

# *Sol y Agua*: A Game-based Learning Platform to Engage Middle-school Students in STEM

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**Abstract**— Full paper, Research-to-Practice. With the nation's continuing shortage of scientists and engineers, there is an urgent need for diverse students, especially Hispanic students, to enter and complete science, technology, engineering and math (STEM) education at all levels. Contributing factors to the low representation in STEM areas are the lack of Hispanic youth's exposure to engaging and relevant experiences with science in their early stages of development and the lack of Latino scientists as role models that are visible, tangible, real, and inspiring to their communities. In addition, student experiences in math and science in the middle grades have emerged as a "filter" that prevents many students from pursuing advanced STEM courses in high school and, therefore, limits their knowledge of and interest in exploring STEM subjects and careers later in their education. This paper presents a research-based approach to attract middle school students to STEM fields in a majority Hispanic region, using a game-based learning platform. The platform integrates computational thinking in the area of water conservation at middle-school level by using simulations and data visualization in concurrent learning modules. The concepts introduced in the platform are universal enough to be successfully employed in other geographical regions with different student demographics.

**Keywords**— *Computational thinking, cultural relevancy, environmental sustainability, game-based learning platform, Hispanics in STEM, middle school*

## I. INTRODUCTION

Science, technology, engineering, and math (STEM) fields have and continue to experience low enrollment numbers, particularly among underrepresented groups, especially among Hispanics and women [41]. As such, industry and government sectors are struggling to fill STEM positions. Following this trend, underrepresented minorities, such as Hispanics, are joining the STEM workforce in low numbers. Between 2010 and 2012, only 19% of all college students nationwide were Hispanic, and a mere 6% of the STEM workforce identified as Hispanic. This paper presents an approach to attract middle

school students to STEM fields using a game-based learning platform called *Sol y Agua* that is modeled after the Smithsonian Latino Center's *Mi Tierra-Mi Mundo/My Land-My World*, a virtual reality role-playing game [26]. *Sol y Agua* was developed to be deployed in the southwest region of the U.S. with a majority Hispanic population. As a result, this platform targets a large pool of students who are introduced to STEM areas at an early age, raising the likelihood of increased STEM enrollment in their later academic paths.

*Sol y Agua* is a culturally relevant, educational, game-based learning platform that aims to improve students' ability to learn, seek evidence, and modify or challenge beliefs through interactive game-play. The platform utilizes components of Computational Thinking [CT] and centers on data science with a theme of water sustainability and stewardship, emphasizing information analysis, negotiation, and decision-making.

In spring 2018, the platform was deployed in two middle-school classrooms with the majority of students identifying as Hispanic. To adequately prepare students for the game-based learning platform, an inquiry-based, commercially-produced module was used to introduce students to how water shapes the land and how, in turn, the land directs the flow of water. Findings suggest the learning platform has strong potential to actively engage students in regional issues concerning water conservation, biodiversity, sustainability, and the human impact on the environment.

This paper presents the design, development, and pilot of the *Sol y Agua* learning platform, and describes how it integrates the application of computing in areas such as water sustainability, xeriscaping, and regional geological structures. The initial work of the research group included a thorough research study on educational games, regional issues, and education standards to inform the design and essential components needed to deeply engage students in a virtual learning platform that focuses on STEM topics.

The remainder of the paper is organized as follows: the Background section presents related work. Section II presents a set of concepts that are critical for developing an engaging game-based learning platform. The Framework for a Learning Platform section presents an overview of the various aspects of the *Sol y Agua* learning platform. We present our preliminary findings in Section V. Lastly, we conclude the paper in the Summary and Future Work section.

## II. BACKGROUND

### A. Game-based Learning

Games have become an integral part of today's youth culture, and it is this popularity that has created a potential for successfully using games in education. In their review of literature on digital gaming and cognitive development, Blumberg and Fisch [4] found that the growing corpus of literature attributes digital game-like platforms with cognitive development in youth, which suggests increased learning potential in STEM-based educational games. Of particular interest are studies showing how students who struggle to learn can be motivated with computer games. Additionally, games can provide an effective context for students to develop deep understanding and engagement with STEM subjects.

Grover and Pea noted that “video gaming as a platform for examining CT among children has been underutilized in recent research” [13]. Game-based learning (GBL) is a pedagogical method using role-plays, board games, or card games to improve learners' soft skills, such as critical thinking, creativity, problem solving, and teamwork [11]. Furthermore, GBL increases learning retention, cognitive development, and socialization [18][21][39] by increasing student engagement while catering to different learning styles [39][24][11][28]. Establishing rules, interactive student-controlled fictional settings, progressively difficult goals, uncertainty, immediate and constructive feedback, situated cognition, and social elements facilitate a successful GBL experience [1][21][26].

