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RESEARCH PAPER

Design of a Serious Game to Teach Water Scarcity Concepts in Rural Communities

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Abstract
The scarcity of natural resources such as water is a growing problem and society is trying to raise awareness of the issue. This problem mainly affects communities that have limited or no access to water. In Mexico, specifically in the Guadalupe Valley, water scarcity has greatly affected the community due to the overexploitation of aquifers, the excessive growth of agriculture and viticulture, and the lack of adequate infrastructure for water management. For this reason, governments around the world are educating children at an early age about water scarcity using new technological and interactive methods. In this article, we present 'Arroyuelo', a serious game on a mobile device embedded in a 3D printed model. We followed a user-centered design methodology and considered that it should be accessible, and engaging and encourage teamwork in rural communities. This article contributes to a serious game called Arroyuelo, to educate children about water scarcity through school group activities, and provides design implications for creating serious games that promote water awareness in rural communities.

Keywords:
Water scarcity; Serious Game; Learning; Educational assistant.

1 Introduction
Water scarcity has become one of the most pressing challenges of our time, affecting communities worldwide and threatening the water security of thousands of people. With global population growth, industrial development and climate change, the demand for freshwater has reached critical levels, while available water resources are becoming increasingly limited [7]. For this reason, governments worldwide have redoubled their efforts to include water conservation issues from the basic levels of education.

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Elementary school plays an important role in the formation of awareness and responsibility in children regarding the care and rational use of water. The use of technologies to reinforce this knowledge is increasing every day and sophisticated tools are made available to schools that contribute, together with teachers, to the motivation of children in the subject [8]. In Mexico, the New Mexican School (NEM) proposes that classroom interaction and experimentation are fundamental parts of learning; placing physical, cognitive, and emotional aspects at the center of this new model [4].

The incorporation of technology in the educational environment has a fundamental purpose: to facilitate and optimize the teaching-learning process, providing tools and resources that allow efficient learning. The use of serious games to teach elementary school water scarcity concepts to children has been explored in recent years. In addition, results show that serious games can help improve understanding of water scarcity concepts [9].

However, the development of a serious game to support schools in rural communities in the process of teaching their students about current water issues has not been thoroughly explored. Moreover, key aspects such as access to technology, the availability of technological resources, and the use of understandable metaphors for rural communities have not been adequately considered [1].
In this article, the process of designing and implementing a serious game to raise awareness among primary school children about water scarcity in rural communities is presented.

The contributions of this article are:

- A set of design considerations that could guide the design of serious games to support water awareness in rural communities.
- A serious game called Arroyuelo embedded in a 3D model, developed to raise children's awareness of water scarcity through the implementation of school group activities.

2 Related work
This section first describes related work with respect to video games designed to support concept learning. Subsequently, video games designed to teach water scarcity concepts are described.

2.1 Serious games for learning support
Multiple games or systems have been created for teaching concepts to elementary school children, an example of these developments is Climate Trail, a video game that combines the adventure and

gameplay of the journey north with elements of visual novels, where the characters reveal how and why this climate apocalypse developed; For the experiment, high school students were brought to a school computer lab and were instructed to fill out a questionnaire before and after playing the designated video game for roughly 30 minutes [3]. On the other hand, SIMA [5] serves as an assistant for teachers or as a tutor at home to teach different subjects. In general, there is evidence that the use of serious games improves learning in children, and creates dynamism and interaction in the classes they receive.

2.2 Serious games for learning support

Video games designed to teach water scarcity concepts to elementary school children facilitate learning about the importance of this resource, the consequences of its misuse, and the need for its conservation. By facing in-game decisions, such as sharing water equitably among characters or prioritizing important uses, children develop critical thinking skills and an understanding of the real-life implications of water scarcity [2].

