HOW ROLE-PLAYING SIMULATION GAMES HELP TO UNDERSTAND THE COMPLEXITY OF HYDROGEN SUPPLY CHAINS

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Abstract:
The research focuses on analyzing logistics and supply chains in the field of hydrogen technologies. Special attention is paid to using simulation role-playing games such as H2Student to improve theoretical knowledge and practical skills. The study aims to develop an innovative approach to transferring knowledge into practice to bridge the gap between academic education and industry needs. With the help of the innovative H2STUDENT game, participants learn about the interaction between different actors in the hydrogen supply chain in a simulation environment. This approach enables a deeper understanding of the basic logistics processes and specifics related to hydrogen technologies. The results point to the vital role of practical learning tools in educational programs to prepare professionals for challenges and innovations in hydrogen-focused logistics and supply chains.

Keywords: *Supply chains, Hydrogen technologies, Role-playing simulation games*

INTRODUCTION

Hydrogen technologies are becoming a key element in the global transition to a low-carbon energy future, as they offer promising opportunities to reduce the carbon footprint, especially in the industrial and transport sectors. Hydrogen production, which uses low-carbon energy sources, promises to decarbonise many industries and thus is becoming an increasingly attractive technology (Guilbert & Vitale, 2021; Peksen, 2021). Despite the promising advantages, transitioning to a hydrogen economy brings many technological, economic and geopolitical challenges (Noussan et al., 2020; Sartbaeva et al., 2008).

Effective implementation of hydrogen technologies, especially in transportation, requires a thorough understanding of hydrogen supply chains. These chains represent a complex system that covers the entire hydrogen cycle — from production to final use (Fredershausen et al., 2021). Each phase in this system is interconnected, and the overall efficiency and sustainability of the chain depend on coordinated management.

Awareness and understanding of how hydrogen supply chains work, especially among young people training to be future decision-makers in energy and transport, are crucial. This knowledge can increase their chances of making informed decisions that promote clean energy and contribute to achieving global sustainability goals.

For these reasons, it is prudent to include the topic of hydrogen supply chains in educational programs. To this end, we have designed an innovative simulation role-playing game, H2STUDENT, as a practical teaching tool for complex systems such as the hydrogen supply chain. This game allows students to understand the dynamics and interconnections within supply chains through hands-on experience, complementing traditional educational approaches and increasing student engagement.

This work aims to analyse and demonstrate how the H2STUDENT simulation game helps students understand the complexity of hydrogen supply chains, thereby contributing to better preparation of future professionals for the challenges and innovations in the field of hydrogen technologies.

LITERATURE REVIEW

Hydrogen is acknowledged as a crucial element in a low-carbon energy future due to its potential in various sectors like electricity, heat, industry, and transport (Staffell et al., 2019). However, challenges such as efficient hydrogen storage, life-cycle CO2 emissions, and techno-economic hydrogen production-process assessments exist (Ozawa & Kudoh, 2021; Zulfhazli et al., 2022). The integration of hydrogen with power systems is vital for future clean energy sources (Pudjianto & Strbac, 2022). Hydrogen's role in reducing carbon emissions, its use in energy storage, and its potential as a fuel source are highlighted (Bakenne et al., 2016; Shojaeddini et al., 2019; Edwards et al., 2007). To realise a sustainable energy transition, advancements in hydrogen production,

storage, and utilisation technologies are essential (Lee & Sim, 2022). Overall, hydrogen is poised to be a key player in transitioning to a low-carbon energy system, but addressing technical, economic, and geopolitical barriers is crucial for its widespread adoption.

Simulation games have been increasingly recognised for their effectiveness in bridging theoretical knowledge with practical skills in educational contexts. Studies by Sitzmann (2011) and Vlachopoulos and Makri (2017) have shown that simulation games can enhance cognitive, behavioural, and affective learning outcomes. Additionally, research by Wilson et al. (2008) and Liao et al. (2015) emphasises the growing realisation of the effectiveness of simulation games in education. These findings support using simulation games to prepare future professionals for managing and developing hydrogen technologies by providing a hands-on, interactive learning experience that complements theoretical knowledge with practical application.