As a learning platform, *Sol y Agua* takes the form of GBL, in particular digital GBL or DGBL, to introduce role-playing. DGBLs have been known to promote cognitive development, resulting in increased retention [39]. This is particularly important for the current generation of middle school children who are “digital natives” [28], i.e., children who grew up with recent advances in digital technology including computers, internet, and smartphones. Prensky [22] hypothesized that digital natives think and process information differently than their predecessors who were much less exposed to these technologies. According to Van Eck [39], these youth “require multiple streams of information, prefer inductive reasoning, want frequent and quick interactions with content, and have exceptional visual literacy skills.”

### B. Culturally Relevant Pedagogy

Culturally relevant pedagogy is defined as “using the cultural knowledge, prior experiences, frames of reference, and performance styles of ethnically diverse students to make learning encounters more relevant to and effective for them” [9]. Studies of culturally relevant instruction in math and science education indicate that it can lead to increased student interest, motivation, engagement, and retention of content among

underrepresented students [2]. High-quality, long-term bilingual education, which uses students' home languages in addition to English for content-area instruction, is a form of culturally relevant instruction and is effective in closing the achievement gap between English language learners and native English-speaking students [6]. By using content familiar to students in the U.S. Southwest region — familiar environmental challenges like water scarcity, familiar geological structures of the Chihuahuan Desert, and familiar characters — *Sol y Agua* draws on both situated learning practices and culturally relevant pedagogy to maximize student engagement while learning STEM topics.

## III. FUNDAMENTAL ELEMENTS OF A GAME-BASED LEARNING PLATFORM

In order to identify the fundamental elements of an engaging game-based learning platform, a qualitative study was conducted with local community experts [29]. This section describes the findings of the study which should be considered while designing a DGBL platform.

### A. Engagement Factors

In order to develop an effective educational game, we specifically focused on regional aspects that would help middle school students to quickly relate to the storyline. We conducted a qualitative study with El Paso community experts to identify important regional issues [29]. The study consisted of interviewing six community members [CMs] who are experts providing specific local information about water issues and concepts of stewardship to reflect the main local issues. Specifically, the CMs had specializations in the fields of agriculture, urban systems, ground water systems, desert ecology, and traditional ecological knowledge. They identified unique aspects of the local community and their individual experience with the local community.

Five community members were directly involved in research related to environmental issues in El Paso Rio Grande area. One community member was a physicist with a Native American background who does research on comparing scientific and Native American world views on the environment. Another belonged to one of the three Native American tribes in Texas and the most well-known Native American in El Paso area. These two community members contributed indigenous knowledge regarding sustainability of local resources. A deliberate decision was made regarding the selection of these community members: they were in the same branch of science, but with different cultural backgrounds, to examine how an individual's underlying values, beliefs, meanings, and knowledge collide, intersect, and aggregate to construct new meaning and knowledge of water sustainability.

Analyses of the qualitative study revealed that, for the demographics of the particular region where the learning platform was developed, the frequently mentioned issues could be broadly categorized as concepts related to *environmental sustainability* and *cultural relevancy*.

### B. Environmental Sustainability

Springer and Goggin [24] analyzed the design of Energyville and Energy City, two video games that promote environmental

literacy. They concluded, “nature is depicted in most multiplayer online games as an inexhaustible dispense of resources.” This concern was also brought up by the community members during the interviews in the qualitative study. For example, a river that supplies water to a city could be depicted as a continuous source of water, and the game could simplify or ignore the complex methods required to supply water to households [29].

*Sol y Agua* was developed for the Paso del Norte region of Texas. Water conservation and environmental sustainability issues are ingrained within local culture and lifestyles as the city of El Paso is situated within the Chihuahuan Desert. One of the community members explained that the local water company, El Paso Water, alternates from three water resources (i.e., the Rio Grande, the Mesilla Bolson, and the Hueco Bolson) depending on the water availability of each source [29]. If the Rio Grande’s water decreases, then the company pumps water from the Hueco Bolson aquifer. Conveying the interchanging process could make the learning platform more realistic and bring attention to the preservation of the Hueco Bolson aquifer and the Rio Grande river.

To address these challenges, students engaged in *Sol y Agua* observe different geological aspects of El Paso through in-game activities that allow them to explore various regions of El Paso using a virtual drone, measure the pH levels of water and soil samples in a virtual laboratory, and create a virtual park. Students are tasked with finding a suitable location for the park and selecting native plants that optimize the use of allocated resources (e.g., water and fiscal budget).

El Paso community experts (i.e., community members involved in the qualitative study) also emphasized the role of hands-on opportunities and outdoor experiences that complements the learning platform for developing sustainable practices [29]. They encouraged *Sol y Agua* to be a platform for sustainability issues to be discussed, practiced, and examined. To this extent, one of the lesson plans of *Sol y Agua* asks students to collect information about water usage in their household. Students then plot the usage data using different visualization techniques taught in class. These plots are later used to facilitate a discussion around water usage and conservation.

