Student Centered Undergraduate Research Experiences in Creating Virtual Digital Twin Cleanroom

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Abstract:

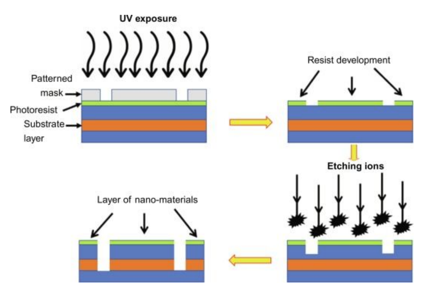
This project aims to create a digital twin of a semiconductor cleanroom, particularly to emulate the process of photolithography. The project aims to address the high costs and logistical challenges of traditional training methods by implementing VR-based training programs. In addition, the project aims to increase interest in the field of semiconductor manufacturing amongst young students by providing accessible simulations as opposed to costly real-world training by simulating real-world environments and scenarios. Prior research indicates that VR training not only reduces costs associated with physical training setups but also shortens the learning curve for new employees, leading to faster integration and improved overall productivity (Cai, 2020). Pilot testing shows that the simulation does indeed meet the above expectations.

Objective

The primary objective of this project is to show that simulation based learning, in particular the digital twin method is an effective and implementable technique to not only train technicians, but also to raise interest in the field. Simulation based learning has shown favorable results in the medical industry (Lateef, 2010) and in machine operator training in naval, aviation and manufacturing industries (Vergnano et al, 2016) which suggests that it can also be successfully applied in semiconductor industry.

Simulation-based learning

With the rise of virtual and mixed reality, several industries have begun to look towards simulation based learning as a cost-effective alternative to physical trainings, onboarding and events. The Semiconductor Industry Association (SIA) reports a major need for semiconductor workers, and the New York Times shows a lack of interest amongst students.



- Simulation based training is useful because it is accessible through virtual reality, giving the feeling that the user is experiencing the simulation in real life.
- Simulation based learning is highly cost effective, as instead of paying large sums of money for expensive equipment, as well as repeated costs for transportation, learners can access training content and material at home, while maintaining accuracy and immersiveness.
- Learners can also operate machinery without fear of mistakes.

Semiconductor Fabrication Process

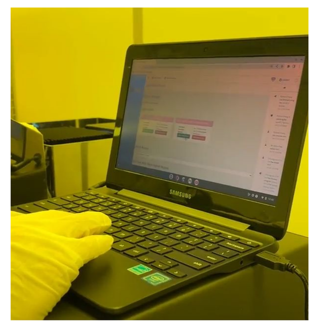
Semiconductor manufacturing comprises a series of procedures for creating integrated circuits (ICs) used in electronic devices. Beginning with silicon wafer fabrication, the process progresses through photolithography, etching, and doping to define circuit patterns and introduce impurities for desired electrical properties. Following the deposition and patterning of insulating and conductive materials to shape transistors and interconnects, final stages involve testing, packaging, and quality control to ensure functionality and reliability.

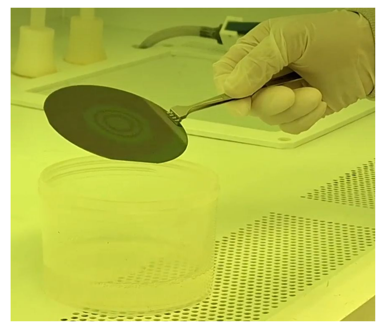
Digital Twin Development

Our digital twin development process began with tours of the UCI Calit2 INRF lab, where we learned about the photolithography process. We documented our experiences and supplemented them with video recordings to outline the process. Utilizing our observations, we sourced 3D models of semiconductor fabrication components and defined scripts for our simulation. To streamline the development process and facilitate collaborative work, we used Hyper Skill, a VR development platform. HyperSkill enables the simulations to be deployed on any XR device, including Meta Quest 2 and Quest Pro, Hololens, and Apple Vision Pro. After development, we conducted usability testing to refine the user experience. Our approach ensured that the digital twin accurately represented the photolithography process and serves as a valuable tool for education and training in semiconductor fabrication.