There are tools that contribute to knowledge improvement in children. Examples of these are Guadi [6] made by ASEAS (Spanish Association of Water Supply and Sanitation) and the Colombian initiative of making a video game for teaching water care, in which players explore a virtual world where they must solve water-related problems, such as water resource management and environmental protection. Its validation is presented in a real educational environment in which 65 fourth grade students participated, from an educational institution in the municipality of Bello, Colombia [2].

The lack of a clear curriculum on water scarcity in serious games can lead to disparities in the quality and focus of technology education in different institutions. This results in a lack of awareness among children about fundamental sustainability issues and a lack of skills to address these challenges in their technology projects.

However, most of these works are not designed and contextualized for rural communities.

3 Methods

A qualitative user-centered design methodology was followed for 5 months to develop a serious game that contributes to learning about water scarcity in students from rural communities. During the study, 15 semi-structured interviews were collected from 11 teachers and 4 immersive learning experts (Total duration=7 hours; μ=41.82 min and S=11.27 min). The teachers had between 9 and 14 years of teaching experience (mean = 12 years; SD = 0.78 years). Twenty questions were asked to each interviewee, and each one gave their consent to be recorded via audio and allowed to be photographed. Topics addressed in the interviews involved the current school curriculum on water scarcity, learning techniques, and considerations for the development of serious games in rural communities, such as access to technology. The interviews and field notes were transcribed and subsequently, a microanalysis was performed on the transcripts. The microanalysis was complemented with interpretation sessions to identify recurrent themes and generate an affinity diagram.

To actively involve specialists in the design process, the interviews were complemented with 8 design sessions. These sessions were attended by teachers from rural communities, traditional school teachers, psychologists, Human-computer interaction (HCI) and Ubicomp experts, educational video game development experts, and education experts (Table 1, total duration=6 hours, μ=115.10 min and S=2.37 min). The dynamics of the sessions were as follows: first, the participants were explained the context of the study; subsequently, brainstorming was conducted and potential design ideas were discussed. Three low-fidelity prototypes emerged from the design sessions. The experts discussed the advantages, and disadvantages and voted to select the prototype they considered most appropriate for teaching water scarcity concepts in rural communities.

Table 1. Summary of design sessions.

	Objective	Results	Role
2	Propose visions concerning emerging themes. Analyze their feasibility.	3 visions of possible prototypes. Analysis of their advantages and disadvantages.	Teachers from rural communities (6), psychologists (2), traditional school teachers (4), HCI experts (3)
1	Analyze the visions created. Consider new visions. Comp are advantages and disadvantages.	A winning vision. Feasibility analysis of the three visions.	Teachers from rural communities (6), psychologists (2), traditional school teachers (4), HCI experts (3)
1	Specify the physical structure of the prototype.	Specification of the size, shape, and material of the prototype.	Traditional school teachers (2), HCI experts (2), Ubicomp experts (2).
2	Specify school curriculum. Define activities within the prototype.	Specification of the curriculum, evaluations and practices to be implemented.	Teachers from rural communities (2), and traditional school teachers (2), HCI experts (2).
2	Specify game mechanics, auditory and visual stimuli.	Specification of the mechanics, visual and auditory elements of the prototype.	HCI experts (4), psychologists (2), educational video game development expert (1)

4 Results

The results of the article have been divided into three: the design implications found, the initial visions and the design of Arroyuelo (Arroyo = Creek), a serious game embedded in a 3D model to contribute to learning about water scarcity in students from rural communities.

4.1 Design implications

As a result of the interviews and design sessions, the following implications were obtained in order to develop a serious game that contributes to learning about water scarcity in students from rural communities.

1. **Use existing or current curricula that align with the teaching models:** The curriculum implemented in the serious game must be aligned with the current educational model of the country for which it is being developed.

2. **Implement didactic practices to illustrate water scarcity issues:** Practices or laboratories illustrating water scarcity should be implemented, as these practices are fundamental for better knowledge development in children from an early age.
3. **Implement group mechanics:** The implementation of group mechanisms should be considered to foster the development of social skills, such as effective communication and empathy. Additionally, these mechanisms help reduce costs by using a single device for a group of children instead of one device per child.
4. **Use positive reinforcers:** Serious play should include the use of positive reinforcers linked to resources familiar to children in their community. Keeping children's attention during the development of activities is crucial.

