

Designing Augmented Reality Learning Experiences for Environmental Education in Afterschool Programs

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This design case describes the design of a workshop that utilized augmented reality (AR) resources to promote environmental education (EE) among young learners in a local afterschool program. The project was motivated by the need to leverage the flexible and extensive reach of afterschool programs to spread environmental awareness to young learners from underserved communities through indoor EE activities. We describe the design process, emphasizing key design decisions, unique challenges, and observed outcomes from the workshop. We conclude by discussing key takeaways and practical implications for various stakeholders.

Introduction

Environmental education (EE) is currently incorporated into the K12 curriculum to promote awareness of environmental issues and foster pro-environmental behaviors among young learners (Ardoin & Bowers, 2020). However, students are unable to perceive the relevance of environmental issues to their personal lives or establish meaningful connections between what they learn in class and the real world when such educational efforts are confined to formal classroom environments (Kinslow et al., 2019). Consequently, EE activities should be extended to informal learning environments to help learners recognize the impact of environmental issues on their lives and society (Ducasse, 2020; Kim & Dopico, 2014). Conducting EE in informal contexts is also useful for engaging young learners from diverse backgrounds and underserved communities, essential for fostering the local and collective action needed to successfully address environmental issues such as biodiversity loss, climate change, and environmental pollution (Rickenbacker et al., 2019).

In this regard, informal environments like afterschool programs are particularly strategic for promoting EE activities because they cater to individuals from diverse backgrounds and allow learners to engage with environmental issues in a more flexible learning context (Bruyere et al., 2012). Ideally, EE activities in afterschool program settings should occur in outdoor nature-rich environments. However, accessing nature-rich environments can be challenging, especially in urban areas, while logistical and resource constraints hinder the planning of such outdoor activities (Ham and Sewing, 2010; Hanna, 1992). Moreover, parents consider afterschool programs a safe space for their children to engage in productive learning activities while they are at work, and there might be concerns about the safety of children, especially younger ones, in outdoor environments (Hanna, 1992). Thus, there is a need for indoor EE alternatives especially in informal learning environments.

Innovative technologies like augmented reality (AR) have great potential for promoting informal indoor EE experiences. AR's affordances and benefits for EE are well documented such as improving learners' understanding of environmental concepts, enhancing scientific reasoning skills, and fostering clear communication about environmental issues (Ducasse, 2020; Huang et al., 2016). Moreover, AR is recommended as a great fit for learning in informal settings such as summer camps and afterschool programs (Ducasse, 2020; Korenova et al., 2023; Zimmerman et al., 2015). Additional examples of their application for indoor EE activities within such informal environments are needed.

Recognizing the importance of informal EE and AR's potential for delivering indoor experiences, a team of educational researchers collaborated with a local afterschool program to implement a workshop using AR resources that provided indoor EE experiences to young learners from diverse backgrounds. In this paper, we present a reflective account of the design process for the workshop, highlighting key decisions, challenges, and outcomes. Our reflection on the design process will highlight key design considerations that can serve as useful precedents to guide the design of AR resources for informal EE experiences.

Background and Design Team Makeup

Our project was conceptualized against the backdrop of a service grant call from a Diversity Fellow at a large Midwestern University which had a broad focus on 'making connections, building community, engagement, and advocacy for diversity, equity, and inclusion in partnership with two local non-profit organizations^[1] –X Education and Y Center". Located in the County home to a large Midwestern University, both X Education and Y Center provide afterschool program activities for children in the local community and collaborate occasionally on programs. While X Education is primarily focused on engaging young talent in experiential learning experiences, Y Center has a broader objective of nurturing the well-being of young individuals in the local community and preserving the cultural heritage of minority populations through programs that improve their quality of life.

At the time of the project, three team members were international doctoral students in the Learning Design and Technology program at the university, while the fourth team member is a professor in the same program. All team members were familiar with designing experiential learning experiences having previously worked on related projects. One member of the team had previous experience in digital storytelling research projects. Another team member had a background in environmental science

and had previously worked on various projects related to environmental sustainability education. The third member of the team had previously worked as an instructional designer.

Design Process and Key Decisions

Design Challenge

In this project, we encountered unique challenges that lend themselves to the subject of a design case. First was the challenge of designing indoor EE experiences, which are usually more immersive and authentic in outdoor environments because students can directly observe and engage with environmental phenomena (Mullenbach et al., 2019). The team understood that replicating such experiences indoors can be challenging considering the need for multisensory stimuli to give the learners a sense of being in a natural environment. Moreover, we recognized that designing informal science learning experiences, such as EE, requires consideration of the unique characteristics of informal learning environments which can differ along a spectrum from formal environments. For instance, informal learning environments are usually more relaxed and flexible, and learners have more autonomy and control over what they learn (Bell et al., 2009). In addition, afterschool programs vary in structure and often serve diverse audiences, including individuals of different ages, backgrounds, academic abilities, and prior knowledge of EE (Bell et al., 2009). The multidimensional goals of EE which span, cognitive, affective and behavioral aspects (Buchanan et al., 2018) also raise questions about potential design considerations that capture each aspect effectively. Hence, the team was faced with the following design challenges: designing indoor immersive and authentic EE experiences; designing experiences that align with informal environments; meeting the needs of a diverse learner audience; and ensuring that design outcomes encapsulate the multidimensional goals of EE.

Context and Learner Analysis

The team visited X Education and Y Center to familiarize themselves with the context and to understand the potential audience for the project. During the visit, we discussed the project with key personnel, took pictures of the learning environment, and journaled our observations of the students, instructors, and learning activities. In addition, we briefly interviewed one of the staff members who was familiar with both X Education and Y Center to understand the dynamics of both settings, as well as the backgrounds and characteristics of the learners. A summary of the observations from the visit is presented in Tables 1 and 2.

After the visit, the team decided to implement the workshop at Y Center because its mission aligned with the diversity focus of the grant, and it catered to children from diverse backgrounds who, unlike the children at X Education, met the profile requirements for the project. Moreover, these students had less access to technology-oriented experiences than the students at X Education. Hence, the team decided that a secondary objective of the workshop would be to provide opportunities for the children at Y Center to explore new technology in addition to environmental education activities.

Table 1

Context Analysis

	X Education	Y Center
Type of Activity	Activities were more technology-oriented, e.g., robotics, Minecraft coding, etc.	Students spent most of their time completing homework. Opportunities to engage students in extracurricular activities arise when there are volunteers.

Space	There are two small rooms with a capacity of 10 each.	There are two rooms: a larger room with a capacity of 24 and a smaller room with a capacity of 10.
Staff-Student Ratio	The observed ratio was 3:10	The observed ration was 3: 20
Program structure	Sessions start around 4 pm and end by 5.30 pm. Planned activities occur within a 45–60-minute time frame.	Students arrive at 3pm. Sessions start around 4 pm and end by 5.30 pm. Planned activities occur within a 45–60-minute time frame. Students have snack breaks. There are also opportunities for activities based on the availability of volunteers.
Facilities	There were tables, laptops, internet access, a television set, robotics kits, and VR headsets.	There were a few iPads, tables, internet access, and a television set.

