Empowering Indigenous Futures by Blending Virtual Environments and Hands-on STEM for Meaningful Learning in Middle School Classrooms in the Navajo Nation (RTP)

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Introduction

The mission of this project is to explore the affordances of hybrid immersive learning environments situated in tribal contexts to engage Diné (Navajo) middle school students in place-based virtual scientific investigations and hands-on physical experiments and engineering design. This culturally responsive approach has the potential to inspire the next generation of Diné engineers and scientists to use their cultural and STEM knowledge to strengthen their communities and promote tribal sovereignty.

While The World Bank reported that 100% of the population in the United States had access to electricity [1], the Navajo Nation had approximately 60,000 people (~34% of the population) living without electricity according to the Navajo Tribal Utility Authority (NTUA). The Navajo Generating Station near Page, AZ generated power from local coal, but became economically and environmentally inviable leading to its closure and associated loss of jobs in 2019 [2]. The Navajo Nation is geographically and topographically well-situated to shift to solar energy [3], which is more in alignment with traditional beliefs about living in harmony with nature [4]. NTUA has partnered with power company Salt River Project (SRP) to build large-scale solar installations in Kayenta and Monument Valley, AZ [5]. The opportunity for solar energy production is particularly ripe in areas of the Navajo Nation with high rates of unemployment that need economic revitalization [6].

Given the 19.2% unemployment rate [7] and 38% of people on the Navajo Nation living below the poverty line[8], renewable energy and water jobs and businesses could provide STEM career pathways for Diné youth. From 2000 to 2009, 0.6% of undergraduate students enrolled in undergraduate engineering programs were Native American [9]. "Native Americans are 1.7% of the U.S. population, but account for only 0.6% of bachelor's degree recipients, 0.4% of master's degree recipients, and 0.2% of doctoral degree holders in science and engineering" [10].

Given these motivations, this study investigates the impact of a culturally situated, hybrid immersive learning curriculum designed to strengthen STEM engagement among Diné (Navajo) middle school students. The project integrates virtual 3D environments with hands-on engineering design activities, co-developed with Diné community members to reflect Traditional Ecological Knowledge (TEK), cultural history, and community goals.

Literature Review

Immersive virtual environments engage students to explore phenomena and ecosystem scenarios that would be otherwise inaccessible [11]. Virtual environments situate students' investigations in authentic, scaffolded contexts using observations and data collected in the virtual world to build and test hypotheses [12] Hands-on design activities for STEM learning are also valuable [13]. K-12 students should learn engineering design processes and apply them to meaningful, real-world challenges [14].

Culturally-centered teaching approaches help engage diverse students in STEM
Research shows that if students perceive usefulness and relevance they are more motivated to persist in STEM fields [15], [16], [17]. Culturally relevant pedagogy supports students to foreground their cultural identities in the classroom [18], [19]. Culturally responsive schooling [20] calls for curricular and pedagogical strategies that focus on deep understanding of the tribal community's culture as well as the importance of tribal sovereignty, Indigenous worldviews, and Tribal Critical Race Theory [21], [22]. Culturally sustaining/revitalizing pedagogy (CSRP) [19], [23], [24], [25] supports Native American students by recognizing the dynamic, pluralistic societies they live in and helping them access their power by reforming pedagogy from a multicultural, multi-linguistic perspective. CSRP has been used to empower tribal communities to reform STEM education [26].

Traditional Ecological Knowledge (TEK), also known as Indigenous knowledge, is "the unique, traditional, local knowledge existing within and developed around the specific conditions of women and men indigenous to a particular geographic area" [27]. It is "land-centered and inextricably tied to the interconnectedness of all its inhabitants" [28]. TEK considers nature in relation to humanity over extended periods of time [29], while WMS relies upon a positivistic logical empiricism that emphasizes control over nature through experiments [30]. However, "there are no simple technical Western solutions that can be easily diffused and adopted by people on the margins" [27]. TEK supports "projects that emerge from priority problems identified within a community, and which build upon and strengthen community-level knowledge systems and organizations" [27].