We are piloting *Sol y Agua* in two middle school classrooms in the El Paso region in 2018. In order to integrate the hands-on, inquiry-based exploration of environmental issues, *Sol y Agua* is used with a Science and Technology for Children module, Land and Water [31], that engages learners in investigating the relationship between land and water. The lesson plans are designed to engage students in dialogues on sources of water, usage of water, and water sustainability.

### C. Cultural Relevancy

Despite the potential of video games, Gee [17] and Goggin [32] noted that development of good educational video games that help people gain a deeper conceptual understanding of real life issues remains “more a hope for the future than a realized possibility, though there are some intriguing beginnings here and there” [17]. Commercial and educational video games that address sustainability issues make simplifications and establish idealistic expectations that do not resemble real life sustainability challenges. Furthermore, video games do not

consider the local and unique settings where these issues take place including the cultural and race diversity of the local stakeholders. For example, Dill, Gentile, Richter, and Dill [7] and Glaube, Miller, Parker, and Espejo [12] concluded that minority characters rarely appear in video games and, when they do emerge in virtual spaces, they are typically stereotyped.

Study participants [29] also shared similar concerns. They pointed out that cultural practices supporting sustainability already exists in the communities. For example, Native American youth follow certain behaviors to demonstrate gratitude and protect Earth (e.g., saying prayers to honor mother Earth). In the greater El Paso region, local people place less value on green yards, and communities use less water per person by U.S. standards. Study participants suggested introducing activities and exercises in *Sol y Agua* that address pro-environmental, sustainable practices. Participants also pointed out that the youth must develop cooperative relationships with community, thus helping them find their role in the community.

*Sol y Agua* provides a meaningful context where activities within the learning platform are relevant, applied, and practiced—that is, learning is situated in meaningful context. It has been noted that the more complex the game, the more likely learners will engage in ways that deepen their learning [39]. In *Sol y Agua*, all students are playing a role, a form of embodied learning wherein learners build meaningful connections, which is the basis for deep learning, through virtual and real action and movement [22]. As such, they think and act like the role they are playing. In *Sol y Agua*, students take the role of scientist, including at times, the role of a computer scientist; that is, they are taking up the identity of a scientist [17]. From a sociocultural theory of development, *Sol y Agua* introduces the character of a wise owl, which represents an expert who scaffolds learning of the user [40]. The species of the wise owl is *Athene cunicularia*, or more widely known by its common name: *Burrowing Owl* [5]. The Burrowing Owl is a small bird of prey found throughout the North and South America. The owl became a character in the game due to its wide population in the El Paso region and to its symbolism of knowledge from Greek mythology.

According to [20] and [23], graphical programming tools, such as Scratch, Alice, Game Maker, Kodu, and Greenfoot, lack authentic and meaningful context and may inhibit learning. On the other hand, *Sol y Agua* brings cultural facts, environmental knowledge, and sustainability concerns into the scenarios in the form of ethnic-specific characters, stories, factoids, and locations to make the context of the platform relatable to support learning.

### D. Computational Thinking

Computational thinking is at the core of all STEM disciplines as a “universally applicable attitude and skill set” [41]. According to Henderson, Cortina, Hazzan, and Wing [14], computational thinking is foundational to all STEM disciplines. *Sol y Agua* integrates CT principles to help students develop this skill at an early age. A few CT areas covered in the *Sol y Agua* platform include:

*Abstraction:* *Sol y Agua* introduces abstraction through activities such as park design, virtual exploration using drones, and data visualization. Such activities focus on the CT aspects

of the experience while hiding the details of the execution from the students and teachers.

**Problem solving:** Students use their problem-solving and decision-making skills throughout the game, such as in the park design activity where students choose a location, select the plants and fixtures appropriate for that location, and meet other constraints and competing demands.

**Algorithms:** Algorithms refer to a set of rules to solve a problem that may include computation. Within *Sol y Agua*, students follow step-by-step procedures to conduct scientific experiments in virtual labs to measure pH, on the molecular level, in water and soil samples. Students will also fly a drone to embark on a virtual exploration of the region. These activities serve to reinforce the lesson around algorithms.

**Decision making:** The park activity within *Sol y Agua* utilizes the notion of competing demands and trade-offs that requires students to analyze data and make informed decisions. The students earn points based on the plants they choose to purchase, as well as where they place those plants. Students use these points to compete with each other, as well as themselves, as they try to improve their score with every iteration.

**Data visualization:** Data visualization provides the necessary tools to efficiently and effectively parse through large amount of data, develop observations and assumptions, which in turn help to extract knowledge from raw data. The data visualizations activities developed as a complementary learning module to *Sol y Agua*, allow the teachers and students to interact with the data to identify information and knowledge embedded in the data. Students learn how data can help in making decisions, increasing their computational thinking skills and ability to create and interpret data visualizations.