Simulation games have also significantly impacted the understanding complex systems like supply chains. Studies such as those by Deshpande and Huang (2011) and Katsaliaki et al. (2014) show practical knowledge and skills improvements through simulation games focusing on supply chains. These games aid in translating qualitative aspects into quantitative economic consequences, teaching service-oriented supply chain management principles, and optimising supply chain performance measures. Simulation exercises like The Beer Game also help understand basic supply chain mechanics and the Bullwhip Effect. Overall, these studies underscore the effectiveness of simulation games in enhancing comprehension and decision-making within supply chain contexts.

The literature review reveals a gap in developing and implementing simulation games, specifically in teaching about hydrogen supply chains. Most existing approaches do not address hydrogen technologies' complexity and interdisciplinary aspects. This paper presents the development of a new simulation game, H2STUDENT, aimed at deepening the understanding of the hydrogen economy, integrating technical knowledge with management skills, and simulating current industrial challenges. The game is designed for interactive learning and is adaptable to different educational levels, allowing it to be widely used in academic and industrial contexts.

SIMULATION GAME H2STUDENT

H2STUDENT is an innovative game that simulates the supply chain of a hydrogen car and includes a competitive edge where participants are divided into groups. The game is designed in such a way that it can be adapted to different age groups, which allows for broad applicability. Due to time constraints and the high cost of components, the participants in the game do not build a real hydrogen car but an electric vehicle built from Lego blocks. However, since a hydrogen car is an electric vehicle, this approach still allows for a realistic simulation experience of how a hydrogen car works. In the following, we present the essential elements of this innovative simulation game, which includes the following parts or contents (Figure 1): Introductory phase, Presentation of the rules and objectives of the game, Competitive dynamics, Quiz and scoring, and Final phase and Grand Prix. The game lasts about 3.5 hours.

Figure 1: Structure of H2STUDENT GAME

The introductory phase of the H2STUDENT simulation game sets the stage for understanding the entire game and the context in which the game takes place. This phase is divided into several key segments, forming a comprehensive introduction to the dynamics of hydrogen technologies and simulation. Participants are first introduced to the basics of supply chains, specially adapted to the field of hydrogen. The key steps are explained, from the production of hydrogen, its storage and transport, to its final use. Special attention is paid to understanding how hydrogen is integrated into energy systems and its advantages and challenges. Participants learn in detail about hydrogen production methods, especially water electrolysis. Alternatives such as hydrogen production from fossil fuels are also presented. The technological, economic and environmental challenges brought about by these technologies' increased use are discussed.

Attendees receive a detailed insight into how hydrogen cars work, including an explanation of the fuel cells that convert the hydrogen back into electricity. The advantages of hydrogen cars compared to other electric vehicles, such as shorter charging times and greater range, are explored. The importance of sustainability in the context of global climate goals and how hydrogen contributes to reducing the carbon footprint, especially in transport, is also explained. The focus is on sustainable mobility and hydrogen's role in creating cleaner transport solutions.

The introductory presentation is supported with educational videos to ensure a better understanding and visualisation of the concepts discussed. These videos cover topics such as hydrogen car safety, the electrolysis process, how fuel cells work, and examples of sustainable hydrogen projects. The introductory phase also includes demonstrations, such as obtaining hydrogen through electrolysis or showing the entire supply chain through storage, fuel cell operation, and final use in a hydrogen car.

After the introductory presentation of the simulation game H2STUDENT, the game's rules are explained, the roles are assigned, and the preparation for the start of the simulation follows. This phase emphasises the dynamics of cooperation and competition within the simulation environment. The participants are divided into groups representing a specific company within the simulated hydrogen industry. The groups are designed to encourage collaboration and competition as each company competes to build and market their car. Particular roles are defined within each group, such as production, procurement, marketing, development and control. Each team member chooses or is assigned a role based on their skills or interests, which encourages greater involvement and optimisation of work.

