Seeing Science: Inquiry-Based Learning at Home Through Mobile Messaging System

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ABSTRACT

This work-in-progress proposes an approach that uses a low-cost, smartphone-based system for at-home, inquiry-driven science learning called STEM-Messaging System (SMS). SMS supports real-time, interactive, message-based science activities and is part of a broader project aimed at integrating science into children's daily lives by uncovering the science behind everyday objects via computer vision overlays. We discuss how three pedagogical principles–inquiry-based learning, culturally relevant pedagogies, and modeling-based learning–inform key design features of the system and its curricular activities. We identify tensions that surfaced from pilot studies involving students, parents, and teachers, providing examples of how pedagogical principles and practical applications influence design decisions.

CCS CONCEPTS

• **Applied computing**; • **Education**; • **E-learning**;

KEYWORDS

Science Education, Inquiry-based learning, Culturally relevant pedagogies, Modeling-based learning, at-home learning

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1 INTRODUCTION

The prototypical image of science for most children is that of a mysterious body of knowledge understood by only a few. Many children perceive a scientist as a white male in a lab wearing a white coat. This perception creates a disconnect between science and children's lives, where being a scientist becomes an unreachable goal [30, 63]. In addition, the COVID-19 pandemic revealed challenges to ensuring high-quality science learning for all children at home due to unequal access to appropriate technology infrastructure and the inadequacy of existing educational materials and practices tailored for remote learning. We examine ways to address these gaps by bringing inquiry-based science activities into children's homes by allowing them to see the science behind everyday objects. This work-in-progress paper explores the viability of a low-cost, low-tech approach for at-home, inquiry-driven science learning. STEM-Messaging System (SMS) is an interactive, message-based platform tailored for households where the family's sole computational device with internet access is a mobile phone, more common in lower-income households in the US [50]. The SMS consists of (1) a low-bandwidth, text-messaging-based system to allow teachers to deliver inquiry-based activities to students at home, (2) a computer vision system that will augment everyday objects with science "modeling overlays," and (3) carefully integrated STEM activities scripts that co-design with middle-school teachers. The work presented in this paper is the initial phase of a three-year-long project that aims to make science education more accessible while avoiding undue pressures on families' infrastructures. We executed scripted activities (Wizard of Oz) with students and teachers and examined the content topics, available infrastructure, and materials at home. Our research question investigates the challenges and opportunities in designing home-based, low-bandwidth inquiry activities rooted in pedagogical principles within real-world settings.

2 THEORETICAL BACKGROUND

The following section will provide a brief background on related work and the three fundamental pedagogical principles leading the design of this platform—Inquiry-based learning, Culturally relevant pedagogies, and Modeling-based learning.

2.1 Inquiry-based-learning

Authentic inquiry-learning activities are essential components of STEM education [43], in which learners formulate hypotheses, conduct experiments, and make observations [15, 38, 45, 46]. Over the last two decades, studies showed that inquiry-based learning is highly beneficial to students, including linking science to phenomena in everyday life [57]; promoting active participation [13], interest in science [44], and collaboration between students [26]; it increases motivation and positive attitude toward science [7, 27], conceptual understanding [23], and the comprehension of the nature of science [35]. It also helps students develop their ability to work in unpredictable and complex environments, especially in our ever-changing society.

Mobile devices provide unique affordances for inquiry-based science, such as portability, interactivity, and context-sensitivity [56]. Research efforts have leveraged these affordances to create mobile-assisted instructional approaches that integrate in-school and out-of-school learning experiences [39, 55, 64], emphasizing the importance of aligning classroom culture, pedagogical principles, design features of the mobile devices, and learning goals for effective science inquiry learning [40]. In previous studies, students have used mobile devices to collect data outside of the school, which the teacher then integrates into classroom activities [11, 39, 42]. It was noted that teacher support in implementing the activities as part of the curriculum is essential [18]. Scripts help teachers coordinate allocating resources and technologies across the learning contexts and adapt to students' progress [55]. However, more research is needed to develop evidence-based design principles for scripted orchestration for smartphone-assisted science inquiry learning [39, 65].