#### IV. FRAMEWORK FOR A LEARNING PLATFORM

The learning platform aims to improve the ability of students to infer knowledge from disparate sources, to derive meaning, and translate data, using an inquiry-based approach, e.g., through data visualization modules [14][30][35]. This section provides a brief overview of various aspects of the design and development of the *Sol y Agua* learning platform.

##### A. Game-based Learning and Educational Standards

The *Sol y Agua* learning platform employs a game-based learning approach to enhance learning related to water conservation and environmental sustainability at a middle-school level. The activities in the platform and the corresponding lesson plans incorporate the Texas Essential Knowledge and Skills state curriculum standards (TEKS) [37] to ensure that the content addressed is relevant to the educational standards in the classroom. The activities in *Sol y Agua* are developed such that the activities cover various subjects, content, pedagogical approach, and prerequisites. The activities are created with a focus on water conservation and environmental sustainability.

##### B. Framework for Developing a Learning Platform

The design and development of the *Sol y Agua* learning platform can be described using three layers: *Conceptual Layer*, *Gameplay Layer*, and *Development Layer* (see Fig. 1). The Conceptual Layer includes components related to the storyline

of the game and includes lessons, tasks, and goals for the game and associated activities. The Gameplay Layer includes the components that affect user experience of the platform. The Development Layer includes all the components that lead to the successful development of the platform.

**Conceptual Layer:** The major task of this layer is to determine the story (storyboarding), the goal of the player, the tasks that will need to be completed within the game, and the lesson plans for these tasks.

**Story:** A story introduces the player to the game and helps him/her navigate through the different scenes or activities. At the initial phase of design, the story is textual and incorporates the flow of the game. A number of storylines around regional water issues were developed for the *Sol y Agua* platform, among which one was later finalized as the main storyline. The particular storyline includes designing an environmentally sustainable park. The storyline dictates that the player gains understanding of certain scientific concepts and should use those concepts to make informed decision (e.g., selecting the right plant based on soil properties). Additionally, all the storylines developed for the different in-game activities are standalone and complementary to each other. All the storylines incorporate aspects of regional issues and diverse characters.

**Characters:** The story is complemented by the development of characters, which help the user relate to the story. The characters are essential for presenting different ideas or perspectives to the player. The characters of the game are designed to have visual similarities to the demographics of the region to create a program that students can relate to. The main characters include the wise owl (*Owlfonso*), a middle school girl (*Danny*, short for *Daniela*), and her brother (*Alex*, short for *Alejandro*). These characters lead the main storyline of the game. Danny and Alex were created with a Hispanic and Mexican-American background in mind. They represent the target demographic of the project to use cultural relevancy to attract the Hispanic and female minority to STEM. Additionally, the other characters created for the game contradict stereotypes and help change the perspective of minorities in STEM. As a result, the characters within the platform include a female scientist, Hispanic doctors, and African-American professors.

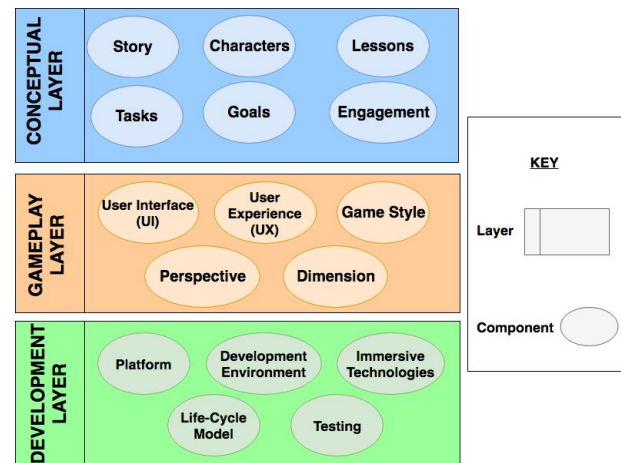


Fig. 1: Design and development framework.

*Lessons:* The lessons include learning objectives that help evaluate the efficacy of the game in teaching or augmenting the learning environment. These lessons also allow the educators to map the platform’s activities to their own lesson plans.

