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Spreadsheet-Based Application Integrated with Virtual Reality for Teaching Economic and Environmental Assessment of Subsurface Gasification for Hydrogen Production

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Emma Smith is a dedicated third-year computer science student at the University of Oklahoma, where she has immersed herself in the dynamic intersection of technology and sustainability. Her passion for sustainability efforts, particularly in the realm of hydrogen energy, has driven her academic pursuits and research interests.

Emma not only excels in her studies but also extends her enthusiasm for computer science to education. She is deeply committed to teaching younger students about engineering concepts, leveraging her technological skills to make complex subjects accessible and engaging. Emma has demonstrated a keen interest in innovative teaching methods that incorporate technology, showcasing her commitment to fostering a new generation of tech-savvy learners.

Building on her experiences in computer science and education, Emma is actively involved in undergraduate research at her institution. Her research endeavors focus on exploring novel applications of technology, with a specific emphasis on contributing to advancements in sustainability and energy solutions. Emma's dedication to both her academic and outreach efforts underscore her commitment to making a positive impact in the fields of computer science and sustainable technology.

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Abstract

The present study report results and insights from the proposed educational game developed by integrating a spreadsheet-based app and virtual reality (VR). This game is a great tool to get college and high school students excited about learning how to design a chemical product while thinking about economic evaluation, environmental impact and sustainability. The game is designed to fit into courses about sustainability or chemical engineering, for both students specializing in these areas and those who aren’t but have a keen interest in sustainability, especially the role hydrogen plays in promoting it. It's also suitable for high school programs, mini study groups and career day presentations. The game is free to use and helps students practice making important decisions in industry, like choosing the right product or process. Experienced teachers and students have tried this game and given their opinions. Based on their feedback, the game can be easily added to current teaching programs.

Keywords: Virtual reality; Hydrogen; Life cycle assessment; Techno-economic evaluation; sustainability.

1. Introduction

Hydrogen holds immense promise as an energy carrier, offering diverse applications. Hydrogen's unique properties, such as being colorless and odorless, coupled with its environmentally friendly combustion byproduct (water vapor), make it an attractive option for various sectors. Figure 1 highlights some of the most notable hydrogen uses.

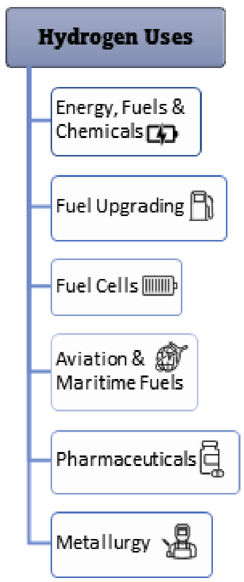

Figure 1: Overview of hydrogen applications

However, about 96% of the hydrogen used today is produced from petroleum-based resources via steam reforming reaction [1]. Although promising, conventional hydrogen production methods, particularly from fossil fuels, contribute significantly to greenhouse gas emissions, emphasizing the need for sustainable alternatives [2]. Renewable resources, such as biomass materials, have been explored for hydrogen production, but face challenges related to intermittent and economic viability, hindering large-scale adoption [4].

Meanwhile, subsurface hydrogen production, utilizing hydrocarbon resources through in-situ combustion (ISC) or in-situ gasification (ISG), emerges as a promising alternative. This method involves injecting steam or oxygen into underground reservoirs, minimizing carbon dioxide emissions by leaving byproducts underground [3]. The benefits include leveraging existing infrastructure, cost-effectiveness, and minimal CO_2 emissions due to carbon capture underground [5][6].

In engineering education, innovative teaching methodologies have gained prominence, especially in sustainable hydrogen production. Innovative teaching approaches such as the gamification and the use of comics are important because they democratize access to complex scientific knowledge, making it more accessible to a wider audience, including students, researchers, and industry professionals [7]. Therein lies the motivation of this work. This paper introduces an integrated approach, combining a spreadsheet-based activity with a virtual reality (VR) game, to educate students on hydrogen energy, subsurface production methods, and large-scale operational challenges. This educational tool is designed for versatility, applicable to diverse educational settings and suitable for both chemistry and non-chemistry majors. Notably, it extends to high school outreach, fostering interest in engineering from an early age.

The use of VR in education settings is not new and has been reported by several research studies [8][9]. Polina et al. [10] presented a teaching methodology of a practical engineering course that involves the simulation of interdisciplinary industrial projects using VR. Halabi. [11] showed that the implementation of VR with project-based learning (PBL) could improve communication, problem-solving skills and effective learning. Bogusevschi et al. [12] presented a case study where VR was used to teach the physics of water cycle. Overall, these studies show the relevance of VR at every level of engineering education.