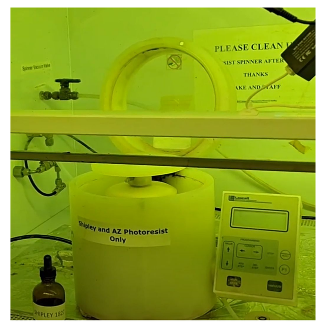
UCI Integrated Nanosystems Research Facility (INRF)

The authors toured the Integrated Nanosystems Research Facility (INRF) at the University of California, Irvine, and gathered documents, images and videos of the equipment and processes in the class-1000 fab. The documents and media were then analyzed to develop the plans for digital twin creation.


INRF computer system log in


Rinsing substrate in SU 8 developer


INRF tour to to gather materials for the digital twin.

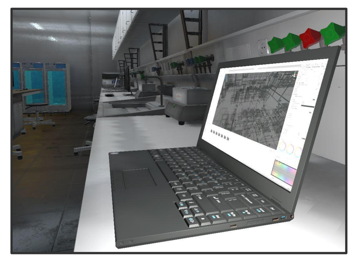

Laurell 3 Spinner


Laurell Spinner controller

Semiconductor Fabrication Digital Twin


Physical Lab


Digital Lab


Computer display showing a model


Nitrogen valve to be checked


Laurel Spinner Controller digital twin

AI Integration

We apply artificial intelligence (AI) models to make the training adaptive to each learner, enhancing engagement and learning outcomes. The AI functions as a virtual guide, allowing learners to ask questions and receive accurate, personalized answers in real-time. By pressing a button on the VR controller, users can activate the microphone to seek assistance or explore topics of interest, e.g., ask what is a spinner. The AI provides a detailed response describing the functions of a spinner. The AI also has spatial awareness of the locations of various virtual objects (VOs) which is useful to highlight and contextualize the instructions. During pilot testing, several participants noted that the AI was effective and easy to use. AI reduces frustration by helping users when they get stuck and encourages curiosity, enabling students to delve into details beyond the scripted curriculum. By offering a tailored learning experience, the AI not only assists in immediate problem-solving but also enriches the overall experience.

Assessment and Evaluation Methods

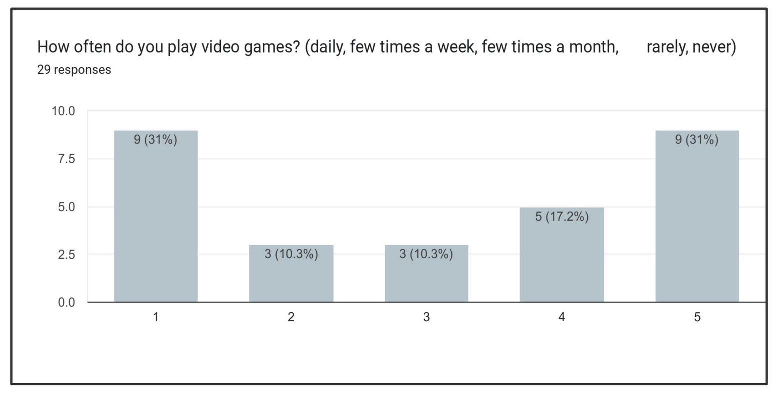
We conducted usability testing to refine the digital twin and the conducted a pilot test with 29 subjects to evaluate the digital twin. We conducted three usability test sessions to gather users feedback and potential areas of improvement and used the feedback to iteratively improve our simulation and prepare for pilot testing. Next, during pilot testing, participants went through the simulation while their interactions and feedback were recorded. We recorded participant feedback using a survey that consisted of 8 questions on a 5-point Likert scale. This allowed us to assess the viability of the simulation to educate users on the photolithography process and identify any areas of improvement. Additionally, we used these questions to gather qualitative feedback from users regarding their overall experience, ease of use, and suggestions for enhancements.