TABLE I: CONCEPTUAL LAYER COMPONENTS

Scenario: Water Sampling and pH Neutralization	
Story	Jason is an employee at a local water treatment plant. He oversees the operations in the plant. Today, the plant had some issues with the water desalination unit. He was alerted right away of a possible contaminated water distribution. He has stopped all operations in the plant and has scheduled pH water analysis on all homes affected. You have to collect and analyze 10 samples from different homes throughout El Paso. You will also need to present your findings to the local board of health.
Characters	Jason and the player.
Description	Students will follow a tutorial on how to properly operate virtual classroom components. Students will then collect water samples from the El Paso-Rio Grande Region. Students will utilize a pH meter to identify the concentration of OH <sup>+</sup> ions in the samples. The students will then utilize a strong acid or base to neutralize the water samples, and report on their findings.
Lessons	<ol style="list-style-type: none"> <li>1. Students will be able to follow proper laboratory procedures in the virtual laboratory.</li> <li>2. Students will be able to collect, interpret, and utilize data to neutralize pH of different water samples.</li> <li>3. Students will be able to correctly identify Personal Protective Equipment (PPE).</li> <li>4. Students will be able to identify different water sources for sampling.</li> </ol>
Tasks	<ol style="list-style-type: none"> <li>1. View factoids.</li> <li>2. Complete the Virtual Lab Tutorial.</li> <li>3. Collect water samples.</li> <li>4. Read pH levels of samples and neutralize water samples.</li> <li>5. Explain what acids and bases are.</li> <li>6. Analyze results from all samples.</li> <li>7. Find correlations in results using data visualization.</li> </ol>
Goals	Students will be able to identify regional issue and conduct laboratory procedures to solve the issue, Students will be able to use knowledge learned from previous activities and other domains to make observations, draw conclusions, and design solutions.
Engagement	<p><i>Personal:</i> The problem statement for this activity is relatable to the students on a personal level because the contaminated water affected the region they live in. Water quality is usually something middle-school students take for granted, so by targeting that which they see as permanent, we attract their engagement.</p> <p><i>Regional:</i> We introduce the Desalination Plant in El Paso, a facility that is of extreme importance for water consumption and use in El Paso.</p> <p><i>Cultural:</i> The main character of this activity, Jason, is a Hispanic engineer. This gives us access to engagement on a demographic level. Students learn more about the water by interacting with characters that look like the students and come from similar backgrounds as the students.</p>

*Tasks and Goals:* Each activity has a set of tasks with specific goals. The tasks identify the requirements to accomplish specific goals. Tasks and goals are critical for developing an effective scoring system. For example, in the park design activity, the player is tasked with creating a design that meets several requirements and are scored based on their adherence to these requirements. The score is influenced by the plants they choose, as well as the distance they have between the plants. In another activity, where the players fly a virtual drone, the players

are required to explore the regions before choosing a location to create their park. They must look at several aspects of each region and select the one they believe will best accomplish their goal of making the best park. In the pH virtual lab activity, the player has a set of tasks to complete, such as measuring and neutralizing water and soil samples of each region, in order to learn about pH and lab procedures.

*Engagement:* Engagement refers to the factors that contribute to the user engagement on personal, regional, or cultural levels. This component enables the game to be relatable to the user. One example is the use of small pieces of facts, called factoids, that are shown to the player at random intervals with the goal of them learning something new about the place they live, or about the water they use. For example, there is a factoid on the Rio Grande river that states that the Rio Grande is a major water source for the region. Some students may already know some of the facts; but for those who do not, factoids present an opportunity to engage students with the platform through interesting facts about the region, environment, culture, and identity. TABLE I shows an example of the components of the Conceptual Layer that appeared in one activity in *Sol y Agua*.

**Gameplay Layer:** The Gameplay Layer adds technical details to the Conceptual Layer. This layer includes designing user interface, user experience, and deciding game style, perspective, and dimension.

*User Interface (UI):* The UI refers to all the visual components of the game, which include background, color scheme, icons, buttons, sprites, and text boxes. The UI is tightly coupled with the user experience. The UI for *Sol y Agua* was inspired by the Chihuahua Desert. The color palette is dominated by earth-tones, and the color intensity is toned down. The UI does not have bright colors to stay true to the look of the region. The buttons have wood-like texture, and the sprites are mostly water-color-based with toned down colors. Fig. 2 shows the Park Design Activity for the game. The background is a cartoon rendering of the Chihuahua Desert. All the other elements in the UI were created to harmoniously interact with the background. The plants the students are able to play with are also native plants, adding a regional relevance to the UI.

*User Experience (UX):* UX refers to the interactive components of the game. These could also be UI components. UX includes the details on movements, on-click effects, interaction types, visual components, and sounds. The UX elements interact with the UI elements to create an immersive and appealing experience for the player. Since the *Sol y Agua* platform contains a toned-down UI, the on-click effects are also subtle. The platform has original music created to augment the user’s experience of the activities. The music, like the UI elements and on-click effects, is subtle, inspired by nature, and incorporated cultural relevance through the use of Native American instruments like the flute.

*Game Style:* Game style refers to the style of the gameplay. The game can be strategy, action-adventure, role-playing, simulation, task-oriented, or a combination of different styles. *Sol y Agua* allows the player to assume a role of someone helping the main characters, which can be described as a role-playing game. The platform also incorporate simulation in the pH virtual lab and drone scenes, which give a semi-realistic



representation of how one would conduct a pH neutralization experiment or fly a drone (quadcopter) in a real-life scenario.