As we prepare the engineers of tomorrow, it is crucial to instill a holistic understanding of sustainability and the economic and environmental implications of their designs. Subsurface hydrogen production serves as a practical and sustainable teaching tool, allowing students to explore not only technical aspects but also the broader context of energy production. This integrated approach aims to inspire the next generation of engineers, cultivating critical thinking and problem-solving skills essential for addressing the challenges in the evolving field of sustainable energy. The proposed game aims to fulfill the following learning objectives: improve the understanding of subsurface technologies for hydrogen production, promote awareness of environmental pollution and equip students with preliminary economic and environmental evaluation skills.

2. Overview of game and VR activity

The spreadsheet activity presented in this study serves as a game-based entrance into the complexities of techno-economic analysis (TEA) and life cycle assessment (LCA) for subsurface hydrogen production. The authors have already published an in-depth review of these topics in a recent study [6]. A link to the review is also available in the spreadsheet application for any educators who wish to learn more about the topic before introducing it to their classroom.

The study aims to ultimately introduce engineering students to TEA and LCA as it is widely utilized in every engineering field. These are vital tools in the field of hydrogen production, playing a crucial role in steering this sector towards sustainability and economic viability. TEA provides a comprehensive evaluation of the economic aspects of hydrogen production technologies, assessing factors such as capital investment, operational costs, and market potential, which are essential for determining the feasibility and competitiveness of different hydrogen production methods. Meanwhile, LCA offers an in-depth analysis of the environmental impacts associated with hydrogen production, encompassing the entire life cycle of the process, from raw material extraction to end-of-life disposal. This includes assessing the carbon footprint, resource consumption, and ecological consequences.

The proposed spreadsheet-based activity is structured in a manner reminiscent of a "word puzzle," this interactive game encourages users, particularly beginner-level engineers, to delve into the intricacies of making important decisions in non-optimal conditions. The core focus of the spreadsheet activity lies in introducing fundamental concepts of capital expenditures

(CAPEX), operational expenditures (OPEX), and optimal location selection. The game prompts users to consider trade-offs and the importance of various selection factors, such as hydrocarbon reserves, proximity to infrastructure, socioeconomic impacts, and environmental impacts. Figure 2 showcases the location selection aspect where users must consider various factors to choose the optimal operation site. This activity encourages users to think critically about non-optimal conditions that may arise in real-world engineering scenarios. Through the "word puzzle" structure, learners are challenged to find optimal solutions to these challenges, emphasizing the need for thoughtful consideration and strategic decision-making. The overall goal is to highlight the significance of factor considerations in engineering fields, especially when confronted with less-than-ideal circumstances.