4.2 Initial design visions

Based on the design implications, 3 low-fidelity prototypes were obtained: a serious game embedded in a 3D object, a web platform, and an interactive floor mat (see Table 2). Given that the serious game embedded in a 3D object, can be customized, can be moved to various parts of the school, is waterproof, and is novel for children, the specialists selected this alternative as the most appropriate and contextualized.

Table 2. Description of initial design visions.

Exergames	Objectives	Advantages	Disadvantages
Serious game embedded in a 3D object 	The serious game is physically implemented inside a 3D model in the shape of a water drop. This allows children to customize it and take it to practices outside the classroom (such as to crops or school yards).	It represents an intelligent guardian, is customizable, waterproof, can be moved to multiple zones, implements group mechanics and parts of the model can be scalable in the future.	So far the 3D model is only representative, it does not have any extra functionality.
Web Platform 	The objective of the web platform is to teach water scarcity concepts through infographics, games, and quizzes.	Addresses elements of water care at home and in the school. You can deploy a large number of academic resources.	Does not allow teamwork. Need for one device per student. An Internet connection is required.
Interactive mat 	The objective of the interactive mat is to build a circuit with "digital mats" in the form of puzzles to represent the water cycle and teach concepts with different pieces.	It is interactive and didactic, promotes group work, and is novel for children.	It is expensive and difficult to implement. Parts are susceptible to breakage or loss. Group mechanics may be limited to the number of pieces.

4.3 Arroyuelo: Design of a serious game to teach water scarcity concepts in rural communities.

Our iterative design process led to the final prototype named Arroyuelo, which is a serious game designed to teach water scarcity concepts in rural communities. The serious game is housed in a tablet embedded within a 3D-printed water droplet (Figure 4), allowing children to interact with it. Teachers can use it as a teaching tool in classes and customize it according to classroom needs. Moreover, it can accompany students in activities outside the classroom, such as in the school garden. Arroyuelo includes group questions and exercises.

4.3.1 Use the existing curriculum of the New Mexican School programs.

Arroyuelo implements a curriculum designed with the Mexican educational model, specifically the "Nueva Escuela Mexicana" (NEM) model. The educational curriculum has been structured in three essential levels that address crucial aspects related to water. First, it focuses on imparting basic concepts about water, including its cycle, properties, and functions in nature and in the daily lives of the community's inhabitants. This level establishes a solid knowledge base for understanding the importance of water in the local and global environment. The second level focuses on the issue of water scarcity and pollution, highlighting the specific challenges faced by rural communities in relation to water availability and quality. Children explore the causes and consequences of water scarcity and pollution, as well as possible solutions and conservation strategies. Finally, the third level is dedicated to water care, promoting responsible attitudes and actions towards water resources. Children learn water conservation practices, wastewater treatment methods and how to actively contribute to the protection and preservation of this vital resource for the community and the environment in general. This comprehensive approach to the curriculum at Arroyuelo not only provides children with an in-depth understanding of water-related challenges and opportunities but also empowers them to take meaningful action in its care and sustainable management.

4.3.2 Implementation of practices to illustrate water scarcity issues.

In order to raise awareness and educate children about this important issue, it is essential to carry out practices that exemplify the problems of water scarcity. One effective strategy is to conduct hands-on activities that allow children to experience first-hand water scarcity and its implications. Arroyuelo implements different practices such as the "Care of water in crops" in which the child has

to go out together with Arroyuelo to the school's crops. Once there, Arroyuelo shows him the process of planting a seed. This practice has the purpose of explaining that each plant requires a different amount of water. Arroyuelo gives the children water points that they can use in their crop to help them identify the correct amount of water to use. Finally, the child must use the water measurements explained by Arroyuelo in his actual crop (Figure 1).