Inquiry-Based Learning in Virtual Environments
Virtual environments provide engaging inquiry-based learning experiences grounded in authentic scientific practices [12], [31], [32]. Virtual environments also support project-based learning with motivating questions or problems [33], [34], and constructivist learning [35], [36] where students learn by exploring complex phenomena. Virtual environments support student-led investigation, increasing motivation, engagement, and situated and experiential learning [12], [37]. Virtual experiments focus on salient phenomena, make visible unobservable processes like chemical reactions, and link to observable outcomes [38], [39], [40]. In prior EcoXPT work, students explore a desktop-based 3D immersive virtual pond ecosystem conduct scientific inquiry, and engage in authentic science practices including observation, data collection, analysis, and experimentation on microscopic bacteria [38].

Pilot Curriculum

The Diné Energy Futures curriculum alternates between virtual experiences and hands-on engineering activities. Web-based desktop Unity 3D immersive virtual experiences provide situated, place-based investigation of energy on Navajo Nation, designed to build student awareness and understanding of the cultural and historical context of the topics, and to provide opportunities for students to explore the past, present, and future of energy and water in the Navajo Nation. The first three lessons focus on historic approaches to energy on the Navajo Nation, coal mining and coal-fired power plants on the Navajo Nation, and solar energy generation and usage on the Navajo Nation. The hands-on engineering design activities support learning of science and engineering content and practices, culminating in an open-ended engineering activity to engage students in designing future-oriented solutions for challenges around energy and water on the Navajo Nation. Figure 1 below provides an overview of the curriculum modules.

Virtual experiences	Hands-on engineering activities
Historic: How people lived before electricity. Help a family prepare for winter. Building a hogan (home), gathering firewood, storing and preserving food.	Design, build, and test the insulation properties of a paper mâché hogan or clay oven.
Coal and Exploring Electricity through Power Plant Models: History of coal mining and power generation on Navajo Nation. Impacts – environmental, financial, spiritual, health. Virtual coal mine, power plant.	Build a model power plant to learn how they generate electricity.
Bringing Electricity to the Remote Hogan: Using the sun to generate electricity. Learn about on-grid solar arrays, and how to set up off-grid solar units. Talk to homeowners, line workers, installers.	Students use solar panels to build models, learn about electrical circuits and energy storage. Design, build, and test a reliable off-grid solar lighting system for a remote hogan
Future: Moving towards energy sovereignty and a sustainable future, considering impacts on the land and the people, career opportunities in renewable energy.	Open-ended engineering design project for a Diné Energy Futures Fair

The full Energy unit is intended to span three to four weeks of class time, including three days of place-based virtual environment activities, and two to three weeks of hands-on engineering projects. In the virtual experiences, students will explore the past and present of energy on the Navajo Nation. Each virtual experience covers approximately one 30 minute class period, and "sets the stage" for an associated hands-on engineering design activity during one or more following class periods, so that the curriculum alternates four times between virtual and hands-on experiences.

The first three hands-on activities involve closed-ended engineering knowledge and/or skill building activities around different aspects of energy on Navajo Nation; the fourth is an open-ended Diné design project for students to prototype future solutions to address energy issues. The curriculum includes bridging through teacher-led classroom activities involving discussion, reflection, and connection with students' and their families' experiences and history with energy.

Virtual experiences

The three virtual experiences represent historic (pre-electricity), coal, and solar usage and experiences within the local community. Each virtual experience begins as a Diné gathering in a hogan (see Figure 1) with a multi-generational family, with the player taking part as a young family member. The conversation turns to energy, and an elder relative starts to tell a story, which becomes a transition to the 3D interactive experience. A map (see Figure 2) represents virtual locations on Navajo Nation during the appropriate time period. Associated with each location are non-player characters (NPCs) that students can converse with. Students are given quests that involve helping the community with tasks associated with energy and the historic context.