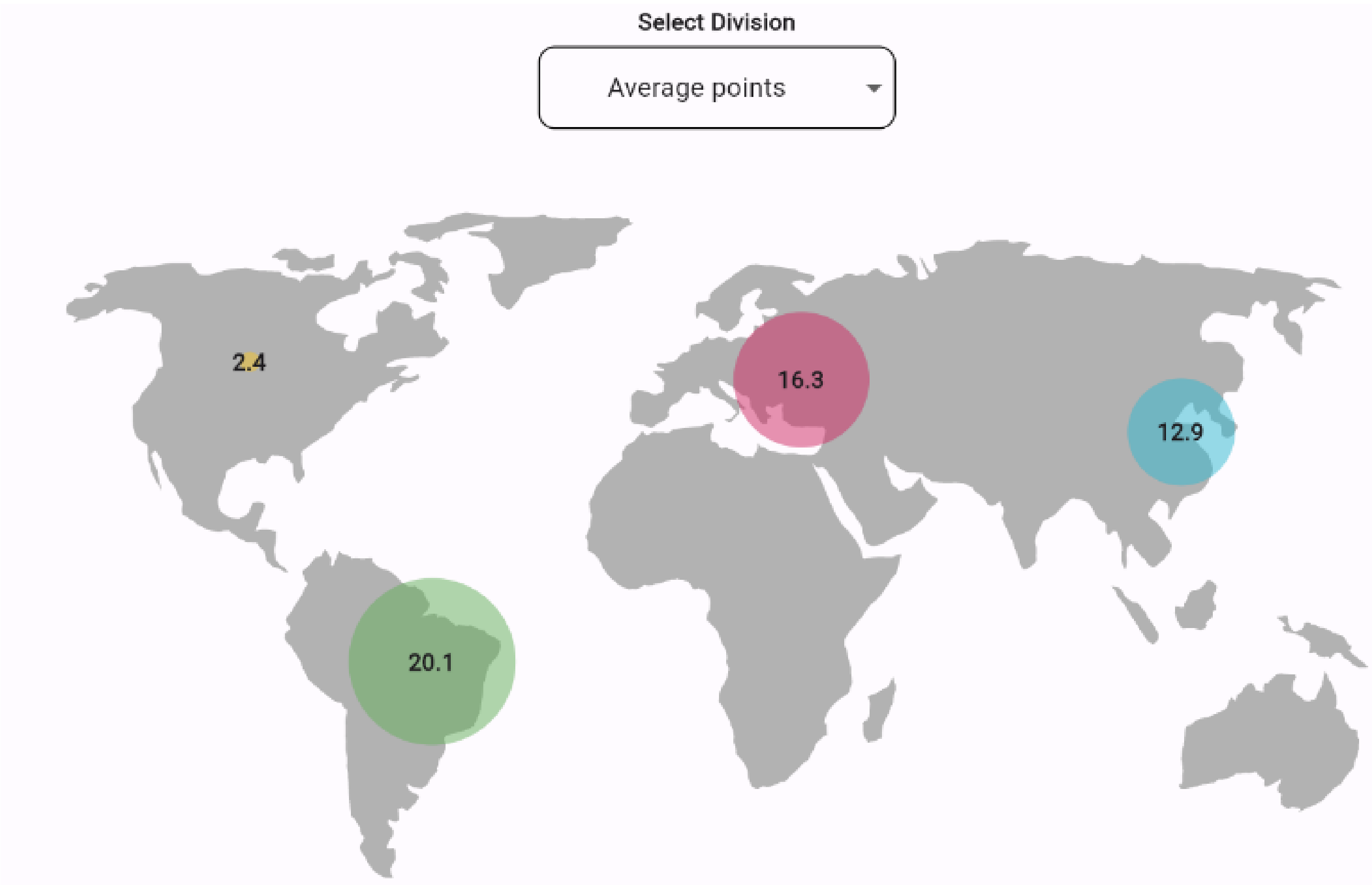

Figure 2: Overview of the location selection map in the spreadsheet-based activity.

The spread-sheet activity is designed to proceed in 6 sequential steps including the selection of subsurface gasification location, CAPEX estimation, OPEX estimation, levelized cost of hydrogen estimation, parametric studies, and environmental assessment. The location selection decision is made by considering factors such as water availability proximity to infrastructure, environmental impacts. Hydrocarbon reserves and socioeconomic impacts. While a location with more hydrocarbon reserves might be more economically viable, factors such as proximity to roads, pipelines and processing facilities should also be considered as well as the closeness to water facilities required for drilling and other operations. More importantly, socioeconomic impacts such as job creation and local economic development should also be considered. The spreadsheet app is designed in such a way that the players are encouraged to vary these parameters and evaluate how it influences their decision in selecting the optimal location for subsurface gasification. Detailed description of the location selection factors as well as the activity instructions has been documented in part 1 of the spreadsheet-based app.

Complementing the spreadsheet activity is an interactive Virtual Reality (VR) desktop game designed to reinforce the importance of alternative energy sources, with a specific focus on hydrogen energy. This VR experience guides users through interactive rooms to optimize the learning experience for users, compared to more traditional teaching methods. Figure 3 shows the first scene of the proposed VR game. As seen in Figure 3, users initially encounter the pressing need for alternative energy sources due to carbon emissions and are introduced to hydrogen-based fuel as a promising solution. Although a screenshot cannot capture every element in the 3D space, the starting scene contains call-to-action posters, educative videos, and an atmosphere model. Shortly thereafter, the game seamlessly integrates economic viability into the narrative, demonstrating how extracting hydrogen via subsurface production from hydrocarbon reservoirs can be a profitable endeavor by utilizing existing infrastructure. Figure 4 shows a glimpse of the room containing videos and interactive elements of hydrogen energy and its economic benefits. As users navigate through the virtual space, they witness and interact with a live demonstration of the intricate process of hydrogen separation in a hydrocarbon reservoir. In Figure 5, users can see the complexities of rock layers, oxygen being injected into the reservoirs, and the ultimate production of syngas to be extracted through the subsurface separation membrane.

Detailed description of the spreadsheet content and activities as well as the entire VR game can be accessible through the bar code provided in supplementary information. A block flow diagram of the game development is presented in figure 6.