**Perspective:** Perspective refers to the interaction of the cameras in the scene. Perspective can be 2D (bi-dimensional), 2.5D, or 3D (tri-dimensional). Perspective can vary from activity to activity. Fig. 2, Fig. 3, and Fig. 4 show *Sol y Agua* examples of 2D, 2.5D and 3D perspectives, respectively. The learning platform uses different perspectives in the activities depending on the nature of the activity. The 3D perspective of the drone activity plays very differently to the 2.5 and 2D perspectives of the pH and park activities, respectively. One reason for not using the 3D perspective uniformly throughout all the activities was to eliminate the dependency of hardware resources. Schools usually have machines that are not up-to-date and less powerful. The rendering of 3D graphics requires substantial amount of processing power. Thus, having a game-based platform that heavily employs 3D graphics is likely to result in a poor player experience.

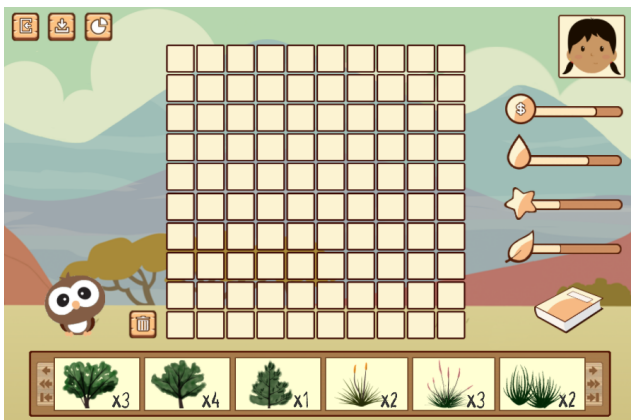


Fig. 2: 2D perspective of the park design activity.

**Dimension:** Dimension refers to the dimension of the game objects. Dimension can be 2D sprites or 3D models. Perspective is closely related to dimension. For example, 2.5D perspective refers to a 2D interaction with 3D objects (e.g., Fig. 3). Fig. 5 and Fig. 6 show examples of a 2D sprite and a 3D model, respectively.

The mountain range where the drone activity takes place are created based on the height maps of actual mountains in the region. The model of the drone are developed using real-life



Fig. 3: 2.5D perspective of the pH lab activity.



Fig. 4: 3D perspective of the drone activity.

drone. The models used in the pH activity are inspired by objects one would find in a school lab. Such realistic modeling allows the players to readily connect with the virtual world. However, when creating or using these virtual assets, we must again be mindful of the deployment environment as 3D objects are more difficult to render and display than 2D objects.

**Development Layer:** The Development Layer is made up of the platform, development environment, immersive technologies, life-cycle model, and testing.

**Platform:** This refers to the development and deployment environments where the game will be played. Decisions about the deployment platform of the game significantly affect the development of the game. Deployment platform includes mobile, desktop, or web.

**Development environment:** The development environment or engine refers to the software used to develop the video game. An example of development environment is the Unity Game Engine [38], which was used for developing *Sol y Agua*.

**Immersive technologies:** This component refers to those technologies used to augment the gaming experience, which can be simulation, data visualization, virtual reality, or augmented reality. Currently, the learning platform employs simulation technologies in the activities to allow players to feel immersed.

**Life-cycle model:** This refers to the software development process for developing the platform and corresponding activities. The learning platform was developed using prototyping, agile, and waterfall life-cycle models [8]. Fig. 7 shows the life-cycle model of the activities within the learning platform. Activity design includes the design of the activity's story, characters, lesson, UI/UX, goals, and objectives. The

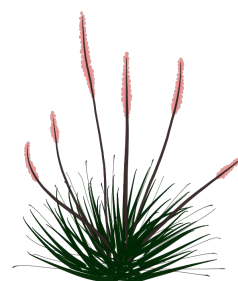


Fig. 5: A 2D sprite of a Red Yucca.



Fig. 6: A 3D sprite of a Pecan tree [7].

development step includes all the development including UI elements and scripting of game objects. The third step is testing. This step aims to find any bugs or errors in the development of these activities. Additionally, we incorporate a level of usability testing to ensure the UI/UX is effective. Next, we integrate the activity to the platform while maintaining the integrity of order of execution and access. Lastly, to evaluate the activity, we conduct beta testing with students and educators to ensure the activity is verified and validated.

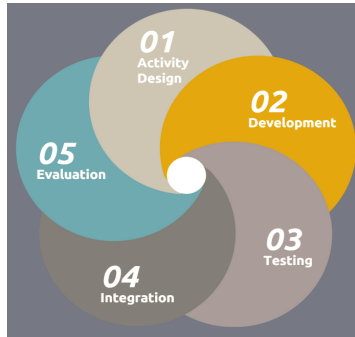


Fig. 7: Life-cycle model of the *Sol y Agua* learning platform.