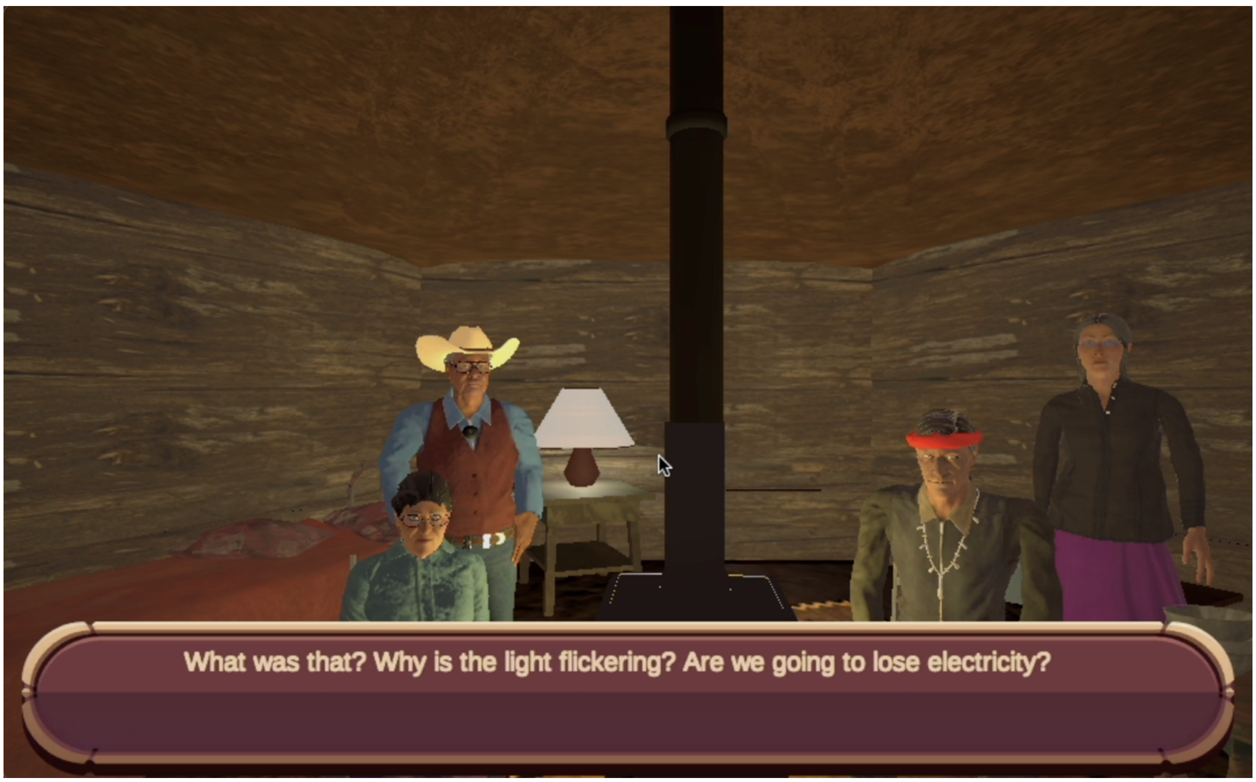

Figure 1: Conversation at the start of a virtual scenario

Figure 1: Example map from virtual experience

Hands-on experiences

During hands-on engineering activities, students engage in engineering design, model-building and testing in order to develop understanding of the science related to energy, and engineering design principles. In the Historic lesson, students build scale models of clay ovens or Hogans (traditional Diné homes) and learn about the science of heat transfer and thermodynamics when a heat source is put inside the structure and the heat conducted to the outside is measured. In the Coal lesson, students learn about the science of power plants and build a scale model of a power plant turbine to generate electricity using a fan, and power different numbers of LEDs in series and parallel circuits. In the Solar lesson, students learn about the cultural significance of the sun, learn about and measure voltage and current with a multimeter, learn about solar panels and how they work, and finally use an engineering design process to design and build a solar lighting system for an off-grid Hogan (see Figure 3). In the final Futures lesson, students create posters or presentations of engineering-based solutions for their communities and exhibit them at a Diné Energy Futures Fair (see posters in Figure 4), which schools are encouraged to make public-facing so that parents and community members can see and discuss their kids' ideas for the future.

