International Society of the Learning Sciences

Place-based mobile AR: Technological development of mobile apps to support families to see and discuss science outdoors

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Abstract: Our team of educational researchers, designers, and programmers are developing a suite of mobile augmented reality (MAR) apps to support rural families to learn science outdoors during their out-of-school time. We present MAR technology designs we have used across four mobile apps for learning about cave formation, land-water interactions over geologic time, pollinators, and pollination. We describe three different MAR app features to support observing science in outdoors: 1) AR filters and visualizations; 2) digital resources tied to place and 3) photo capture and question prompts to integrate observations and science.

Introduction

As mobile devices have become common in everyday use, theory and designs for mobile learning in non-formal learning settings have proliferated. Mobile technologies, according to Sharples and Pea (2014), radically change how contexts can be shaped for learning, as they open novel opportunities to enrich available resources for meaning making outside of classroom settings. Our research and development project involves creating a suite of interactive, mobile augmented reality (MAR) applications (Ryokai & Agogino, 2013; Zimmerman et al., 2021) that are used by rural families in the outdoors to learn science in their communities. By layering digital resources (i.e., animations, AR filters, photos) onto outdoor places through screens of mobile devices, families observe science as they walk through a children's garden, environmental center, or their own backyards. MAR uniquely affords the augmentation of scientific perspectives, representations, and conversations not typically visible or realized without such support. Our focus on place-based learning outdoors during non-formal educational programs assumes that learners' agendas, mobilities, and interests must be honored in our designs. We developed a series of short MAR experiences that guide families' interactions with both designed and emergent elements of place, including garden exhibits, MAR visualizations, and conversations with each other. Taken together, these perspectives inform a socio-technical arrangement for supporting families' science learning-on-the-move (Marin, 2020) that are grounded in localized understanding of science (Smith, 2002) and made visible through MAR.

Overview of the MAR apps and technology design

Our team of educational researchers, designers, and programmers have conducted design-based research with over 63 families using our MAR apps as they walk though outdoor community spaces together. The MAR apps were developed initially in *Swift* and now in *Unity* (optimized for iPads) and provide short, micro learning experiences ranging between 15-45 minutes. The apps are developed in partnership with University scientists, arboretum and nature center staff, educational researchers, and Centers charged with advancing innovation in technology and immersive experiences for teaching and learning. Evaluation methods included capturing video data of families using the apps as well as knowledge assessments. This paper highlights three MAR design features used across the four mobile apps developed to date:

1. *AR filters and animations that are viewed through the iPad display or camera viewfinder:* These MAR features serve as visualizations or representations of science concepts to support families to observe science around them in ways not otherwise possible. AR filters and animations also add an immersive element to the experience (Georgiou & Kyza, 2018).
2. *Digital resources tied to place while learning-on-the-move:* These MAR features guide both navigation of place and serve as triggers for science resources to be deployed based on location (Ryokai & Agogino, 2013). For example, we use GPS tracking to illustrate the next stop on a map in relation to current positioning, and content is displayed when in proximity to the location. Other methods include scanning 3D objects to trigger and layer an animation that virtually appears on or nearby the object scanned, and user selection of when to see app resources (e.g., click to launch content when you are ready).
3. *Photo capture and question prompts to direct attention and conversations*: We designed MAR elements to engage families in actively integrating aspects of place with science resources (Zimmerman et al., 2021). We accomplish this through a combination of photo capture and photo journaling activities with app check lists that prompt either annotating photos with observational criteria or that prompt families to look at and

talk about their surroundings through a scientific lens. Checklists serve as fast and simple ways to check understanding and engage in conversations that can be easily deployed while walking.

Cave Explorers (topic: limestone cave formation)

Cave Explorers is a 15–20-minute MAR app experience that was designed for a children's garden within a university arboretum. The children's garden consists of exhibits and play spaces inspired by regional landscape features, geologic history, and native plant and vegetable gardens. The app focused on how caves form in the U.S Appalachian region (Karst landscapes) and was designed to augment a large cave exhibit that included stalactites, stalagmites, columns, bat sculptures, and two ceiling openings with slow drips of water. The cave simulated a sense of being in an actual limestone cave.

MAR filters and animations included (1) 2D animations viewed within the app that illustrated how caves are formed from interaction of limestone rock and water over time (figure 1a); (2) Animation of how stalactites and stalagmites join over geologic time to form a column; the AR animation is virtually displayed within the cave when viewed by holding up the iPad screen; (figure1b); (3) AR filters displayed stalactites and stalagmites through the front-facing camera for a "family cave selfie". *Digital resources tied to place* were triggered by user selection or by scanning an object within the exhibit space. Science content was launched in 2 ways: (1) families tapped a "next" button to launch content or were prompted where to look or what to discuss; or (2) families scanned 3D objects in the cave using the iPad (e.g., a stalagmite on the ground of the cave) to trigger an animation. *Photo capture and question prompts* guided families' observations within the cave. The app deployed a rear-facing camera for families' to take photographic evidence of water-limestone rock interactions. They could then annotate their photos using "tags" that prompted them to articulate evidence they found (figure 1c). This served as a photo journaling activity that connected app content and families' observations.