*Testing* refers to the different types of testing necessary to ensure verification and validation of the activity or the platform. This can be unit, integration, or acceptance testing [8]. Testing also includes the usability testing of the UI [3], as well as surveys, observation, and journal entries.

### C. Complementary Modules

*Sol y Agua* promotes a hands-on, inquiry-based exploration of environmental issues. As part of the complementary material to the *Sol y Agua* learning platform, we developed a number of educational modules. The platform and corresponding educational modules are designed to encourage activities and exercises that address pro-environmental, sustainable practices as suggested by the community members [29]. Thus, the complementary educational modules include activities that takes place in real-life. One of the modules, *Water Use at Home*, covers introductory topics on Data Science. This module has six steps as follows: 1) Introduction to Data Science, 2) Data Collection, 3) Data Transcription, 4) Data Transformation, 5) Data Visualization, and 6) Reflection. The module investigates water usage at home that combines the elements of data science, data analyses, and data visualization. This module enables students to collect data, transform data gathered from multiple sources to infer knowledge, to derive meaning through data visualization tools, and conduct discussion on water conservation issues.

**First Step:** This step serves as the starting point for the rest of the module. This step covers the basics of Data Science by introducing the need for data literacy, the impact of data and data science in our everyday lives, samples of big data sets, and samples of different types of data visualizations and their uses.

**Second Step:** Data is collected on the amount of water usage at home, which is collected in different areas at home. This step allows students to drive the module because they will be using the data they collected throughout the module. We have observed a higher interest and motivation in the module when students use their own data.

**Third Step:** Students transcribe the data they collected into a spreadsheet for future use.

**Fourth Step:** Students transform the data they collected using mathematical formulas and the normalization of their data.

**Fifth Step:** This consists of three components: 1) After students have transformed and normalized their data, they create low-level digital graphs of their data (e.g., excel charts). This allows students to understand their data as they are visualizing it; 2) Students identify patterns in their data; 3) Students modify the source of a Data Driven Document (D3) [25], developed as part of the *Water Use at Home* module, to observe data in a dynamic format.

**Final Step:** Students reflect on the module by comparing their visuals to those of other students. Students are encouraged to ask questions about the data collection process and the demographics of the household. Students see if the patterns they observed in their own data are similar to the patterns of their peers. Students use this opportunity for constructive criticism of their peers' data and visuals. We conclude the module with a discussion on the elements in the module. Students are asked to provide feedback on the entire process, including content.

### D. Ease of Adaptability of *Sol y Agua*

The *Sol y Agua* learning platform is intended to be used by middle-school and high-school teachers. We developed a website [32] that acts as a hub for teachers to access the game and create new lessons using supplementary material. The supplementary material includes learning outcomes from game activities, state standards (TEKS), and complementary in-class activities. The website will also serves as an outlet for news and future releases. It is important to note that the participatory processes to elicit culturally relevant data and design aspects can be replicated at other sites through qualitative, in-depth interviews with experts.

## V. FINDINGS BASED OF PRELIMINARY STUDY

Demos conducted at school events have allowed us to gauge the effectiveness of the user interface of the learning platform by observing our target audience with the platform, as well as asking them to reflect on the activities and their experience with the overall UI of the platform. Fig. 8 presents the result of the Usability testing that was conducted using the prototype release of the learning platform and following a think-aloud methodology [16]. Testing used a five-point Likert scale with 1 being "Very Low" and 5 being "Very High". The User Interface test was conducted on a group of 20 students with an average age of 11.8 years after 15 minutes of exposure to the game prototype. The findings (Fig. 8: A through D) indicate:

- 70% of the student thought the activities were relevant to the lessons in the classroom (Fig. 8: A).
- More than 60% liked the user interface (Fig. 8: B).
- More than 60% thought the game was intuitive.
- 66% knew which items they could interact with.

The Visualization test was conducted on a group of seven students with an average age of 12.1 years. The results (Fig. 8: E through H) indicate:

- 100% of the student thought the visualization taught them about water usage and plants (Fig. 8: E, F).
- Close to 80% showed high interest in learning more about plants (Fig. 8: G).

- About 45% of students expressed a very high interest in learning more about water usage, and an additional 45% expressed high interest in the same category yielding a total of 90% students with high or very high interest in water usage (Fig. 8: H).