Table 2

Observations of Learner Characteristics Across X Education and Y Center

Learner Analysis	
Age/Educational Level	6-10 years (Elementary and early middle school students)
Demography and Background	Y Center had greater ethnic and racial diversity than X Education. Some students at Y Center also come from lower socio-economic backgrounds.
Personalities and dispositions	Students were lively, energetic, and chatty. They appeared to have a short attention span and moved around a lot. They mostly interacted with peers, except for a few reserved ones. • X Education students appeared better self-regulated than those in Y Center. • Staff revealed that students at Y Center demonstrated greater enthusiasm for learning and loved engaging in hands-on activities.
Technology proficiency	Most students were observed to be proficient technology users based on their engagement with the resources. However, a few of them appeared to need more guidance in using some of the tools.
Communication skills	Most students communicated proficiently in English. We did not observe anyone experiencing language difficulties at this point.
Collaboration	Although some students generally kept to themselves, most were willing to discuss and collaborate with their peers during projects and activities.

Defining Learning Objectives and Project Scope

In addition to the overarching goal for the project, we also defined our specific learning objectives for the workshop. Our goal was to promote environmental awareness among children at Y Center and provide opportunities for them to explore new technology. Based on our observation of the students' ages, we decided to focus on providing a foundational knowledge of environmental sustainability and conservation, with specific reference to three main areas: 1) characteristics of the environment, 2) the importance of the environment and the need for its conservation, and 3) environmental conservation through waste management. These were further decomposed into five learning objectives (see Table 3). We tailored the learning objectives for 6-to-10-year-olds, based on our observations of the learners at Y Center. We wanted the learning activities to be delivered in a way that would help the learners perceive the importance of the environment to their personal lives and prompt them to take action towards its conservation. Consequently, we framed the workshop around the [Z Bog](#), a local wetland habitat in the County. We recognized that although the students might have heard about the Z Bog, not all would have visited it or understood its important ecological functions. The team also believed that recycling and waste management were conservation practices that 6- to 10-year-olds would easily relate to. Having defined the learning objectives, the team also outlined the sequence of activities. Because the program structure at Y Center allowed us to meet with the students for only 45 minutes to 1 hour, we decided to organize a workshop consisting of three one-hour sessions that would be held on separate days. Moreover, the team considered the possibility that there would be students who could not attend all three sessions, and we needed to brainstorm strategies to address knowledge gaps resulting from such situations. We resolved to design the sessions so that each one could run independently while providing a recap of the previous session at the start of each new session.

Assessments

To understand the effectiveness of the workshop sessions, the team decided to engage learners in various forms of assessment aligned with the learning objectives. We were cognizant of the complexities around conducting assessments in informal learning environments given the limited effectiveness of formal assessment strategies, their incompatibility with the unstructured nature of activities, and possible interference with learning intentions (Bell et al., 2009). With this in mind, and drawing on constructivist principles, the team selected less formal assessment strategies that students could engage with in a fun way. Although we used a paper-based worksheet, we gamified how students were to complete them. Instead of text-based assessments, we provided an alternate way for students to visually represent their knowledge and ideas through a sketching activity. We also decided to observe the students keenly and record our observations for each meeting.

Table 3

Workshop Focus Areas and Learning Objectives

Session	Focus Area	Learning objectives	Assessments
1.	Characteristics of the environment	Describe wetland habitats	Gamified 'Habitat Bingo' assessment and observations
		Identify flora and fauna in wetland habitats.	Gamified 'Habitat Bingo' assessment and observations
2.	The importance of the environment and the need for its conservation	Describe the value of wetlands to humans and their ecological functions	Sketching activity and observations
		Recognize the impact of human activities on wetland habitats through pollution	

3	Environmental conservation through waste management	Describe effective waste management strategies (Recycle and reuse)	Waste sorting activity Observations
		Identify and sort waste material into different recyclable, reusable, and landfill categories.	Would you rather – Gamified assessment and observations

Choice of Technology

Beyond promoting environmental awareness, a secondary objective of the workshop was to provide opportunities for students from underserved communities to engage with modern technologies. It was therefore important to consider the specific technology that would support our learning objectives and provide novel learning opportunities for the students early in the project. Since we had decided to build the workshop around the concept of wetlands, we needed to identify technologies that would provide some degree of immersion while allowing hands-on exploration and engagement. For example, we believed that while a video of a wetland could effectively convey information about its features and functions, it would fall short of meeting the immersion requirements and would not provide the hands-on learning experience we wanted.

The team decided to explore extended reality technologies, specifically virtual reality (VR) and augmented reality (AR). We considered both options suitable for the workshop based on evidence of their successful deployment for EE activities in literature (Fauville et al., 2020; Huang et al., 2016). After considering various factors for both VR and AR, the team opted for AR for several reasons. First, AR represented a more feasible option for the project in light of limited project resources and the cost of VR headsets. Moreover, although VR would have offered a more immersive and entertaining experience (Huang et al., 2019), we preferred that the students should have a more context-aware experience despite AR's limited immersion. In this project, partial immersion was particularly important not only for accessibility considerations but also for safety reasons given the limited classroom space at Y Center and evidence of VR's potential adverse effects on young learners (Tychsen & Foeller, 2020). Since afterschool programs are considered a safe space for learners, the last thing we wanted was for the children to get injured from collisions with one another or objects in the room due to the full immersive properties of VR.

Moreover, besides being accessible on various mobile devices, we believed that AR offered flexibility in line with the mood and "spirit" of informal learning environments such as afterschool program settings (Bell et al., 2009). In other words, students could learn and engage with the content in a more relaxed manner, having greater autonomy and control over their learning by moving around and interacting with both AR learning elements and their peers (Salmi et al., 2016). Evidence from the literature also supports the successful deployment of AR for enriching EE activities for young learners in both formal and informal learning environments, with benefits such as enhanced interest, engagement with scientific concepts, self-regulation, and greater collaboration between learners (Arici, 2024; Ladykova, 2024; Salmi et al., 2016).

Consequently, we proceeded to use AR for the workshop, despite the tradeoffs in immersion, engagement, and excitement compared to VR. Similar considerations guided the selection of specific AR resources as the team chose to explore AR platforms that offered free or trial versions. Although the team initially prioritized the representational fidelity of the designs, time and budgetary constraints as well as the limited skill within the team impinged on our ability to proceed with the initial plans. Our best bet to deliver the workshop within the short time frame was to explore AR platforms with pre-built assets that offered simple and intuitive interfaces as well as drag-and-drop functionality with very little technical skill requirements. As expected, this decision would come with trade-offs related to the level of fidelity and immersion of some of the AR experiences.