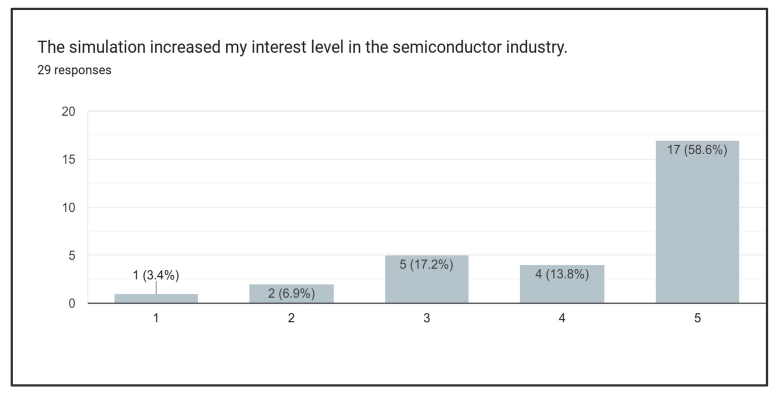
The instructions were very clear and this simulation is so amazing!

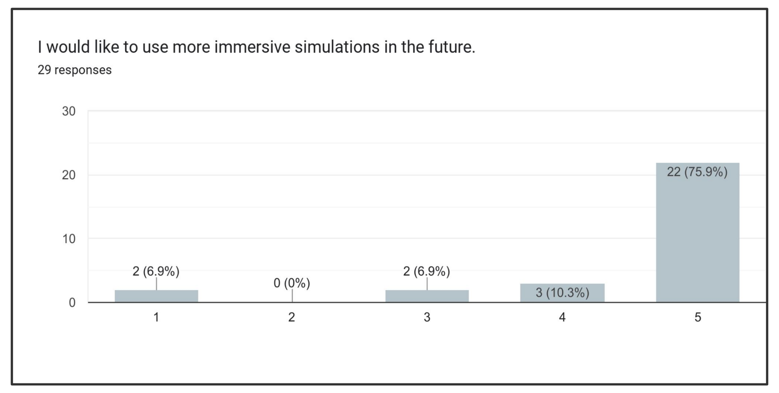
I get motion sickness easily but I was okay in this simulation which was a pleasant surprise!

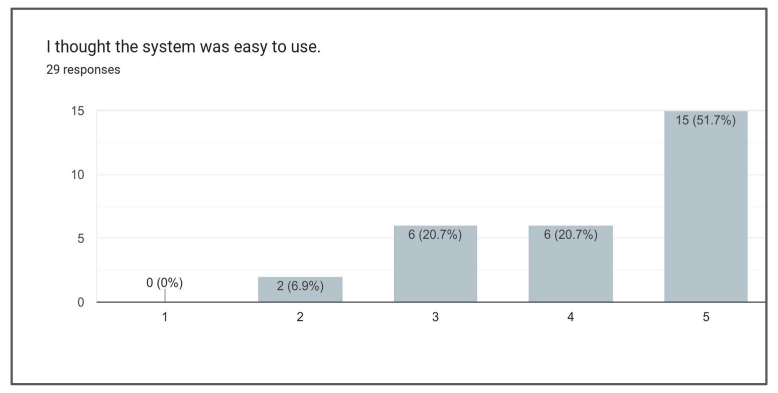
Students involved in designing the system seemed very engaged.