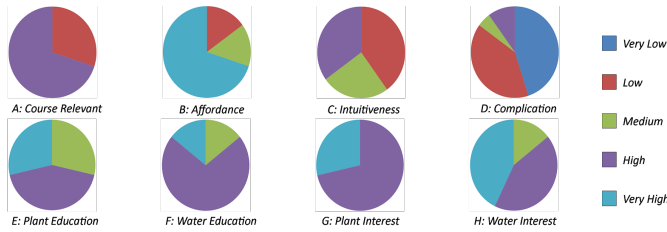


Fig. 8: Usability testing of the prototype platform.

Fig. 9 shows the results of a survey provided to 120 students after 650 minutes (10.33 hours) of exposure to the project over the course of 13 school days at Hernando Middle School in El Paso. The survey was completed by 64 students in the 6<sup>th</sup>, 7<sup>th</sup>, and 8<sup>th</sup> grade. The findings indicate:

- 57% of the students felt inspired to seek a career in STEM after participating in *Sol y Agua*.
- 64% wanted to learn more coding.
- 68% wanted to learn more about data science.
- 71% felt motivated by the *Sol y Agua* learning platform to study computer science.
- 70% students were inspired to seek a higher education, after being exposed to *Sol y Agua* (Fig. 9: E).
- 86% felt coding was important.
- 95% thought visualizing data was useful.
- 78% agreed that the *Water Use at Home* activity helps them understand water sustainability issues in El Paso.
- 64% want to see *Sol y Agua* in their school next year.

As already noted, we also implemented *Sol y Agua* throughout the spring 2018 semester; and, as such, conducted a number of surveys with these students. We are currently analyzing these

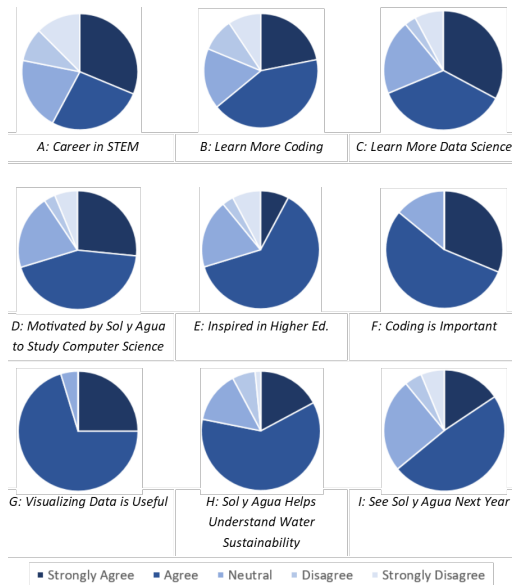


Fig. 9: Preliminary findings.

surveys and do not have summative evaluation at this point. However, we do know that students were highly engaged in the material because our staff and research assistants were integral to much of the implementation at that site. We anticipate similar findings at Slider Middle School at a minimum and possibly better results given the concentration of implementation throughout the spring semester over the course of 18 weeks.

## VI. SUMMARY AND FUTURE WORK

This paper presents a case study [29] that examined how the underlying values, beliefs, meanings, and knowledge of community members collide, intersect, and aggregate to construct new meaning and knowledge of local sustainability issues. The majority of community members believed that to create a deeper connection with the Rio Grande river students must participate in real-life activities along with the virtual learning platform. Other community members suggested that everyday activities that are part of local culture should be integrated with learning activities. Tracking community members' logics revealed their individual values, knowledge, and beliefs, which helped construct new knowledge for developing a culturally-relevant game-based learning platform.

One of our major findings indicates that, in order to engage students in a game-based learning platform, the game's storyline needs to immerse students in familiar issues. Considering the environment, i.e., the desert Southwest on the border with Mexico and demographics of the Southwest region of the U.S. where the platform was developed, i.e., majority Hispanic, these issues were broadly categorized as concepts related to environmental (water) sustainability and cultural relevance. The learning objectives of the activities within the platform also needed to align with state education standards to allow effective and faster adoption by the educators. Both the storyline and the platform needed to be flexible enough to support future expansions and selective adoption by the educators.

The *Sol y Agua* learning platform touches a number of different areas in order to engage and excite middle-school students into STEM areas. These areas include integrating culturally relevant and environmentally related concepts in the platform which fosters computational thinking. The lesson plans use data visualization to help students make informed decisions. Relevant facts are shared throughout the game to broaden the knowledge of the students and to encourage them into exploring more. Initial studies indicate students find the platform relevant and easy to use. Majority of the students indicate excitement about visualization and express interest in learning more about water issues. Further studies are currently ongoing.

*Sol y Agua* allows users to complete STEM-related activities on local iconic locations around the Paso del Norte region. Throughout the gameplay, the user is given factoids about the location they are exploring, facilitating immersion and cultural awareness. Although the platform focuses on the regional issues in the Southwest United States, it can be adapted to other regions with similar characteristics. In the future, we plan to add other language support in the platform, include additional activities that enrich the STEM topics addressed by the platform, and develop a rich set of educational modules to complement the learning activities in the platform.



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