Table 4

Brief Description Of AR Platforms Used Across Workshop Sessions

Session	Name of AR Tool/Platform	Description of Platform	Purpose/Use in Session
1	AR Makr	• AR MAKR is available on the Apple App Store. • It can be used to create simple AR experiences. • 2D and 3D objects can be sourced from the app's asset library or external sources to create AR scenes.	This was used to design the wetland for the treasure hunt activity. (See Figure 2)
2	Sketchfab and Free 3D	• Sketchfab and Free 3D are platforms for 3D models. • Users can upload, view, and share 3D models and scenes. NB: Sketchfab supports AR viewing, while Free 3D does not. • 3D content can be embedded on websites or accessed through QR codes.	We sourced various 3D models from these platforms and embedded them on a website. Students accessed the models through QR codes generated from the website. (See Figures 3 and 4)
3	ARLOOPA	• ARLOOPA is an AR and VR app. • It is used to create interactive, content-rich experiences. • The app includes an AR scanner, 3D models library, feed, and map. • It can be used to create marker-based, markerless, and location-based experiences.	ARLOOPA was used to create image-activated videos of various waste materials.

Theory-Guided Selection of Design and Pedagogical Strategies

Our selection of design and pedagogical approaches for the workshop was informed by our knowledge of learning theories along with considerations of the learning objectives and information from the analysis. As previously mentioned, environmental education embraces a broad set of goals incorporating cognitive, affective, and behavioral dimensions. Although most of our learning objectives focused on cognitive outcomes, we wanted a compelling delivery of the content to arouse students' interest and foster positive attitudes towards the environment. We also considered age-appropriate strategies for the audience aligned with the flexible structure of the afterschool program setting. Moreover, we were careful not to prioritize the AR technology over selecting an appropriate pedagogical approach, even though our secondary objective for the workshop was to engage students with new technologies. This meant that the AR technology would only enhance and optimize our chosen engagement strategies for the workshop.

We grounded our design of the workshop resources and pedagogical approaches primarily in constructivist principles, considering informal learning environments as fluid spaces where learners navigate freely with little guidance (Bell et al., 2009). Constructivism emphasizes the learners' active role in constructing new knowledge from prior experiences through meaningful and authentic contexts (Bada & Olusegun, 2015). Constructivist learning environments encourage learners to take ownership of their learning and provide opportunities for collaboration (Bada & Olusegun, 2015). The team believed that constructivist principles are well-suited to informal learning environments like afterschool programs, given the focus on active engagement and learner autonomy. Moreover, AR aligns with constructivist approaches by embedding learning tasks within meaningful and authentic contexts, fostering active exploration, and granting learners control and autonomy over their learning (Abdoli-Sejzi & Bahru, 2015; Goff et al., 2018). Having established an appropriate theoretical grounding, we brainstormed on the appropriate pedagogy and engagement strategies for the workshop.

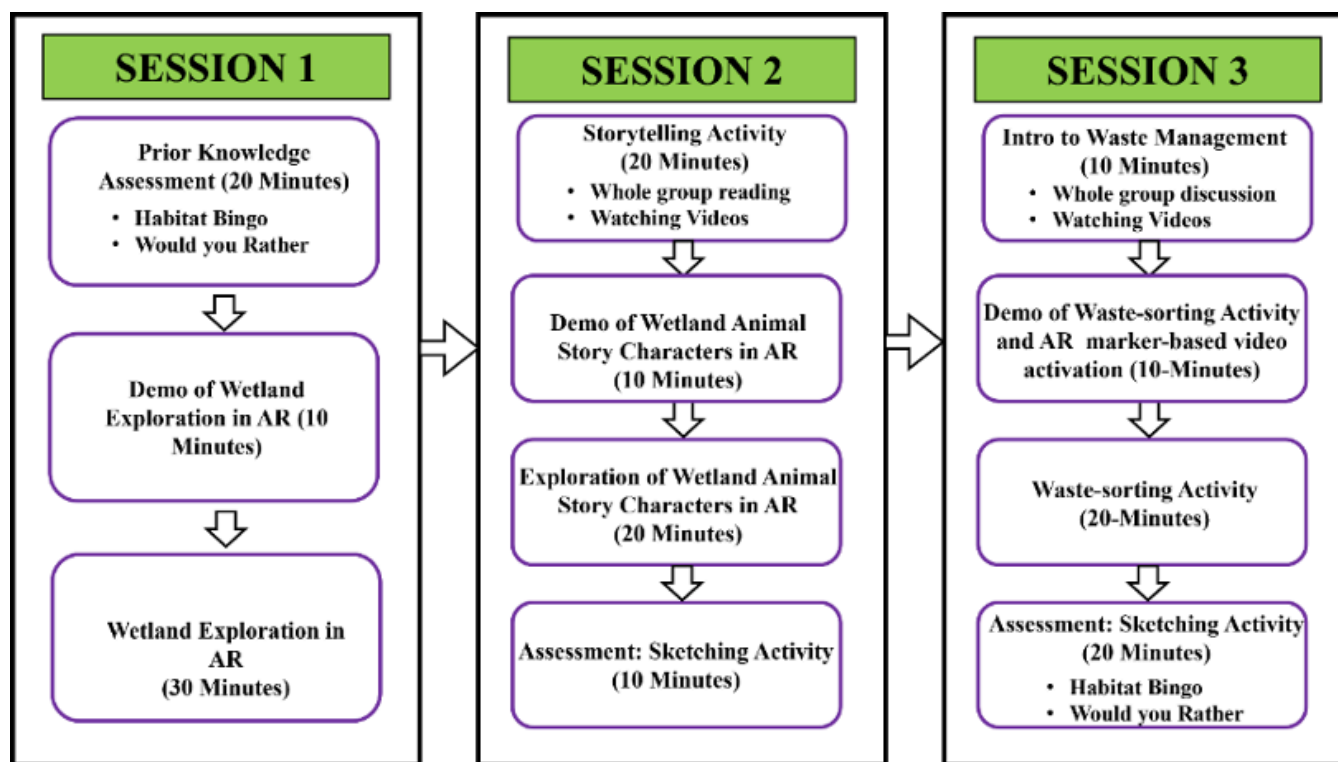
In the first session, we decided to engage learners in a treasure-hunt-styled activity designed to help them explore and identify wetland fauna. Through this activity, learners were to be immersed in an authentic wetland context where they could actively explore and interact with the different fauna, constructing new knowledge in the process. Constructivist principles also guided our choice of a storytelling approach in the second session, which aimed to familiarize learners with key concepts, such as wetland fauna and functions, and the negative impact of human activity on wetland habitats. These concepts were framed within the story narrative and illustrated in a relatable manner so that the learners could connect them to their personal experiences, as encapsulated in constructivist principles (Palmer et al., 2001). AR technology was employed to enhance the story experience for the learners by bringing the events and characters from the story to life. The sketching activity was designed to complement the storytelling activity, in line with constructivist principles, by providing learners with opportunities to reflect on and represent their knowledge of solutions to wetland pollution challenges in diverse ways, drawing on their prior knowledge (Reutzel & Cooter, 2020). The collaborative waste-sorting activity in the third session was designed to incorporate the social dimensions of constructivism by engaging learners in knowledge co-construction through a sequence of goal-directed interactions with peers (Cummings, 2001). Constructivist principles also informed other engagement strategies implemented across all three sessions, such as whole-group discussions at the start of each session, where general instructions were communicated interactively. However, it is noteworthy that the learning activities were not entirely constructivist; for example, assessments that utilized gamified approaches had a stronger behaviorist leaning. Nevertheless, a majority of the selected strategies were grounded in constructivism.