Figure 1a-1c: Screen captures from the *Cave Explorers* mobile AR app for use in an arboretum.

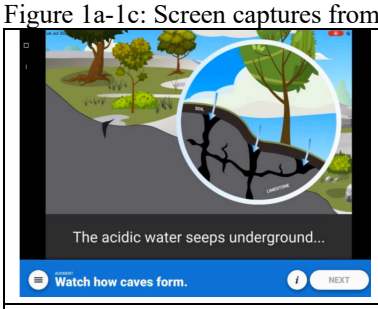

Fig 1a: Image from animation of how caves are formed

Fig 1b: Animated column (right) virtually appearing in cave after scanning stalagmite to the left.

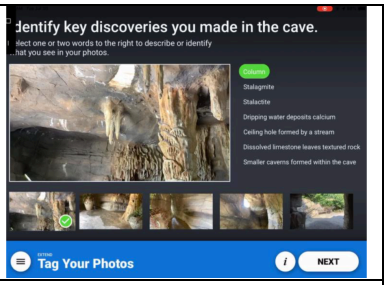

Fig 1c: Tagging photos with descriptions of land-water interactions

Time Explorers (topic: Land-water interactions over geologic time)

Time Explorers is a 30–45-minute MAR experience, which was designed as a walking tour for a children's garden in a university arboretum that contains features and play spaces inspired by regional landforms and geological history including: a time spiral, a coral sculpture, limestone and sandstone boulders, and a model creek, cave, arched rock wall, and spring. The app focused on how land and water interact in Karst landscapes over geological time to form common regional landforms. It was designed to augment the existing features of the children's garden as families traveled from the Ordovician to the Quaternary Period (present day).

MAR filters and animations included (1) an animation of a time spiral feature that narrated families' journey through time (figure 2a); (2) an AR photo filter of nautilus floating underwater to connect a coral sculpture to science content about formation of limestone rock (figure 2b); (3) virtual chemical and microscopic scans of limestone and sandstone boulders that reveal their approximate age and material components (figure 2c); (4) 2D animations and photos showing the formation of ridges and valleys and caves over time; and (5) AR filters showing stalactites, nautilus and the time spiral through the front-facing camera for a family selfie. *Digital resources tied to place* were triggered by GPS and a map that tracked the families' location and showed their next stop in geological time as they went on a walking tour around the children's garden (figure 2d). Science content was launched when families reached the GPS location specified for that stop. *Photo capture and question prompts* guided families' observations and discussions in the children's garden. Families were given discussion questions alongside images and videos to prompt their observations of different geological features throughout the tour. The app deployed a rear-facing camera for families to collect evidence of what they had learned at each stop which then went into a travel journal that the families could view at any time (figure 2e).

Figure 2a-2e: Screen captures from the *Time Explorers* Mobile AR app designed for an arboretum.

Fig 2a: Image of time spiral animation

Fig 2b: AR water filter with nautiluses

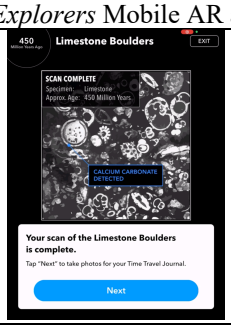

Fig 2c: Scan of the limestone boulders

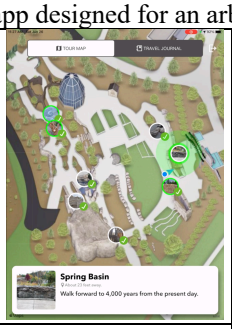

Fig 2d: GPS map of the children's garden

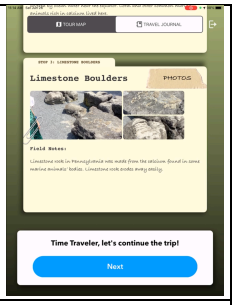

Fig 2e: Travel journal with learners' photos

Backyard Explorers (topic: pollination)

Backyard Explorers was a 15–20-minute experience designed to be used in families' backyards to observe pollinators and flowers. Unlike the other apps we developed, Backyard Explorers was not designed for a specific location, but rather was intended to be used in any outdoor setting. This required different strategies for designing and launching app resources. Because we could not know precisely what kinds of pollinators or flowers families might be observing, we worked with pollinator experts to generate a series of checklists and guiding questions that highlighted observations that likely might be seen and that reflect important concepts in pollination. The MAR app has 3 main menus: (a) Pollinators and flowers; (b) Seeing what we can't; and (c) Be a pollinator friend.