2.2 Culturally Relevant Pedagogies

The idea of building on local students' cultures, knowledge, and life experiences has been widely researched and used in education. Culturally responsive/relevant teaching [20, 21], culturally responsive pedagogy [33], culturally sustaining pedagogy, and place-based education have common attributes [1, 16, 29, 32, 48, 51]. Research on culturally relevant pedagogies elevates the integrity of students' sociocultural contexts, experiences, expectations, family knowledge, networks, and values. Researchers in science education have applied for this work in different ways, calling for science teaching to be situated in meaningful contexts, bridging the cultural gaps between students and science content [4, 5, 16, 17]. According to researchers, context impacts education [6, 34]; thus, learning science outside a typical classroom setting presents opportunities. Learning in one's community or home could facilitate learning in several ways: (1) It enables students to see the application of learning science and mathematics to their lived environments, (2) Students can dive deeper into their communities' sophisticated (but often undervalued) knowledge, making connections to canonical school content, and (3) Learners can use their environments as an extension of the classroom or school lab, either as a fertile ground for data collection [59] or as a source of significant problems and scientific questions. Culturally relevant pedagogies are also connected to students' identity, determining engagement, epistemology, career choice, and learning [41].

2.3 Modeling-based Learning

Modeling holds a crucial place in K-12 STEM [8, 22, 36, 52, 58]. Educational researchers extensively explored model-based inquiry [9, 28] as a powerful tool for inquiry-based learning [22, 24, 49, 53]. It enhances students' disciplinary knowledge [49] and fosters their understanding of the nature of scientific inquiry [37, 52]. Lab experiments in middle-school classrooms are common, but viewing empirical inquiry as a step-by-step "recipe" negatively impacts students' understanding of the role of experimentation in science [10, 45, 60]. Researchers have explored combining physical experiments and computational models [2, 3, 14, 19, 31, 61, 62], linking experiments and computer models, comparing them, and making explicit connections. Implementing classroom modeling faces challenges due to the lack of tools and the high technological infrastructure requirements. In recent years, modeling has gained prominence in mainstream science education [22, 54], as highlighted in the Next Generation Science Standards (NGSS), a set of K-12 science content standards originating in the United States that explicitly identify eight science and engineering practices, including one dedicated to developing and using models [47]. Implementing modeling in classrooms faces challenges due to the lack of tools and the high technological infrastructure requirements. Our research aims to help students connect scientific principles through models to objects and phenomena in their lives.

3 THE DESIGN OF SMS

Our design utilizes a low-cost, low-bandwidth, mobile-based approach for at-home, inquiry-driven science learning; SMS supports real-time, interactive, message-based science activities and requires only the family's mobile phone as the computational resource. Through mini-lessons via SMS, students capture home images of their experiments and receive on-time feedback from an autonomous system.

In a more advanced project stage, still in development, students will send images of experiments or household objects to the system, which will augment them with a "modeling overlay" and send back enhanced images that will capture the micro-mechanism of the phenomena. Imagine a scenario where a student can text a brief video of a diffusion experiment of a tea bag in water to the system and receive back the same video enhanced with an animated modeling overlay depicting the movement of molecules. Therefore, these overlays would unveil fundamental scientific concepts within the objects surrounding students, offering a genuine computer model derived from the learner's collected data.

Our initial research focuses on determining suitable inquiry-based, at-home activities that are engaging personally and culturally relevant while addressing limitations and parents' privacy concerns. We found that parents are wary of any activity that uses personal phone numbers, and school and district administrators are not allowed to obtain and share that information from students. As a response, we are developing a web-based system that simulates a messaging app interface, eliminating the need to use students' phone numbers. With regards to the activities themselves, we collaborate with teachers to co-design curricular activities, seamlessly incorporating these advancements into NGSS-aligned curricula.

The curricular activities delivered through SMS covered three subjects: 1. Acid-base reactions, 2. the water cycle (both of which were developed simultaneously), and 3. Diffusion (developed after piloting and receiving feedback from the first two activities). Specific criteria guided the selection of these topics: a. they encompass fundamental scientific principles relevant across scientific fields, b. their mechanisms can be visualized through a micro-level model, c. they involve experiments that are engaging and suitable for middle school children, and d. the materials required are simple and accessible for most households. For the first activity, we asked the children to make "fluffy pancakes." The text messages led them through activities that included adding baking soda and lemon juice to create an acid-base reaction that forms in the pancake batter. For the second activity, we asked children to clean salty water from the ocean and took them through a message-based conversation that led them to a thermal desalination experiment. Students boil salty water and turn it into vapor—leaving the salt behind—that is collected and condensed back into the water by cooling it down. For the third activity, we asked them to explain diffusion. Children were asked to experiment using tea bags with cold and hot water and examine the phenomena.