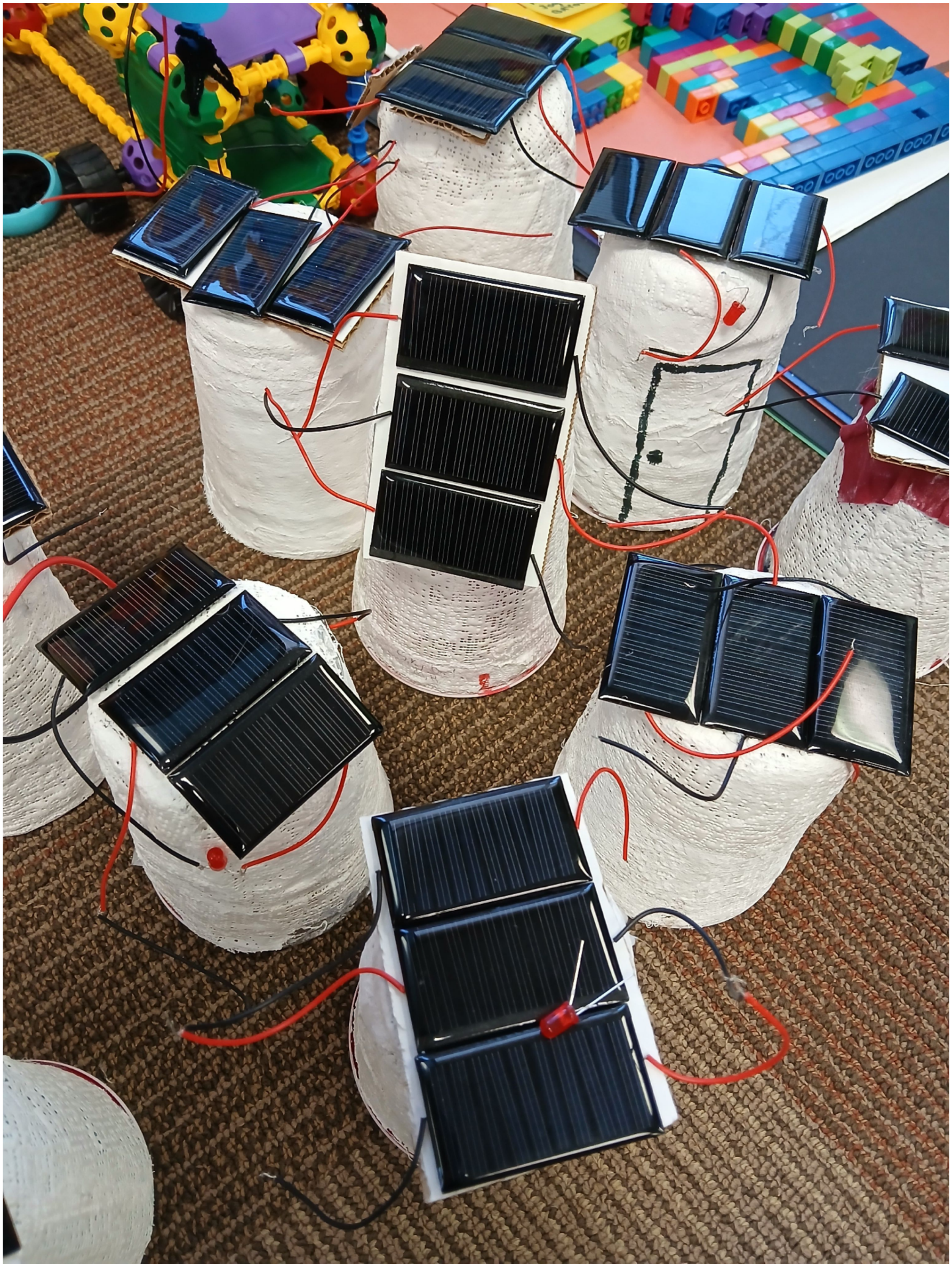

Figure 3: Solar lighting systems for Hogans

Figure 4: Diné Energy Futures Fair posters

Methods

The following research questions guided this study:

> *RQ1.* What are the ways in which teachers on the Navajo Nation experience teaching with a hybrid culturally-situated immersive learning environment?
>
> *RQ2:* What are the ways in which Diné students experience learning in a hybrid culturally-relevant immersive learning environment?

Research Methods

Semi-structured interviews were conducted with a sample of teachers and students who piloted the curriculum in 2025. Transcripts were analyzed using inductive thematic analysis. This study was approved by both an institutional IRB and the Navajo Nation Human Research Review Board.

Population and Sampling
A total of 6 teachers across 4 schools participated in interviews (see Table 2), and a total of 6 students from two of the schools were interviewed following their experience with the curriculum.

Table 2: Teacher interview participants

School A	School B	School C	School D	Total
2	2	1	1	6

Data Collection
Semi-structured interviews of ~1 hour were conducted with each research participant to explore their experiences of the hybrid curriculum. The interview protocols (teachers and students) were adapted from prior work with the Navajo Nation [41], developed in collaboration with Diné community members to elicit participants' experiences, and piloted beforehand.