The game's primary goal is to build a functional Lego car and successfully present it at the Grand Prix race, which requires the successful cooperation of all departments within the company. Additional objectives include collecting deduction seconds through game activities such as quiz questions, marketing and car design, which can improve the final position in the Grand Prix race. Every company starts with a standard set of resources that they can use to build their car. All additional resources must be obtained through the procurement department, which answers technical questions or solves logistical challenges. The purchasing department may face supply disruptions, simulating real market conditions, including resource shortages or delivery delays.

The marketing and development department is responsible for the design and promotion of the car, which can lead to additional deduction seconds if their projects are considered highly creative or innovative. Victory depends not only on the car's speed in the Grand Prix race but also on the number of accumulated deductible seconds gained by the teams during the different stages of the game, such as quiz performance, marketing effectiveness and car aesthetics. In addition, the company's overall performance is also evaluated, including innovation, teamwork and problem-solving ability. The game includes several interactive elements that simulate a real business environment, such as time-limited decisions, adaptations to unexpected events and strategies to improve market position.

The competitive dynamics of the H2STUDENT game allow participants to experience various aspects of working in the hydrogen technology industry. The process begins with assembling a Lego car, where each team's production department simulates realistic production challenges, including precision and technical skills. The procurement department faces logistical challenges, such as delivery delays or resource shortages, which require agility and flexibility in finding alternative solutions. The marketing and development department must create a compelling and

creative presentation of the car that highlights its technical specifications and builds the company's brand. Once the car is assembled, the development department adds aesthetic and functional improvements that add deductible seconds to the race. The first highlight of the game is the competition on the testing ground, where the driving time is measured, and the team with the best total time wins after deducting all the gained deduction seconds.

H2STUDENT's quiz and scoring game combines fun and education and plays a vital role in the game's dynamics. Quiz questions distributed throughout the game are related to hydrogen technologies and supply chains and encourage thinking and group collaboration. Correct answers earn deductible seconds that count towards the final race, increasing the game's competitive element. Success in the quiz directly affects the technological and strategic options of the teams in the following stages of the game, which may include access to better materials to build the car or more advanced marketing tools.

The final stage of the H2STUDENT is the Grand Prix race, where each team tests its hydrogen car, representing the game's climax, as all the activities so far are combined and verified in practice. Competition on the training ground is timed, and speed is not the only determining factor for victory. After the competition on the training ground, all results and seconds deducted are added up, with the team with the lowest total time, considering all bonuses, gaining a better position in the Grand Prix. Ultimately, the best and fastest car wins the race.

At the announcement, occasional awards and recognitions are given for outstanding achievements in various categories, such as innovation, teamwork and creativity. This final phase represents a cumulative evaluation of all previous activities and allows teams to see the practical results of their work and strategies. In addition, the closing event provides an opportunity for reflection and learning from experience, which is crucial to the educational purpose of the game as it encourages participants to reflect on their progress and skills acquired.

DISCUSSION

The H2STUDENT game offers a pioneering approach to education within the realms of hydrogen technologies and supply chains, bringing significant potential impacts on various aspects of learning and professional development. The game is designed to enhance understanding of complex hydrogen technologies and logistics concepts by facilitating practical learning where participants translate theoretical knowledge into practical scenarios. This hands-on approach is crucial as it helps solidify abstract concepts into tangible skills and comprehension.

By simulating the entire hydrogen supply chain, H2STUDENT highlights the interdependencies and connections among industry segments, enabling participants to develop a comprehensive view of industrial ecosystems. This facet of the game is vital as it mirrors the complexity of real-world systems and emphasises the importance of understanding each segment's impact on the overall operational chain.