Design and Implementation Considerations for Workshop Sessions

Before designing the workshop resources, the team visited the Z Bog to familiarize themselves with wetlands and study their educational materials. We took pictures of the bog, including the vegetation, flora, and fauna, as well as water levels to help us recreate the experience in AR. We then proceeded with designing the workshop activities. Figure 1 shows the flow of activities within and between sessions.

Figure 1

Flow of Workshop Learning Activities Within and Across Sessions.



Session 1

In the first session, we designed assessments to evaluate students' prior knowledge of habitats, wetlands, and waste management. These assessments were administered through gamified worksheets featuring *Habitat Bingo* and *Would You Rather* games. The *Habitat Bingo* game assessed students' knowledge of animal habitats, and bingo patterns were formed on the worksheets if correctly identified. The *Would You Rather* game evaluated students' decision-making around waste management. For instance, one question asked, "When you go out, would you rather (A) carry a reusable water bottle from home, or (B) buy a single-use water bottle outside?" We incorporated gamified assessments because we wanted the process to be interactive and fun, and to feel less like regular schoolwork.

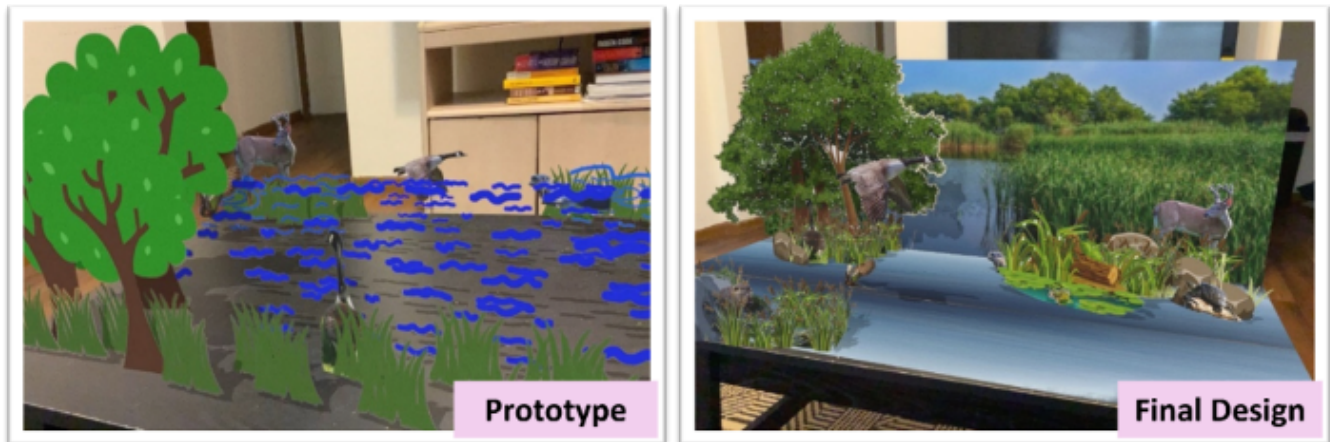
After the prior knowledge assessment, we wanted the students to engage in a hands-on wetland exploration activity in AR through a treasure hunt activity. We designed the wetland environment in ARMAkr, a free AR app available on IOS devices, and we chose this app for the earlier described reasons, such as its simplicity and intuitiveness. The design of the wetland went through several iterations. First, one team member created a prototype of the wetland in ARMAkr using hand-drawn images to illustrate wetland features such as water and plants. The team met to review the prototype and suggested improvements, including replacing the hand-drawn elements with more realistic images, maintaining a consistent level of fidelity for all images and objects in the environment, and rearranging the placement of wetland flora and fauna for visibility and ease of identification.

Subsequent iterations featured some of the images from the Z Bog as well as some pictures under the Creative Commons license on Freepik, an online platform that provides a range of graphic resources. We depicted wetland fauna, e.g., deer, beaver, otters, duck, frog, geese, and bees, so that they were slightly hidden but still visible enough for students to discover them through a treasure hunt-style activity. The AR environment was designed to allow students to go closer to a specific part of the wetland to view that part more closely by walking or moving across the classroom with the iPad in their hand. It also allowed students to change the orientation or angle of view by tilting the iPad in different directions enabling them to get a variety of views (top view, bottom view, side angle view) of any element of the wetland. This gave students an immersive experience of

being in a wetland environment and observing it closely within their classroom environment. We also took advantage of the shadow effect in ARMakr app to provide a more authentic view of the environment. Figure 2 shows the prototype and final design of the wetland environment used in the session. After finalizing the design of the wetland environment, we proceeded to test our design (along with designs for sessions 2 and 3), first in an office space, and subsequently at the workshop venue in Y Center. During the testing phase in Y Center, we discovered that the wetland environment in the ARMakr app could not load on the iPad models at Y Center because their cameras were unable to detect flat surfaces. This meant that we could not use the iPads Y Center provided, and we needed to source alternative iPads compatible with the design.

Figure 2

Prototype and Final Designs of Wetland Environment in AR



Note. Images of wetland and animals and plants were designed by Freepik, n.d. www.freepik.com

Session 2

The goal of the second workshop session was to highlight the importance of wetlands and provide a rationale for their conservation. We decided to use a storytelling approach because we believed it would make the information more relatable to the students. We started with a vision of creating the story with 3D animations which students could access through AR by scanning codes. One team member created a prototype using Hololink, a platform with an AR editor for generating 3D animations. The prototype was a wetland flood control simulation demonstrating how wetlands absorb water to prevent flooding. However, we encountered several challenges including limited 3D model options for wetland animals and plants and challenges with creating and modifying existing models to align with wetland themes. Moreover, the team considered the loading times for the 3D animations too long, considering the internet speed at Y Center. Having observed students' short attention spans during the visit to Y Center, we believed the long loading times would negatively impact students' experiences.