MAR filters and animations included an AR filter that simulates "bee vision" in order to show how some pollinators see colors from the light spectrum differently than humans, helping them find flowers with nectar and pollen. This AR filter visualizes how a flower in a garden would look to a bee, which families observe by holding up their mobile device to a flower and toggling between human and bee vision (fig 3a). *Digital resources tied to place* were triggered by user selections in response to guiding questions or prompts. For instance, families were first asked, "where do you think you might find pollinators in your backyard" (fig 3b), which typically prompted them to move to a location in their yard with flowers, where they would then find pollinators to observe. From there, they selected the next button to advance the app material. *Photo capture and question prompts* guided families to take photos and videos of pollinators and/or flowers and to answer questions about them. We used a 3-stage sequence for structuring the learning experience: (1) Provide a list of key scientific features to notice; (2) capture observations through photos/videos; and (3) answer a series of yes/no questions about observations which were designed to prompt noticing. For instance, prior to observing, families were provided with a list of pollinator behaviors to guide their observations and channel their attention. Then, the families were encouraged to take photos or videos of pollinators. Their photos were presented to the families to analyze, along with a series of yes-no questions, to prompt reflection on specific behaviors they observed (e.g., did the pollinator visit multiple flowers? Did it visit different colors of flowers?) (fig. 3c)

Figure 3a-3c: Three AR screens from *Backyard Explorers* MAR app designed for at-home use.

Fig 3a: Bee Vision AR filter

Fig 3b: Guiding Questions

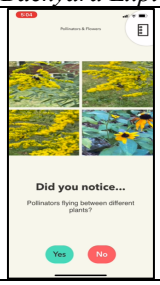

Fig 3c: "Did you notice?" questions

Pollinator Explorers (topic: Pollinator habitats and health)

This 45-minute MAR app experience was designed as two different walking tours for two different sites at an environmental center and Arboretum's pollinator and bird garden. The app at the environmental center focused on what pollinators need in the meadows and forests around the center, while the app at the Arboretum's pollinator and bird garden focused on what pollinators need in gardens and farms. Some of the core content was the same

across both locations, but was tied to different locations at each site. Other content was customized specifically to the features of that location. Using place-specific content, the app helped families observe and understand what habitats and foods pollinators need to live a healthy life.

MAR filters and animations included (1) an animation of what bees need in their habitats that narratively tied the stops together (figure 4a); (2) microscopic scan of a pollen grain and x-ray scan of a log (environmental center location) or bee hotel (arboretum) containing native bee's nest (figure 4b); (3) an AR filter showing content elements like bees, butterflies, and flowers through the front-facing camera for a family selfie (figure 4c). *Digital resources tied to place* were triggered by GPS (figure 4d) and tracked the families' location on a map and showed their next stop on their journey to learn about pollinator habitats as they walked the environmental center. Science content was launched when families reached the GPS position specified for that stop, with families then tapping a "next" button to navigate through the location-specific content. *Photo capture and questions prompts* guided families' observations and discussions of pollinators and their habitats. Families were given discussion questions and observation checklists to prompt their observations of pollinator behavior and what pollinators need in their habitat throughout the tour. The app deployed a rear-facing camera for families to collect evidence of what they had learned at each stop which then automatically populated a travel journal that the families could view at any time. This functioned as a photo journaling activity where families chose the pictures that best represented a bee's needs (figure 4e).

Figure 4a-4e. Five AR screens from *Pollinator Explorers* MAR app designed for a nature center.

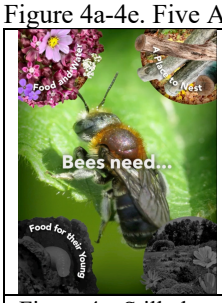

Figure 4a: Still photo of narrative transition screen animation

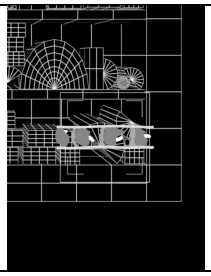

Figure 4b: Still photo of bee hotel scan

Figure 4c: Congratulatory AR selfie filter

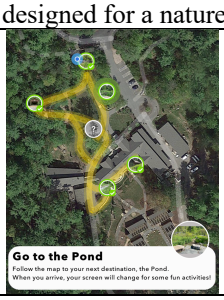

Figure 4d: GPS guided tour map

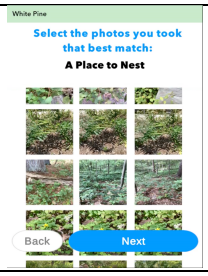

Figure 4e: Photo journal of bees need

Conclusions

Our research provides insights into the design of mobile AR that creates learning ecologies where learners engage with technology, each other, and the outdoor environment during learning-on-the-move. This work contributes to emerging perspectives on how to develop technologies that take into account people's walking and movement as sense-making resources (Marin, 2020) outdoors. Future work will comparatively explore different design iterations of our Mobile AR to support learning about the environment in grounded and embodied ways.

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Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 1811424. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.