4 METHODS

4.1 Participants

The study engaged both student and teacher cohorts. Initially, data collection comprised individual online sessions with five 6th-grade students (aged 11-12) in their homes, along with their parents. In addition, we connected with three middle school science teachers. Each session with students and teachers took place in the participants' homes and lasted around 40 minutes. The session was recorded through Zoom and conducted via a readily available, free messaging platform like WhatsApp, employing a Wizard-of-Oz approach. All SMS-based curricular units include a script for hands-on activities that students conduct at home, interacting with a researcher through our enhanced text messaging system (at first without the computer vision overlay representation component), delivering messages based on the method known as Wizard-of-Oz prototyping - an established approach in human-computer interaction research [12]. During the experiment, we asked students to take photos of their in-process experiment and answer questions about those photos, probing their understanding.

4.2 Data source and collection

Data for this study were collected through the first iteration of a Design-based-research approach [25], which involved the evolution of initial design features rooted in theory and their subsequent modifications based on empirical data collected during interactions with children and teachers. Data collection included complete SMS responses (with time-stamped message logs) and post-activity interviews with participants. The interviews were designed to assess participants' perceptions of the SMS activity and system, as well as gain insights into the materials available at participants' homes for potential use in future SMS science activities. Additionally, multiple-choice questions were embedded at the end of the SMS activity to assess students' conceptual learning and their ability to explain the phenomenon at a micro-level, as illustrated in the activity.

5 CURRICULUM DESIGN FINDINGS

In this section, we share the design considerations and challenges of the SMS curricular activities. Our iterative design process was driven by three key pedagogical principles identified in the theoretical background section and refined based on student and teacher feedback following pilot implementations.

5.1 At-home inquiry-based learning

5.1.1 Design an independent exploration activity. We aimed to strike a balance between open-ended inquiry and ensuring safety for children to perform the tasks on their own at home. The first two SMS activities (exploring acid-base reactions in the kitchen by making pancakes with different ingredients and learning about the water cycle via thermal desalination) both required the use of a stove. Feedback from interviews with students and their parents following the activity indicated that some tasks were unsuitable to conduct independently (e.g., safety). One example from an interview with a 6th-grade student and his mother highlighted the need for parental supervision during the task involving stove use, suggesting that older children (13-14) might handle it autonomously. This feedback prompted us to be mindful of possible risks associated with household appliances as well as parental involvement as both a potential resource and an impediment to student-led inquiry in SMS activity design. Our second SMS activity centered around a diffusion experiment using tea, allowing for independent exploration and eliminating the need for adult assistance, thus encouraging inquiry-based learning.

5.1.2 Design an engaging home-based activity with progress monitoring. In response to the absence of real-time teacher control and feedback in at-home experiments, our goal was to design an activity with a "guidance messenger." Messages were sent in real-time to students, offering feedback and prompting their responses to ensure active participation and adherence to instructions. Feedback embedded in the script design facilitated the breakdown of steps into smaller activities, enabling effective progress monitoring and the receipt of visual updates from students in the form of photos (figure 1). Our results revealed that the average time students dedicated to the activity was about 20 minutes. The time was spent engaging in the experiment, with messages coming in at consistent intervals. While this information did not provide details about students' actions at home, it indicated that they were actively conducting the experiment in accordance with the script in a timely manner. Furthermore, the teachers expressed during their interviews that the activity was structured enough for students to stay engaged. All three teachers said they could see themselves offering this to their students.