After several consultations and brainstorming sessions, we decided to make several design adjustments. Instead of 3D animations, we designed two short videos in Articulate Storyline using 2D animations to demonstrate wetland functions. We then created a print storybook that featured wetland fauna as the main characters. To enhance the storytelling experience, we incorporated 3D models of the story characters so that students could view the animals in closer detail. We sourced the 3D models from Free 3D and Sketchfab, which are websites for 3D object assets. To prevent long loading time issues, we selected low-poly 3D models. We leveraged the in-built AR visualization system in IOS devices and embedded QR codes into the storybooks so that students could access and view the 3D models directly after scanning without needing to download external software. Hence, the experience was limited to IOS devices. Figures 3 and 4 show the prototype and final designs for session 2 and the resources linked to the QR codes.

Figure 3

Prototype and Final Design of First Day in Wetland Storybook with QR-codes

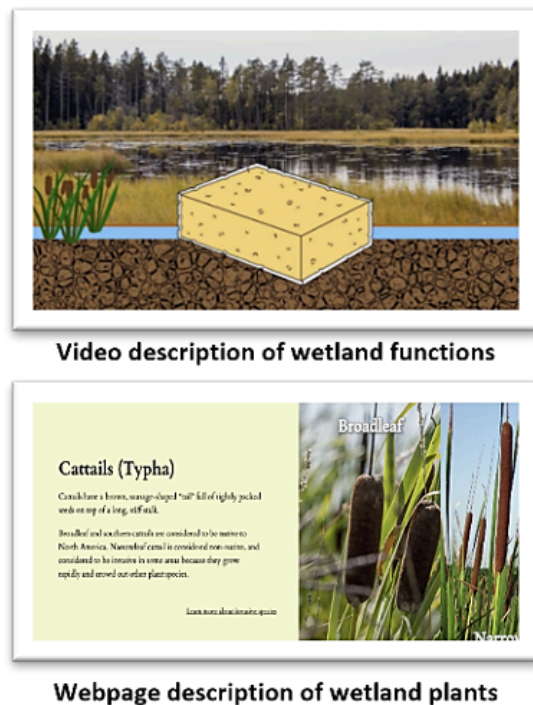


Prototype in Hololink

Pages from the final design of the storybook embedding QR codes to videos, webpage, and AR

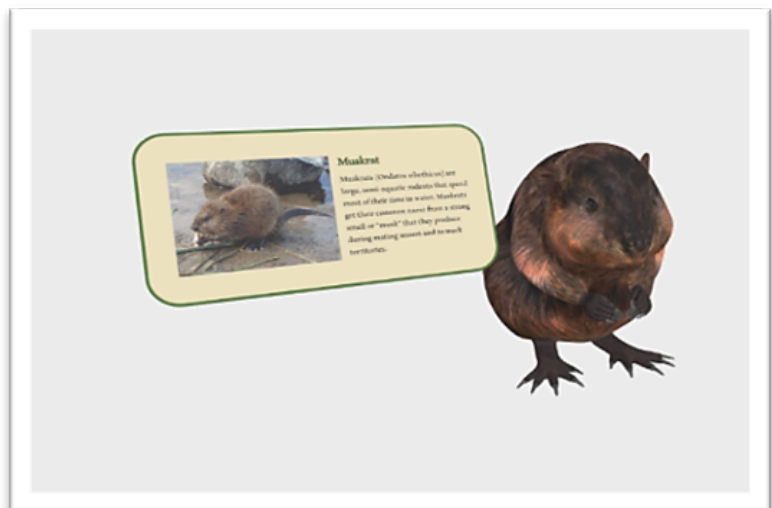
Figure 4

Resources Linked to QR Codes



Video description of wetland functions

Webpage description of wetland plants



3D models of wetland animals (Muskrat) in AR with description in a callout box.

Note. From North American Muskrat [3D Model], by Printable_Models, 2019, Free3D, <https://free3d.com/3d-model/northamericanmuskrat-v1--257204.html>

Session 3

Our team recognized that moving from wetland characteristics and functions to environmental conservation could pose a significant conceptual leap for the students, and it was important to ensure a smooth transition. To address this, we

connected the wetland story narrative from the previous session to the conservation theme. In the story, the human invitees to the wetland party had littered the environment, and the wetland fauna needed to conserve their precious habitat by dealing with the mess humans had created. This provided a segue into the concept of waste management and sorting, the theme for the third session. The third session consisted of two parts: 1) an initial session describing environmental conservation strategies such as waste management and 2) a plenary session where we assessed what students learned from the workshop.

We designed the third workshop session to start with a video describing the importance of environmental conservation through effective waste management practices. Given time constraints, the team opted to select a suitable introductory video on waste management and recycling from YouTube instead of creating one from scratch. When selecting the video, we considered its alignment with the learning objectives, content accuracy, engagement value for younger learners, and short runtime. To help learners contextualize and apply the information from the video to their personal lives, we designed a card-based waste-sorting activity using Learn-To-Recycle Activity Boxes sourced from Amazon. Each box contained several card-based illustrations of various household waste items, along with six boxes representing various waste categories: plastic, cardboard, paper, compost, aluminum, and glass categories. Students were expected to sort the waste items on the cards into their respective categories or boxes. To provide students with information about the waste categories, we created six informative videos, each describing a specific waste category and its recycling process. These videos were 3-minute long and featured illustrated characters from the boxes describing each waste category. We hosted the videos on YouTube, generated QR codes for each of them, and placed the QR codes on their respective waste category boxes so that students could scan them.

We had some time to re-evaluate and redesign the workshop activities for the third session, based on our observations from the first and second sessions. We maintained the introductory waste management and recycling video sourced from YouTube which was to be viewed at the start of the workshop. Instead of focusing the waste-sorting activity only on categorizing the different types of recyclable waste (plastic, cardboard, paper, compost, aluminum, and glass), we expanded the activity, so that students could categorize various items based on whether they could either be recycled, reused, or trashed in landfills. Having observed students' interactions with the learning activities in the first session, we decided that the 3-minute videos would not provide the information students needed to sort the cards efficiently, because they would need to memorize the content for each of the six 3-minute videos. We also considered that since the 3-minute informative videos were hosted on YouTube, there was a possibility that the algorithm could generate video recommendations that could distract some of the students.

Based on these observations and considerations, we made modifications to the initial design of the waste-sorting activity for the third session. First, we created additional cards to represent reusable items, (e.g., fairly-used shoes and jackets, and water bottles), and landfill waste, e.g., grease-stained pizza boxes, since these did not come with the original boxes from Amazon. The redesigned waste sorting activity now involved two components: 1) deciding whether each waste material should be recycled, reused, or sent to the landfill, and 2) if recyclable, identifying its specific category, e.g., plastic, glass, etc. To aid students' decision-making during the waste-sorting activity, we provided the physical versions of the different materials, e.g., a greasy pizza box, empty soda can, used jacket, etc., and positioned them around the classroom so that the students could see and feel the real versions of the materials they were going to be sorting. Next to each physical item, we placed image-based AR markers which when scanned, activated video snippets of the items as embodied agents. For instance, an image of an aluminum can was transformed into an AR marker and placed close to the physical aluminum can. When scanned with the iPad, the AR marker would display a short video snippet of the aluminum can as an embodied agent, saying: "Hi! I am made of aluminum, and you can recycle me." After watching the video snippet of the aluminum can, students would return to their seats to sort the aluminum can card into the aluminum recycle box, repeating the process for the rest of the cards. We created the AR-marker-activated snippets using ARLoopa, an app for visualizing AR experiences. The advantage of this approach was that students could quickly get the information they needed from the videos instead of watching and having to memorize the information from a 3-minute-long video. Moreover, students could view the videos directly on ARLoopa, and we no longer needed to worry about potential distractions from the YouTube video recommendations. Figure 5 shows the initial and final video designs for the waste sorting activity. The placement of the physical objects around the class was done to encourage

movement in the informal environment, and students did not need to sit in one spot while doing the activity. After completing the waste-sorting activity, we planned a plenary to wrap up the entire workshop and administer the same gamified worksheets students had engaged with during the first session.