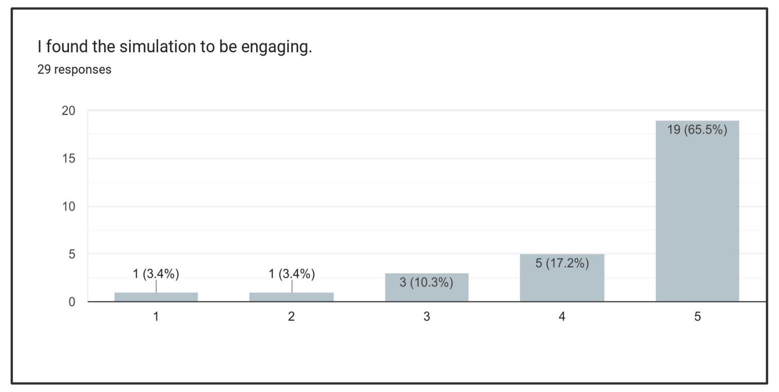
User Study Results (N=29)

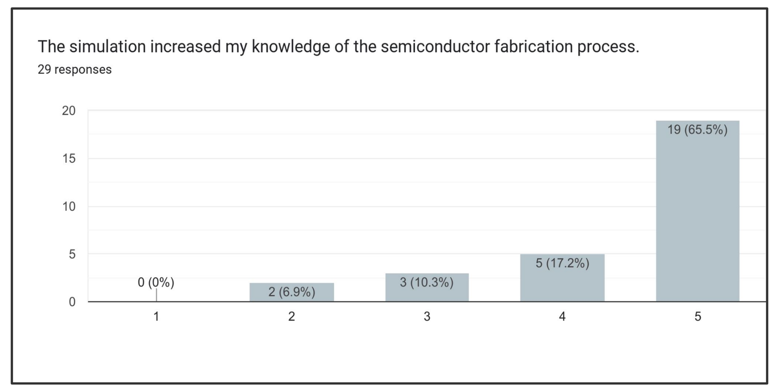












Conclusions

Our pilot testing included a diverse sample of students, ensuring a balanced representation of both experienced and novice VR users, as well as a varied frequency of video game play. This randomness in our sample indicates potential for generalizability of our findings across the student population. Survey responses indicated that the majority of students found the system easy to use and highly engaging. Additionally, the simulation significantly increased their knowledge of semiconductor fabrication processes and sparked greater interest in the semiconductor industry.

The students expressed a strong preference for using more simulations in the future, as evidenced by the overwhelmingly positive responses to this survey question. These results suggest that our simulation-based learning approach is not only effective in teaching complex technical knowledge but also successful in enhancing student engagement and interest in the field. This promising feedback suggests the need for continued development and integration of immersive simulation technologies in educational and training programs. These insights validate the potential of our VR-based training to revolutionize semiconductor education.

Future Work

- Explore additional semiconductor fabrication processes beyond photolithography to create a training suite.
- Expand the scope of the AI coach powered by the Large Language Model (LLM) to provide more personalized and adaptive learning.
- Collaborate with experts to continuously update and refine the simulation to reflect evolving standards and best practices.
- Investigate the potential of incorporating augmented reality (AR) features to overlay real-time data and information onto the virtual environment for enhanced learning.
- Conduct longitudinal studies to assess the long-term impact of simulation-based training on skill acquisition and workforce readiness.

References

1. Cai, Siyao. "Training of Semiconductor Machines Based on Virtual Reality(VR)." Dr.ntu.edu.sg, 2020, dr.ntu.edu.sg/handle/10356/141493.
2. "Semiwise Leads Virtual Reality Semiconductor Training Fab Consortium - News." Silicon Semiconductor, siliconsemiconductor.net/article/118044/Semiwise_leads_Virtual_Reality_Semiconductor_Training_Fab_consortium.
3. Lateef, Fatimah. "Simulation-Based Learning: Just like the Real Thing." Journal of Emergencies, Trauma, and Shock, vol. 3, no. 4, Oct. 2010, pp. 348–352, www.ncbi.nlm.nih.gov/pmc/articles/PMC2966567/, https://doi.org/10.4103/0974-2700.70743.
4. Vergnano, A. (2016). Interactive Simulation-Based-Training Tools for Manufacturing Systems Operators – An Industrial Case Study. IRIS. https://iris.unimore.it/bitstream/11380/1129819/5/sbt10.pdf

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