Participants in H2STUDENT would face unexpected challenges and need to make rapid decisions, fostering the development of critical thinking and problem-solving skills. These skills are essential in today's fast-paced, problem-rich environments, particularly in cutting-edge industries like hydrogen energy. Moreover, the game requires collaboration, communication, and shared responsibility within teams, strengthening interpersonal skills and underscoring the importance of team dynamics and leadership. This reflects professional realities where effective teamwork and clear communication are often the cornerstones of successful projects and enterprises.

Additionally, vehicle design and marketing strategy development are intended to cultivate creativity and innovation—key for advancement in modern technological industries. These activities allow participants to apply their knowledge creatively, proposing innovative solutions and strategies that could be translated into real-world applications.

By realistically simulating industrial scenarios, H2STUDENT aims to prepare participants for the complexities and dynamics of the real world, which is particularly advantageous for those intending to engage professionally with hydrogen technologies or logistics. Integrating sustainability concepts into the gameplay is designed to enhance the understanding of the significance and impact of environmental practices within the industry, supporting the development of professionals committed to sustainable solutions.

Moreover, H2STUDENT aims to stimulate interest in green technologies and increase awareness of the potential of hydrogen technologies to reduce carbon footprints. With an enriched understanding of industrial challenges and needs, participants are envisioned to become more active in discussions about policies and standards, potentially leading to more informed and practical regulatory frameworks.

Therefore, H2STUDENT serves as a conceptual platform for developing future innovators, leaders, and responsible citizens who will shape the future of sustainable energy and industry. Through an interactive and dynamic gaming experience, it is designed to impart knowledge and cultivate the essential skills necessary for success in the rapidly evolving fields of technical and environmental professions. This discussion underscores the implications of employing innovative educational tools like H2STUDENT to enhance academic outcomes and prepare students for professional challenges in sustainable technology sectors.

CONCLUSION

H2STUDENT showcases an innovative approach to education within hydrogen technologies and supply chains, demonstrating the considerable potential of innovative educational methodologies. This game highlights how dynamic and interactive learning methods can significantly improve outcomes, especially in technical and engineering disciplines. By engaging participants in practical scenarios that reflect real-world challenges, H2STUDENT promotes a deep understanding of complex systems and encourages the practical application of theoretical knowledge.

Implementing such cutting-edge educational tools comes with a set of challenges. The technical demands of the game, the necessity for ongoing content updates, and the need for integration into existing curricula present significant hurdles. These challenges require careful consideration and adaptation to maximise the game's applicability and effectiveness across various educational settings.

There are many opportunities for further development of H2STUDENT. Recommendations include adapting the game to different educational contexts, incorporating new technologies to boost its interactivity, and broadening its scope to include additional disciplines. There is also potential for international expansion or localisation to meet specific regional educational needs.

H2STUDENT is a model for future educational advancements, especially valuable in fields that require a deep understanding of complex systems. Its influence on educational practices indicates a potential to transform learning environments and methodologies. A comprehensive analysis of the effects of the H2STUDENT game and its broader implications underlines its practical impact and theoretical importance, offering a clear view of its benefits and potential to enhance future education. This overview highlights the game's crucial role in shaping educational strategies and boosting learner engagement in sophisticated technical fields.