Figure 5

Initial and Final Video Designs for Waste-Sorting Activity



Note. On the left the initial design of QR code-activated videos hosted on YouTube with illustrated characters describing the waste categories. On the right is the final design of AR marker-activated video snippets with waste materials designed as embodied agents.

Design Outcomes and Observations

For each workshop session, one team member would serve as the main facilitator, while the others would assist the students as they engaged with the activities. All team members noted their observations during each session. The team met after each session to discuss their observations. In this section, we provide a synthesis of our observations and summarize the main outcomes of the design across the three sessions.

Observed Cognitive and Affective Learning Outcomes

At the start of the workshop, very few students had heard about wetlands, and only a few knew about their characteristics. After the last session, students were generally more knowledgeable about wetlands and some students could provide examples of wetland animals. Students' comments during the workshop indicated that they had become more cognizant of human-induced environmental challenges, e.g., pollution, and the need for conservation. For instance, one student expressed their frustration with how humans littered the wetland environment after they had been invited to the wetland party. Moreover,

our conversations with students during the waste sorting activity, and some of their responses to the Would you Rather game, suggest that more students had become aware of the concept of recycling and the importance of making proper waste management decisions regarding which waste should be recycled, reused, or discarded. However, not all students could remember important details from the workshop, especially the younger ones. Beyond cognitive outcomes, we observed instances where the learning experience evoked affective responses from the students. In the second session, for instance, some students appeared to have developed some affinity with the wetland animals while playing and interacting with them in AR. Students also vented their frustration with humans after learning how they had littered the wetland after the party in the story.

Students' Enthusiasm, and Engagement with Learning Activities

Students appeared excited and enthusiastic about learning resources and activities in all three sessions. There were regular exclamations of amazement from the students, particularly in the sessions where wetland animals were revealed through AR. In the second session, for instance, one student shouted, "Wow, that's so cool!" when the animal images popped up after scanning the QR code in the storybook. With the AR resources, the students were particularly excited about the ability to "drop" and interact with the content on various surfaces and in different parts of the classroom. Students were also excited when they saw the recycling boxes in the third session and were enthusiastic about engaging in the card sorting activity. The students also appeared to be engaged with the learning activities in all three sessions. In the first session, where students explored the wetland in AR through a treasure-hunt-styled activity, many students appeared completely immersed while searching for the animals in the wetland. Most students listened with keen interest and attention while reading the wetland story and watching the videos in the second session. We also observed high engagement levels in the third session as well, as students actively participated in the waste-sorting activity, moving around the classroom to scan the AR markers and watch the video snippets.

Flexibility and Learner Autonomy

Although the sessions were designed with some structure in mind, we observed some flexibility and autonomy in the way students navigated the experiences. In the first session, for instance, some of the students could be observed redesigning the wetlands in the ARMaker apps using the assets from the app's library, e.g., one student was observed adding more frogs. There was also some flexibility and autonomy in the way students explored the wetland by moving around the classroom to "drop" and interact with the experiences on their preferred surfaces or spots. During the card-based waste-sorting activity, students used different strategies to categorize the items. While some students preferred to scan and watch the video snippets for multiple items in the room before returning to their table to sort the cards, others chose to do it one item at a time. Some students were observed returning to the objects to re-scan and watch the snippets again if they had forgotten the information or were confused.

Cross-Age Tutoring and Collaboration

During all three sessions, we observed several instances of collaboration between students, including sharing personal stories or experiences related to the activities, providing suggestions or opinions on the issues being discussed, assisting peers in resolving device-related challenges, correcting mistakes or misconceptions, and working together to complete the waste-sorting activity. Although most of the collaboration occurred between peers of similar age, we also observed instances where the older students were either teaching the learned content to the younger ones or guiding them through the activities. Thus, some of the older students helped the workshop sessions run smoothly.

Metacognitive Strategies

In all three sessions, students employed various metacognitive strategies to regulate and control their learning and to connect learned material to their personal experiences. The most commonly observed strategies included think-aloud techniques, critical questioning, and reflective analysis. It was very common for the students to verbalize their thoughts while performing activities or making task-related decisions. During the wetland exploration activity in the first session, for instance, one student wondered aloud if the wetland animals they were being introduced to were dangerous. Similarly, some students attempted to clarify tensions in their understanding by asking critical questions. For instance, during the waste sorting activity, students questioned whether a grease-stained pizza box should be recycled with cardboard or trashed into a landfill. Some of the students' questions also suggested that they were considering the implications of their choices on their personal lives, e.g., one student noted "Does that mean more work for doing the dishes if we choose reusable bottles?" Students also made comments that indicated a careful and reflective analysis of the discussed topics, e.g., one student noted how reusable bottles represented a more cost-effective option, while another suggested that orange peels could either be recycled as compost or trashed into the garbage bin. We were also encouraged to see how students were reflecting on the impact of human activities on the environment, as one student expressed their frustration, saying, "Why can't they clean up? The trash can is right there!"

Challenges Observed During Sessions

Across the three sessions, several challenges were observed that impacted students' experiences in the workshop. Some of the challenges were a result of design decisions, while others pertained to contextual factors. One major challenge was the variable pick-up time at Y Center which interrupted the learning experience for some of the students, as they could not participate in the full range of activities. This also affected students' ability to make connections between the sessions despite efforts to mitigate such occurrences. As with many projects involving technology, we encountered our fair share of technical difficulties during the workshop sessions. Despite the decision to select short videos and use low-poly 3D models, there were still challenges with long loading times. Moreover, some students found scanning the AR or QR codes difficult because the iPads were too heavy, or the AR code images took too long to trigger the animated snippets. Students with short attention spans were visibly frustrated or impatient when the AR experiences took too long to load. They also appeared to prefer learning activities involving digital resources over traditional methods (e.g., whole-class discussions) or paper-based tasks (e.g., worksheets and sketching). This had a negative impact on some of the assessments as some students appeared to "tune off" and did not appear fully engaged. Although we designed the workshop to encourage flexibility and movement, we observed that some aspects of the sessions were a little rowdy, particularly in the third one, as students needed to move back and forth to scan several objects and watch the videos for the card sorting activity.