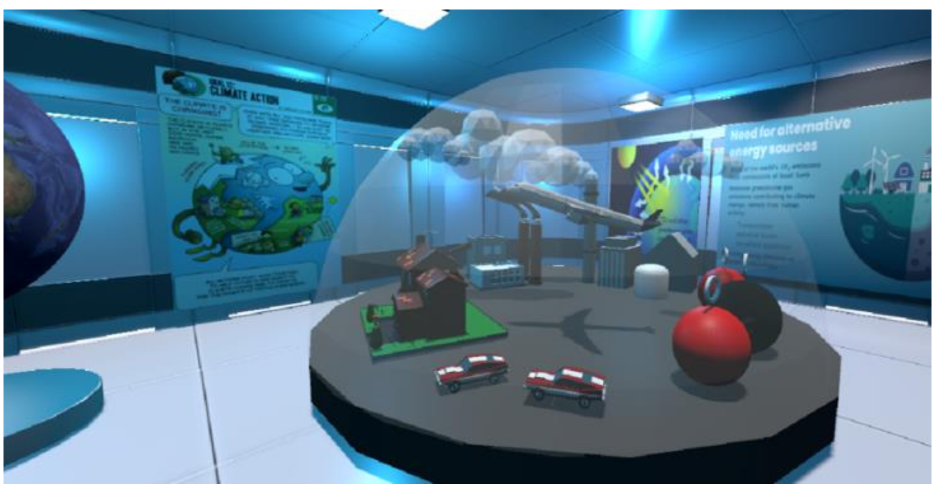

Figure 3: First scene of the VR game showing the importance of reducing carbon emissions.

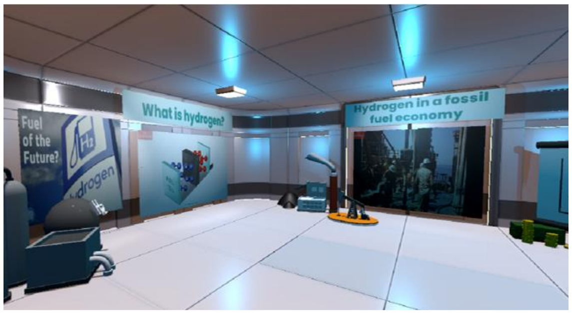

Figure 4: Users are shown the advantages of hydrogen in a fossil fuel economy.

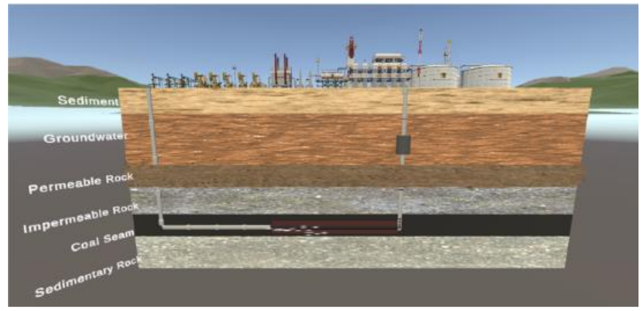

Figure 5: Demonstrates the subsurface gasification process.

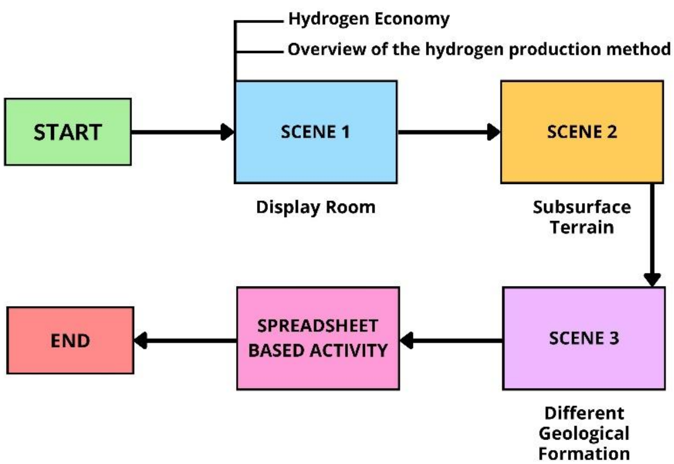

Figure 6: Block flow diagram of game development.