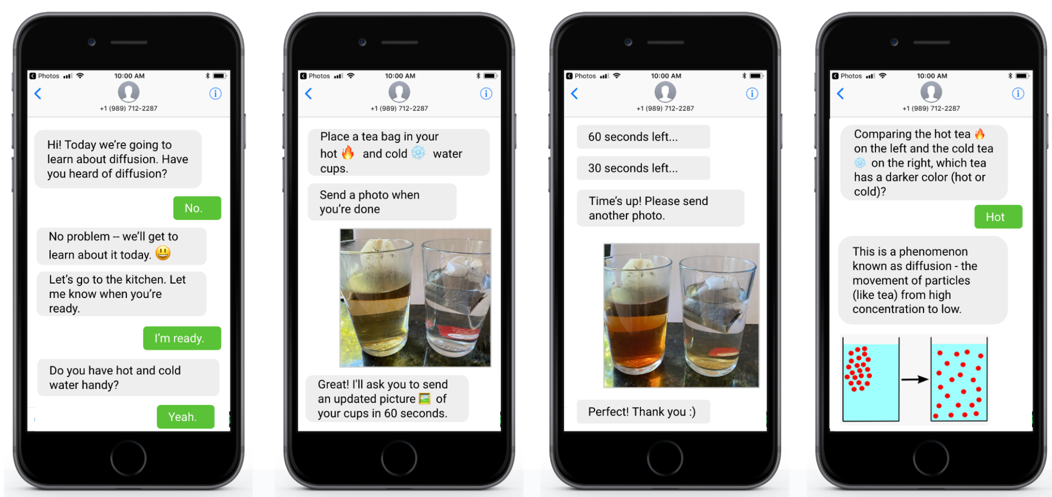

Figure 1: Example student interaction with the text-message-based SMS interface for a diffusion experiment.

5.2 Culturally relevant pedagogy and curriculum alignment

5.2.1 Design for personal and cultural relevance. Based on the culturally relevant pedagogical principle, we aimed to guarantee personal and cultural relevance in lesson design, catering to diverse student backgrounds while utilizing the materials that are readily available to students. This involved pinpointing activities and materials at home that are both suitable for sharing and effective as learning tools. Initial pilot tests illustrated how experiments with food, in particular, can introduce unknown points of reference. In one case, a Brazilian student who participated in the acid-base activity noted that while cooking pancakes was novel and engaging, he did not initially have the ingredients and was unfamiliar with some instructions. For example, he did not know how thick the batter or how fluffy the resulting pancake should be to properly evaluate the different ingredients. His parents offered an alternative recipe featuring ingredients more common in a typical Brazilian household–prompting the team to incorporate flexibility and alternative materials in future activity scripts. In ongoing work, we developed a survey asking participants to describe more materials they could use for at-home science activities. Moving forward, special consideration was given to substances, especially food-related, that might be inappropriate to use or "waste" in some households.

5.2.2 Design activities aligned with school curriculum and topics. In addition to being personally and culturally relevant, our goal was to connect classroom activities with students' home learning via SMS, using the school curriculum as a foundation. This proved challenging as many NGSS curricular standards did not align with experiences students would generally conduct at home. We interviewed three teachers to understand classroom activities, garnering ideas for linking school content with home. For instance, one teacher suggested exploring crystal growth, while another proposed activities like growing mold on bread. However, selecting topics posed challenges due to the need for short-term impact testable within hours, as longer processes like mold growth take days. We are still determining the most effective activities for extended processes at this project stage and observing how this evolves over time.

5.3 Modeling-based learning

Modeling-based learning was the third pedagogical principle guiding this system's design. We are designing the system so that the photos collected during the experiments can be sent to the system, processed, and returned to the students with a "modeling" overlay, i.e., an animation of the micro-mechanisms operating in the phenomenon. In the diffusion experiment, this overlay would move tea molecules from high to low concentrations in the water. Our preliminary technical and conceptual research indicated that the design decisions involve choosing content from the scene that will be suitable for the computer vision system to "understand" automatically, the efficient generation of a modeling layer, and the actual improvement of the mechanisms' visibility for students. This component of the project is still under development and is not included in the scope of this paper.

6 DISCUSSION AND CONCLUSION

This paper presents a work in progress of the design process of the SMS, a learning technology platform committed to broadening the accessibility of science education. We illustrate core design decisions guided by three pedagogical principles and those influenced by real-world use, highlighting the responsive nature of the design process. A key finding for transporting science experiments to the home is that even when the activities are familiar and common, shifting them to a science experiment changes the ways in which parents and children need to participate, their time, attention, and supervision–making otherwise common activities unfit for these remote learning experiments. Additionally, our findings highlight the responsive engagement with teachers in selecting topics that captivate students' interests but also align with the school curriculum and draw upon community and cultural knowledge. Through a design-based research approach, we highlight the significance of iterative design research, with the results emphasizing the role of the designer/researcher in addressing the evolving needs of the target audience, improving usability, and ensuring content accessibility. We argue that this paper contributes to the understanding of barriers and difficulties in introducing a new platform for inquiry-based science learning at home – even after years of remote learning and a recognized need to expand instruction to outside the school.

In the short term, our plan for future work involves iterating and implementing additional design interventions to gather more empirical data on the dynamics of student learning. This includes a specific exploration of how students learn at home and an investigation into their self-efficacy and identity as scientists. In the long term, we plan to complete the development of the platform and incorporate computer vision to visualize the model overlay.

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