Reflection and Key Takeaways

With the support of a diversity-focused service grant, our team organized and implemented a three-session environmental education workshop in collaboration with a local afterschool program. Our goal was to promote environmental awareness among children from diverse and underserved communities through indoor EE activities. Although we generally accomplished the grant's objectives, our observations during the workshop's implementation phase revealed the strengths and shortcomings of our design decisions, some of which were unanticipated. Designing indoor environmental education experiences within an afterschool program setting presented unique challenges and opportunities suitable for the subject of a design case. Having reflected on the experience, we discuss our key takeaways.

First, despite the tradeoffs in immersion and authenticity from not using VR, AR proved to be an excellent choice for promoting environmental education within the informal afterschool program setting. AR's visualization and interactive features gave students at the workshop an interactive experience of the wetland flora and fauna. We also achieved our goal of maintaining high student engagement levels using the AR without any safety or injury incidents. Although we were initially focused on designing AR experiences with high representational fidelity, our observations from the workshop sessions suggest that simple and intuitive platforms such as ARMaker can be equally effective in designing indoor environmental education

experiences. Moreover, such AR tools are cost-effective options for creating engaging educational experiences in learning contexts that operate on a low budget, e.g. afterschool programs.

We also consider AR suitable for designing learning experiences in informal environments such as afterschool programs. Tools like AR can offer flexibility and learner autonomy, which are crucial considerations for designing informal experiences. However, achieving flexibility and learner autonomy when designing informal EE experiences is not contingent on just implementing AR technology. It requires careful consideration and selection of appropriate pedagogical approaches, aligned with the learning objectives, and grounded in a rigorous analysis of the learners and the learning context. We recognized the need to deformatize the experience when planning the sessions, and this guided our choice of pedagogical strategies that would make students feel more relaxed and in control during the sessions. The wetland exploration activity and storytelling appeared to be particularly effective in engaging the students. At the same time, the gamified assessments and waste-sorting activity also added an element of fun which is essential in such informal environments. Thus, our use of AR, while helpful in capturing student interest, was mainly beneficial in the context of broader engagement strategies such as storytelling, hands-on exploration, etc.

Our experience in this project underscores the compatibility of constructivist strategies when designing informal EE experiences. These strategies, reflected in the selection of pedagogical approaches such as storytelling, treasure-hunt, and waste-sorting activities were central to inspiring both cognitive and affective learning outcomes related to environmental education. Storytelling for instance, can help students connect story narratives with their prior knowledge and personal experiences, triggering emotional responses in the process, while the treasure-hunt and waste-sorting activities encourage learners' active engagement in ways that foster critical thinking, problem solving, and metacognitive strategies essential for deepening their understanding. We also noticed how students seemed to "tune off" during some of the whole group sessions, and how our use of paper-based assessments in all three sessions seemed to formalize and slightly interrupt the dynamic ambiance of the learning environment. Although some of the students appeared to enjoy the gamified aspects of the assessments, we recognize in retrospect that digital or multimedia formats could have enhanced the assessment experiences, given how some of the students, particularly the younger ones, struggled to write or draw on the provided sheets. We could also have benefited from using game-based assessment formats that incorporate stealth assessment strategies (Ke & Shute, 2015) so that students could be assessed while navigating the game without making it obvious. As Krishnamurthi et al. (2013) noted, afterschool learning activities should feel distinct from those in school, and constructivist principles can help select engagement strategies that align with informal learning environments.

Some observations during the workshop were unanticipated. One instance was how some students opened up the app's design canvas after exploring the wetland and began redesigning the wetland by adding new animals. Although this observation might be expected given that the children can be considered digital natives, it also made us consider how we might have approached the design differently, for instance, having the children create their own wetlands using the assets from the app after showing a picture or video of what a wetland looks like. Another positive observation that was unanticipated was cross-age tutoring between the older and younger students. We understood during the design of the activities that AR could promote collaboration between the students, but we did not anticipate the older students taking an active role in guiding and supporting the younger ones through the learning activities. We believe there are opportunities for cross-age tutoring in informal learning environments that design considerations should leverage. Furthermore, we did not anticipate that some students would be picked up early in the session, and for such students, we believe this might have affected their ability to make connections between the three workshop sessions. In retrospect, we could have designed learning packets that the students could take home, though this may not have been feasible for all students, especially those without Internet or technology devices at home.

The workshop also highlights the importance of planning for supervision and support when designing immersive EE experiences for afterschool programs that cater to younger learners. Although students were excited to explore the learning activities independently, they still needed prompting and guidance to recognize the educational aspects of the AR learning activity, such as identifying the wetland features and functions and sorting the waste materials. We provided individualized

support for some students, including an English Language Learner (ELL), though ideally, we could have made the resources accessible in other languages, e.g., Spanish, given our audience demographics. Supervision was especially important in the third session, where students had to walk around the classroom with iPads to scan the AR markers and view the video snippets for the waste-sorting activity. This proved to be a little chaotic, and all three facilitators, as well as the Y Center staff, helped coordinate movement to avoid accidents. Apart from assisting with supervision, Y Center administrators and staff provided other forms of support, including recruiting the student participants, canvassing parental consent and buy-in, and providing information and workshop resources. Our experience with the Y Center administrators and staff underscores the importance of regular communication with stakeholders during multiple phases of the project to ensure planned activities run smoothly.

Conclusion

With the support of the service grant project, we successfully implemented a workshop that promoted environmental awareness to students from diverse backgrounds. At the end of the workshop, each student received a copy of the First Day in a Wetland storybook, and we donated the Learn-To-Recycle Activity Boxes to Y Center. Despite various constraints, our team was able to leverage simple AR tools to promote indoor EE experiences in an afterschool program. In light of the workshop's success, we believe EE activities provide opportunities to enrich students' learning experiences if incorporated into afterschool programs. More importantly, integrating EE activities in afterschool programs can help spread awareness of environmental issues to learners from underserved communities. Even in urban areas where nature-rich environments are scarce, students can still be virtually transported to nature using less immersive, but suitable and safe alternatives, designed with simple AR tools. While AR can enhance several aspects of EE, we recommend considering its use strictly in the context of broader engagement strategies to maximize its effectiveness and foster student engagement. Equally instructive for designers, is the need to prioritize design considerations that align with the flexible and relaxed afterschool program setting. In our opinion, constructivist principles should guide the design of learning activities in afterschool program settings, but insights from the learner and context analysis should be taken into account as well when making design decisions. Depending on the afterschool program context, there might be opportunities to leverage the age differences among learners in promoting cross-age tutoring, where the older learners guide the younger ones. As with every design endeavor involving technology, we recommend using non-technology alternatives as design accommodations to address potential challenges. Design accommodations should also consider ways of supporting students from diverse backgrounds, including ELLs. Supervision is essential for programs with younger learners to support their learning and ensure their safety, and afterschool program staff can be supportive in this regard if open communication channels are established and maintained. Our project exemplifies how multistakeholder engagement with the local community can drive efforts to promote environmental awareness to people from different backgrounds. More collaborations of this nature are needed to foster local and collective action toward preserving our dear planet.