Results
Teachers experienced teaching in a hybrid culturally-relevant immersive learning environment as…

Theme 1: Strengthening cultural identity and community connection.
Teachers experienced the hybrid curriculum as culturally affirming, connecting students' Navajo heritage, community knowledge, and local places to energy contexts (e.g., Kayenta coal mine, Diné bizaad, and family interviews).

Theme 2: Enhancing student engagement and critical thinking through experiential and inquiry-based learning.
Teachers recognized hybrid experiences foster student engagement, curiosity, and critical reflection on cultural and energy concepts. "In interviewing their grandparents students learned to "appreciate their grandparents, how they survived long time ago, without this source of energy that we are enjoying now."

Theme 3: Encouraging pedagogical shift toward student-centered and reflective teaching.
Teachers experienced a change in their teaching approach from more passive textbook methods to more facilitative, inquiry-based approaches. "Because I have these resources, I have to transition from virtual to hands-on. So it's gonna be more on a student-centered thing."

Theme 4: Technologically challenging.
Teachers experienced persistent barriers such as unstable internet, limited materials, and lack of technical support. Although these challenges hindered implementation, they were resilient adapting and modifying lessons.

Theme 5: Providing instructional scaffolding that deepens conceptual and comprehensive STEM understanding.

Teachers recognized the virtual environment as providing conceptual background for hands-on experiences and an opportunity to deepen understanding of STEM concepts.

Students experienced learning in a hybrid culturally-relevant immersive learning environment as…

Theme 1: Identity development and empowerment.
Students begin to see themselves as future change-makers who can apply STEM skills to serve and uplift their communities. “Getting knowledge, this past school year, of how solar energy works and how, just different ways you can make energy. And I think that's something I look forward to, on helping my community in the near future.”

Theme 2: Meaningful cultural engagement.
Students recognized cultural connections related to Diné language, values and lived experiences they had not experienced in STEM before. “The grandparents are speaking back to you like shíyázhí (my little one). Just those things were something new to see, because I've never played a virtual game where it connected to your culture, but you're actually learning from it”

Theme 3: Learning through challenge, resilience, and support.
Students understood learning as an iterative process with opportunities for trial-and-error within a scaffolded environment. “You try to find different solutions for the problem you’re facing and never give up.”

Theme 4: Interconnected and complementary.
Students recognized virtual game introduced STEM concepts and understanding through storytelling while the hands-on experiences put those concepts into practice. “The virtual game gave us a rough draft...so when we got to the hands-on, all of us understood it very well.”

Conclusions and Future Work
This study investigated the impact of a culturally situated, hybrid immersive learning curriculum designed to strengthen STEM engagement among Diné (Navajo) middle school students. The project integrates virtual 3D environments with hands-on engineering design activities, co-developed with Diné community members to reflect Traditional Ecological Knowledge (TEK), cultural history, and community goals.

During the 2024–2025 academic year, an Energy Futures curriculum unit was piloted across four Navajo Nation schools with over 100 students and six teachers. The curriculum alternated between virtual simulations—depicting historic, coal, and solar energy contexts—and hands-on engineering projects addressing energy and water issues. Analysis of teacher interviews and student feedback indicates that the curriculum increased engagement, motivation, and cultural relevance in STEM learning. Teachers reported that students demonstrated strong identification with the virtual characters and settings, enhancing comprehension of scientific and engineering concepts through familiar cultural narratives. Findings include that teachers experience teaching the curriculum as strengthening cultural identity and community connection, enhancing student engagement and critical thinking through experiential inquiry-based learning, encouraging pedagogical shifts toward student-centered and reflective practices, technologically challenging, and providing instructional scaffolding that deepens conceptual and comprehensive STEM understanding. Additional findings include that students experienced the curriculum as supporting identity development and empowerment, providing meaningful cultural engagement, learning through challenge, resilience, and support, and learning in interconnected and complementary ways.

Future research will extend these findings by analyzing quantitative learning gains and expanding the model to additional schools and topics such as water sustainability. This project contributes to the growing evidence that culturally responsive, immersive education can effectively bridge community knowledge systems and modern STEM education, promoting both academic achievement and tribal sovereignty.

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