Figure 1. Guided practice by Arroyuelo for planting a seed in the school garden. The process of planting the seed that the child must follow is explained, and the amount of water needed for each planted seed is indicated. After completing the activity, they earn the Water Guardian medal, which is cumulative and serves as motivation.

4.3.3 Promoting collaborative work

Arroyuelo implements group activities to reduce costs. One of the activities is: "Team trivia", where the classroom must divide into two teams "sunflower team" and "lily team" to answer questions asked by Arroyuelo. One of the questions implemented in Arroyuelo is:

Team Sunflower, what can we do to avoid water shortage in our community?

a) Water plants during the hottest hours of the day.
b) Repair water leaks at home quickly.
c) Let the water run while washing dishes.

These activities help children understand the effects of water scarcity in everyday life, fostering teamwork, empathy and communication among group members. By sharing devices between groups, the cost per child is reduced, making the learning experience more accessible and inclusive.

4.3.4 Using positive reinforcers to maintain children's attention

Arroyuelo implements the use of positive reinforcers such as field medals, water points, and seeds. These reinforcers are real symbols of their context and can achieve active participation by the children within the game. These reinforcers are not only attractive to children, but are also useful within the activities that Arroyuelo performs, for example by earning a seed, the child unlocks new types of plants, fruits, and vegetables. On the other hand, the water dots are reflected inside Arroyuelo's face, giving the appearance of a real water drop (Figures 2 and 3).

Figure 2. Medals, seeds and rewards

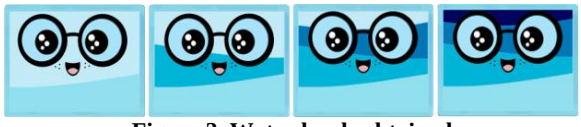

Figure 3. Water levels obtained

4.3.5 3d model physical structure specifications

Arroyuelo is a 3D-printed water droplet with dimensions of 40 x 35 cm that incorporates a tablet and a speaker for interaction with children. The structure is made of PLA (Polylactic Acid). The HUAWEI MEDIAPAD T3 10 tablet is added through a case that acts as external protection (9.6-inch diagonal, 229.8 x 159.8 x 8 mm, 460g). The circular speaker used is from Redlemon (11 cm in diameter x 4.5 cm in width) incorporated in the back (Figure 4).

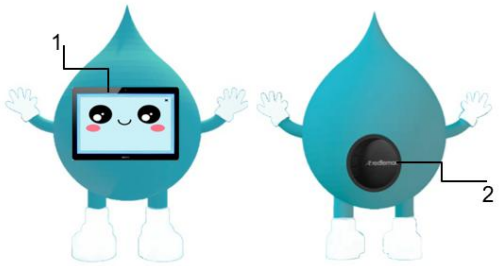

Figure 4. Arroyuelo: serious game embedded in a 3D droplet to teach water scarcity concepts in rural communities, 1) embedded tablet for visual feedback, 2) circular speaker for auditory feedback

5 Conclusions and future work

In this paper, we present a study following the user-centered design methodology to design Arroyuelo -a serious game embedded in a 3D droplet with an illustrative curriculum to contribute to learning about water scarcity in students from rural communities. The main contribution of this paper is to present a set of design implications and the development of a prototype called Arroyuelo, a serious game to teach water scarcity concepts in rural communities.

While the design space has been thoroughly explored, future work will focus on conducting comprehensive usability. These insights will guide the implementation of the video game according to the identified specifications. Following this, a formative evaluation will be conducted to assess the effectiveness of the game in meeting the predefined objectives. Furthermore, specific aspects of the physical prototype will be refined to enhance user interaction and overall experience. Additionally, the study will extend to evaluate the long-term impact of the game on children's understanding and behaviors related to water conservation, incorporating follow-up studies to determine the retention of knowledge and practices over time.

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