3. Survey design and results

This study aimed to assess the effectiveness of the previously discussed teaching approach. A survey was created to address certain objectives, which gathered responses from two distinct groups: first-year diversified engineering students at the University of Oklahoma (15 students) and fourth-year chemical engineering students at the University of Benin (35 students). Participants were asked to provide responses on a scale of 1-5, where 1 indicated “strongly disagree and 5 indicated “strongly agree.” The results revealed insights into the perceived impact of the educational tool across the two groups. As seen in Table 1, questions are further grouped together by a color-coded scheme of three key objectives. It should be mentioned that these color codes were selected to align with the primary learning objectives of the proposed game.

- Yellow – Did the game increase participant's understanding of subsurface hydrogen production?
- Green – Did the game prove relevance to their declared studies and does it help improve their awareness of environmental pollution?
- Blue – How well was the game organized?

As shown in Table 1, the average response was calculated by taking every individual's numeric response and dividing it by the total number of participants. This number represents a response on the same Likert scale of 1-5 of 1 being strongly disagree through 5 being strongly agree.

It is important to note that our study focused on engineering students as the target audience, which inherently limited the sample size of the population. The two classes involved in the study comprised 15 and 38 students, respectively. Despite the relatively small cohort size, it is worth highlighting that both groups yielded similar responses in the student response evaluations. This suggests that observations drawn from these groups were reliable, given that they were entirely independent of one another and located in different regions. While a larger sample size might have provided additional data to draw conclusions from, the consistency of responses across the two groups lends credibility to the observations and conclusions made within the constraints of the cohort size. The evaluation of a VR game aimed to assess its logical structure and presentation clarity. Over 80% of participants found it well-organized, though suggestions for improvement included adding detail to illustrations and providing hints. Chemical engineering students found the game relevant to their course comprehension, particularly in engineering design and economic assessment. University-specific feedback indicated higher relevance ratings from University of Benin students, emphasizing the importance of tailoring educational tools. While both groups rated hydrogen production similarly, variability existed in feedback on organization and engagement levels. Overall, students desired more illustrative concepts for enhanced engagement, suggesting potential refinements to improve the learning experience.

Table 1: Survey responses based on color codes of their key information.

Question #	Objectives	University of Benin	University of Oklahoma
Q1	**The game effectively enhanced my understanding of hydrogen production**	4.23	4.07
Q2	**I believe the knowledge gained through the game is valuable in my studies**	4.23	3.73
Q3	**The game was engaging and captured my interest**	4.23	4.07
Q4	**The educator demonstrated enthusiasm in using the game as a learning tool**	4.26	3.87
Q5	**The game content was logically structured and sequenced.**	4.34	4.47
Q6	**Information within the game was presented clearly and was easy to follow.**	4.37	4.13
Q7	**The game encouraged productive group interactions and collaboration.**	4.14	3.67
Q8	**Group activities within the game were relevant and beneficial to learning.**	4.00	3.67
Q9	**The educator was approachable and available for help during the game-based learning.**	4.29	4.33
Q10	**I felt comfortable sharing my thoughts and questions during game sessions.**	4.09	4.07
Q11	**The game covered all necessary topics related to hydrogen production.**	4.13	4.14
Q12	**The topics covered in the game were relevant to my overall course understanding.**	4.30	3.71
Q13	**The assessments within the game were clear and fair.**	4.21	4.14
Q14	**My performance in the game accurately reflects understanding of content.**	4.09	3.93
Q15	**The game presented a reasonable workload and challenge.**	4.18	4.21
Q16	**The difficulty level of the game was appropriate for my level of understanding.**	4.06	3.93

Conclusion

Overall, these findings underscore the importance of tailoring educational tools to specific audiences and continually refining them to meet diverse learning needs. The feedback gathered from both groups suggests an opportunity for improvement, particularly in incorporating more illustrative concepts to enhance engagement. Ultimately, this study contributes to the efforts in advancing effective and engaging teaching methodologies in subsurface hydrogen production.

The VR game, while serving as an effective educational tool, does have some limitations that merit consideration. One notable limitation pertains to the accuracy of rock formations depicted in the game. For demonstration purposes, the layers lack complexity found in actual geological formations, as the primary focus was on showcasing the depth of coal seams. Additionally, the simplicity of the chemical reactions portrayed in the game is another limitation. The syngas production process, although demonstrated, simplifies the actual complexities involved in various methods and materials used for injection into the reservoir. The game offers a basic illustration of injection processes and the advantages of a hydrogen fuel economy without delving into the intricacies of the diverse chemical reactions that may occur. In summary, the brevity of topics in the VR game may not fully capture the inherent complexities of subsurface hydrogen production operations.

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Supplementary information

Desktop version of VR activity

Spreadsheet-based activity