REFERENCES

- Bakenne, A., Nuttall, W., & Kazantzis, N. (2016). Sankey-diagram-based insights into the hydrogen economy of today. International Journal of Hydrogen Energy, 41(19), 7744-7753. https://doi.org/10.1016/j.ijhydene.2015.12.216
- Deshpande, A. A. and Huang, S.H. (2011). Simulation games in engineering education: a state-of-the-art review. Computer Applications in Engineering Education, 19(3), 399-410. https://doi.org/10.1002/cae.20323
- Edwards, P.P., Kuznetsov, V. L., & David, W.I.F. (2007). Hydrogen energy. Philosophical Transactions of the Royal Society a Mathematical Physical and Engineering Sciences, 365(1853), 1043-1056. https://doi.org/10.1098/rsta.2006.1965
- Fredershausen, S., Lechte, H., Willnat, M., Witt, T., Harnischmacher, C., Lembcke, T.-B., Klumpp, M., & Kolbe, L. (2021). Towards an Understanding of Hydrogen Supply Chains: A Structured Literature Review Regarding Sustainability Evaluation. Sustainability, 13(21), 11652. Crossref. https://doi.org/10.3390/su132111652
- Guilbert, D., & Vitale, G. (2021). Hydrogen as a Clean and Sustainable Energy Vector for Global Transition from Fossil-Based to Zero-Carbon. Clean Technologies, 3(4), 881–909.
- Katsaliaki, K., Mustafee, N., & Kumar, S. (2014). A game-based approach towards facilitating decision making for perishable products: an example of the blood supply chain. Expert Systems With Applications, 41(9), 4043-4059. https://doi.org/10.1016/j.eswa.2013.12.038

- Keeley, A., Takeda, S., & Managi, S. (2022). A systematic review of the techno-economic assessment of various hydrogen production methods of power generation. Frontiers in Sustainability, 3. https://doi.org/10.3389/frsus.2022.943145
- Lee, S. and Sim, D. (2022). Excellent electrocatalytic hydrogen evolution reaction performances of partially graphitised activated-carbon nanobundles derived from biomass human hair wastes. Nanomaterials, 12(3), 531. https://doi.org/10.3390/nano12030531
- Liao, Y., Huang, Y., & Wang, Y. (2015). Factors affecting students' continued usage intention toward business simulation games. Journal of Educational Computing Research, 53(2), 260-283. https://doi.org/10.1177/0735633115598751
- Noussan, M., Raimondi, P. P., Scita, R., & Hafner, M. (2020). The Role of Green and Blue Hydrogen in the Energy Transition—A Technological and Geopolitical Perspective. Sustainability, 13(1), 298. https://doi.org/10.3390/su13010298
- Ozawa, A. and Kudoh, Y. (2021). Assessing uncertainties of life-cycle CO2 emissions using hydrogen energy for power generation. Energies, 14(21), 6943. https://doi.org/10.3390/en14216943
- Peksen, M. (2021). Hydrogen Technology Towards the Solution of Environment-Friendly New Energy Vehicles. Energies, 14(16), 4892.
- Pudjianto, D. and Strbac, G. (2022). Whole system value of long-duration electricity storage in systems with high penetration of renewables. Energy, 1(1), 114-123. https://doi.org/10.23919/ien.2022.0004
- Sartbaeva, A., Kuznetsov, V. L., Wells, S. A., & Edwards, P. P. (2008). Hydrogen nexus in a sustainable energy future. Energy & Environmental Science, 1(1), 79.
- Shojaeddini, E., Naimoli, S., Ladislaw, S., & Bazilian, M. (2019). Oil and gas company strategies regarding the energy transition. Progress in Energy, 1(1), 012001. https://doi.org/10.1088/2516-1083/ab2503
- Sitzmann, T. (2011). A meta-analytic examination of the instructional effectiveness of computer-based simulation games. Personnel Psychology, 64(2), 489-528. https://doi.org/10.1111/j.1744-6570.2011.01190.x
- Staffell, I., Scamman, D., Abad, A., Balcombe, P., Dodds, P., Ekins, P., … & Ward, K. (2019). The role of hydrogen and fuel cells in the global energy system. Energy & Environmental Science, 12(2), 463-491. https://doi.org/10.1039/c8ee01157e
- Vlachopoulos, D. and Makri, A. (2017). The effect of games and simulations on higher education: a systematic literature review. International Journal of Educational Technology in Higher Education, 14(1). https://doi.org/10.1186/s41239-017-0062-1
- Wilson, K., Bedwell, W., Lazzara, E., Salas, E., Burke, C., Estock, J., … & Conkey, C. (2008). Relationships between game attributes and learning outcomes. Simulation & Gaming, 40(2), 217-266. https://doi.org/10.1177/1046878108321866