data. *IEEE Transactions on Visualization and Computer Graphics* 16, 6 (Nov. 2010), 1139–1148. doi:10.1109/tvcg.2010.179

[85] Javier Senent-Aparicio, Adrián López-Ballesteros, Anders Nielsen, and Dennis Trolle. 2021. A holistic approach for determining the hydrology of the mar menor coastal lagoon by combining hydrological & hydrodynamic models. *Journal of Hydrology* 603 (2021), 127150. doi:10.1016/j.jhydrol.2021.127150

[86] Arman Shehabi, Alex Hubbard, Alex Newkirk, Nuoa Lei, Md Abu Bakkar Siddik, Billie Holecek, Jonathan Koomey, Eric Masanet, Dale Sartor, et al. 2024. 2024 United States Data Center Energy Usage Report. (2024).

[87] Dorota Siemieniecka, Wioletta Kwiatkowska, Kamila Majewska, and Małgorzata Skibińska. 2017. The Potential of Interactive Media and Their Relevance in the Education Process. *Psycho-Educational Research Reviews* 6 (12 2017), 1–10.

[88] Cláudia Silva, Catia Prandi, Nuno J. Nunes, and Valentina Nisi. 2020. Blue whale street art as a landmark: extracting landmarks from children's cognitive maps for the design of locative systems. In *Proceedings of the Interaction Design and Children Conference* (London, United Kingdom) *(IDC '20)*. Association for Computing Machinery, New York, NY, USA, 602–613. doi:10.1145/3392063.3394399

[89] Mara Solen, Nigar Sultana, Laura Lukes, and Tamara Munzner. 2024. DeLVE into Earth's Past: A Visualization-Based Exhibit Deployed Across Multiple Museum Contexts. doi:10.48550/ARXIV.2404.01488

[90] Lisa J Sonter and Desley J Jones. 2018. Drawing as a Tool to Support Children's Executive Functions in Play. *Art in Early Childhood* 1, 1 (2018).

[91] Andrew Stanciulescu, Fadi Castronovo, and Jesús Oliver. 2022. Assessing the impact of visualization media on engagement in an active learning environment. *International Journal of Mathematical Education in Science and Technology* 55, 5 (March 2022), 1150–1170. doi:10.1080/0020739x.2022.2044530

[92] Mike Stieff. 2017. *Drawing for Promoting Learning and Engagement with Dynamic Visualizations*. Springer International Publishing, Cham, 333–356. doi:10.1007/978-3-319-56204-9_14

[93] Kim-Pong Tam. 2014. Anthropomorphism of nature and efficacy in coping with the environmental crisis. *Social Cognition* 32, 3 (2014), 276–296.

[94] Gianni Tumedei, Chiara Ceccarini, and Catia Prandi. 2025. How are you, Mar Menor? Fostering Awareness About an Ecological Crisis through Children's Art and Conversational Generative AI. In *Proceedings of the Nineteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '25)*. ACM, 1–7. doi:10.1145/3689050.3705984

[95] Sveva Valguarnera, Cristina Maria Sylla, and Monica Landoni. 2022. Magic and Reality: what children's drawings tell us about their perception of technology. In *Proceedings of the 21st Annual ACM Interaction Design and Children Conference* (Braga, Portugal) *(IDC '22)*. Association for Computing Machinery, New York, NY, USA, 498–503. doi:10.1145/3501712.3535295

[96] Jose Domingo Villarroel and Iker Ros. 2013. Young Children's Conceptions of Rainfall: A Study of Their Oral and Pictorial Explanations. *International Education Studies* 6, 8 (July 2013), 1–15. doi:10.5539/ies.v6n8p1

[97] Ge Wang, Jun Zhao, Max Van Kleek, and Nigel Shadbolt. 2022. Informing Age-Appropriate AI: Examining Principles and Practices of AI for Children. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 536, 29 pages. doi:10.1145/3491102.3502057

[98] Zijie J. Wang, Robert Turko, Omar Shaikh, Haekyu Park, Nilaksh Das, Fred Hohman, Minsuk Kahng, and Duen Horng Polo Chau. 2021. CNN Explainer: Learning Convolutional Neural Networks with Interactive Visualization. *IEEE Transactions on Visualization and Computer Graphics* 27, 2 (Feb. 2021), 1396–1406. doi:10.1109/tvcg.2020.3030418

[99] Philip Waters. 2011. Trees Talk: Are You Listening? Nature, Narrative and Children's Anthropocentric Place-Based Play. *Children, Youth and Environments* 21, 1 (2011), 243–252. http://www.jstor.org/stable/10.7721/chilyoutenvi.21.1.0243

[100] Nancy M. Wells and Kristi S. Lekies. 2006. Nature and the Life Course: Pathways from Childhood Nature Experiences to Adult Environmentalism. *Children, Youth and Environments* 16, 1 (2006), 1–24. doi:10.1353/cye.2006.0031

[101] Marc O. Williams, Lorraine Whitmarsh, and Diarmait Mac Giolla Chríost. 2021. The association between anthropomorphism of nature and pro-environmental variables: A systematic review. *Biological Conservation* 255 (2021), 109022. doi:10.1016/j.biocon.2021.109022

[102] Zheng Zhang, Ying Xu, Yanhao Wang, Bingsheng Yao, Daniel Ritchie, Tongshuang Wu, Mo Yu, Dakuo Wang, and Toby Jia-Jun Li. 2022. StoryBuddy: A Human-AI Collaborative Chatbot for Parent-Child Interactive Storytelling with Flexible Parental Involvement. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 218, 21 pages. doi:10.1145/3491102.3517479

[103] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '07)*. Association for Computing Machinery, New York, NY, USA, 493–502. doi:10.1145/1240624.1240704

[104] Zeynep Çetin and Nimet Güneş. 2019. Drawing as a means of self-expression: a case study. *Early Child Development and Care* 191, 1 (April 2019), 136–147. doi:10.1080/03004430.2019.1608195