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References

Abdoli-Sejzi, A., & Bahru, J. (2015). Augmented reality and virtual learning environment. *Journal of Applied Sciences Research*, 11(8), 1-5.

- Ardoin, N. M., & Bowers, A. W. (2020). Early childhood environmental education: A systematic review of the research literature. *Educational Research Review, 31*, 100353.
- Arici, F. (2024). Investigating the Effectiveness of Augmented Reality Technology in Science Education in Terms of Environmental Literacy, Self-Regulation, and Motivation to Learn Science. *International Journal of Human-Computer Interaction, 1*-21.
- Bada, S. O., & Olusegun, S. (2015). Constructivism learning theory: A paradigm for teaching and learning. *Journal of Research & Method in Education, 5*(6), 66-70.
- Bell, P., Lewenstein, B., Shouse, A., & Feder, M. (2009). *Learning science in informal environments: People, places, and pursuits*. National Academies Press.
- Bruyere, B. L., Wesson, M., & Teel, T. (2012). Incorporating Environmental Education into an Urban After-School Program in New York City. *International Journal of Environmental and Science Education, 7*(2), 327-341.
- Buchanan, J., Pressick-Kilborn, K., & Maher, D. (2018). Promoting environmental education for primary school-aged students using digital technologies. *Eurasia Journal of Mathematics, Science and Technology Education, 15*(2), em1661.
- Cummings, T. G. (2001). Co-constructivism in educational theory and practice. *International Encyclopedia of the Social and Behavioral Sciences, 11*, 2058-2062.
- Kim, M., & Dopico, E. (2016). Science education through informal education. *Cultural studies of Science Education, 11*, 439-445.
- Krishnamurthi, A., Bevan, B., Rinehart, J., & Coulon, V. R. (2013). What Afterschool STEM Does Best: How Stakeholders Describe Youth Learning Outcomes. *Afterschool Matters, 18*, 42-49.
- Ducasse, J. (2020). Augmented reality for outdoor environmental education. *Augmented Reality in Education: A New Technology for Teaching and Learning, 329*-352.
- Fauville, G., Queiroz, A. C. M., & Bailenson, J. N. (2020). Virtual reality as a promising tool to promote climate change awareness. *Technology and Health, 91*-108.
- Freepik (n.d.) Images of wetland animals and plants in the AR wetland environment. www.freepik.com.
- Goff, E. E., Mulvey, K. L., Irvin, M. J., & Hartstone-Rose, A. (2018). Applications of augmented reality in informal science learning sites: A review. *Journal of Science Education and Technology, 27*, 433-447.
- Ham, S. H., & Sewing, D. R. (1988). Barriers to Environmental Education. *The Journal of Environmental Education, 19*(2), 17-24. <https://doi.org/10.1080/00958964.1988.9942751>
- Hanna, G. (1992). *Jumping Deadfall: Overcoming Barriers to Implementing Outdoor and Environmental Education*.
- Huang, T.-C., Chen, C.-C., & Chou, Y.-W. (2016). Animating eco-education: to see, feel, and discover in an augmented reality-based experiential learning environment. *Computers in Education, 96*, 72-82.
- Huang, K. T., Ball, C., Francis, J., Ratan, R., Boumis, J., & Fordham, J. (2019). Augmented versus virtual reality in education: An exploratory study examining science knowledge retention when using augmented reality/virtual reality mobile applications. *Cyberpsychology, Behavior, and Social Networking, 22*(2), 105-110.

- Ke, F., & Shute, V. (2015). Design of game-based stealth assessment and learning support. *Serious Games Analytics: Methodologies for Performance Measurement, Assessment, and Improvement*, 301-318.
- Kim, M., & Dopico, E. (2016). Science education through informal education. *Cultural Studies of Science Education*, 11, 439-445.
- Krishnamurthi, A., Ottinger, R., & Topol, T. (2013). STEM learning in afterschool and summer programming: An essential strategy for STEM education reform. *Expanding Minds and Opportunities*, 31.
- Kinslow, A. T., Sadler, T. D., & Nguyen, H. T. (2019). Socio-scientific reasoning and environmental literacy in a field-based ecology class. *Environmental Education Research*, 25(3), 388-410.
- Korenova, L., Severini, E., & Cavojsky, I. (2023). The use of augmented reality in the afterschool club from the point of view of future educators. In *INTED2023 Proceedings* (pp. 5254-5263). IATED.
- Ladykova, T. I., Sokolova, E. I., Grebenshchikova, L. Y., Sakhieva, R. G., Lapidus, N. I., & Chereshneva, Y. V. (2024). Augmented reality in environmental education: A systematic review. *Eurasia Journal of Mathematics, Science and Technology Education*, 20(8), em2488.
- Mullenbach, L. E., Andrejewski, R. G., & Mowen, A. J. (2019). Connecting children to nature through residential outdoor environmental education. *Environmental Education Research*, 25(3), 365-374.
- Palmer, B. C., Harshbarger, S. J., & Koch, C. A. (2001). Storytelling as a constructivist model for developing language and literacy. *Journal of Poetry Therapy*, 14, 199-212.
- Printable_Models. (2019). North American Muskrat [3D Model]. Free3D. Retrieved from <https://free3d.com/3d-model/northamericanmuskrat-v1-257204.html>
- Reutzel, D., & Cooter Jr, R. B. (2000). *Teaching children to read: Putting the pieces together*. Order Processing, Merrill, an imprint of Prentice Hall, PO Box 11071, Des Moines, IA 50336-1071.
- Rickenbacker, H., Brown, F., & Bilec, M. (2019). Creating environmental consciousness in underserved communities: Implementation and outcomes of community-based environmental justice and air pollution research. *Sustainable Cities and Society*, 47, 101473.
- Salmi, H., Thuneberg, H., & Vainikainen, M. P. (2016). Making the invisible observable by Augmented Reality in informal science education context. *International Journal of Science Education, Part B*, 7(3), 253–268. <https://doi.org/10.1080/21548455.2016.1254358>
- Tychsen, L., & Foeller, P. (2020). Effects of immersive virtual reality headset viewing on young children: visuomotor function, postural stability, and motion sickness. *American Journal of Ophthalmology*, 209, 151-159.
- Zimmerman, H. T., Land, S. M., & Jung, Y. J. (2016). Using augmented reality to support children's situational interest and science learning during context-sensitive informal mobile learning. *Mobile, Ubiquitous, and Pervasive Learning: Fundaments, Applications, and Trends*, 101-119.

[1] X Education and Y Center are pseudonyms for the local afterschool programs

[2] Z Bog is a pseudonym for the local wetland habitat



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