ChipQuest: Gamifying the Semiconductor Manufacturing Process to Inspire Future Workforce

Serene Cheon
University of Florida
Gainesville, USA
hcheon@ufl.edu

Hyo Kang
University of Florida
Gainesville, USA
hkang2@ufl.edu

ABSTRACT

Semiconductor manufacturing is crucial for national economies; however, the industry faces significant talent shortages. While extensive research exists on motivating students in STEM learning, there is little work specifically addressing semiconductor education. To fill this gap, we first examined current barriers and motivational factors influencing students' pursuit of careers in semiconductor fields through interviews with 13 participants. Findings reveal that limited recognition of semiconductor companies relative to software engineering poses a barrier, while early exposure to the field and hands-on experience emerge as pivotal factors motivating prospective students. Drawing upon these insights, we introduce ChipQuest, an educational game designed to enhance K-12 students' engagement and interest in semiconductors. ChipQuest integrates gamification elements to simulate the complexities of semiconductor chip manufacturing, featuring a pedagogical agent, interactive tasks, a reward system, and competitive components. By incorporating gaming principles into semiconductor education, ChipQuest aims to offer a promising approach to inspire young students as the future workforce in the semiconductor industry.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in interaction design**.

KEYWORDS

Semiconductor, gamification, educational game, pedagogical agent

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1 INTRODUCTION

In response to the global surge in chip demand, the U.S. government enacted the CHIPS and Science Act in 2022 to revitalize the semiconductor industry and establish reliable supply chains through the development of a self-sustaining chip production sector [7]. Despite these government efforts, the U.S. semiconductor industry continues to face a significant talent shortfall [22]. Semiconductors are the foundation for critical technologies across various sectors, including automotive, medical, aerospace, transportation, and military applications. Thus, bridging the talent gap in semiconductor manufacturing and fabrication, and developing a future workforce, is crucial for the nation's economic stability and security. Recent surveys by McKinsey & Company [2, 21] highlight several factors contributing to challenges in talent acquisition within the U.S. semiconductor industry. These include (1) lower brand recognition of semiconductor companies (e.g., Micron, Texas Instruments) among engineering students compared to software companies (e.g., Microsoft, Google), and (2) a lack of student interest in the field, compounded by industry-specific issues such as limited hybrid work options and lower flexibility [20].

This study aims to address these challenges through a twofold approach. First, we seek to identify specific factors that discourage engineering students from pursuing careers in the semiconductor industry and to uncover motivating factors that influence current workers' career choices through in-depth interviews. Second, based on insights from these interviews, we propose potential design interventions to inspire young students to consider careers in semiconductors. To this end, we introduce "ChipQuest," an educational simulation game designed to immerse players in the role of an engineer at a semiconductor fabrication plant. Players navigate all eight steps involved in the fabrication process using state-of-the-art technology. ChipQuest integrates various game elements known to enhance student engagement, including task-based challenges, competition, and a reward system. This work contributes to the existing literature, which has predominantly focused on gamification and education in computer science, by addressing the underexplored topic of teaching semiconductor manufacturing and fabrication. This is a critical area for national importance that has received limited attention in the HCI community.

2 IDENTIFYING REQUIREMENTS

Method: To better understand the current barriers for engineering students pursuing careers in semiconductor fabrication and manufacturing, as well as to identify motivating factors, we conducted in-depth interviews. We recruited 13 participants through convenience sampling: six graduate students, three undergraduate students, and two engineers currently employed at Intel and Qualcomm. Participants majored in electrical and computer engineering, materials science, and chemical engineering. The interview questions focused on: (1) reasons for pursuing studies and careers in semiconductors, (2) factors that make semiconductor manufacturing fascinating, (3) perceived barriers to studying semiconductors

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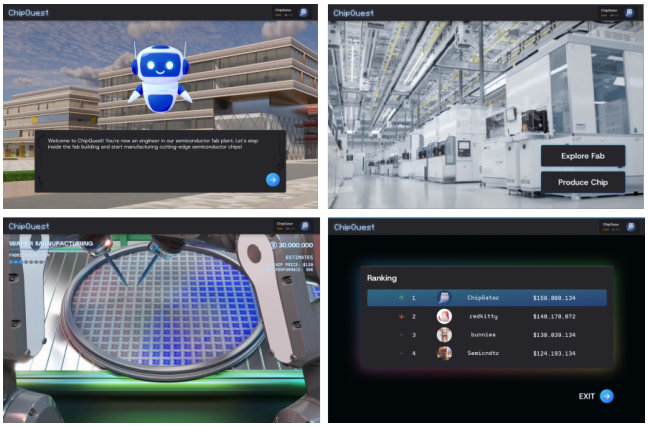

Figure 1: ChipQuest Game: The game features a pedagogical agent that explains essential learning content. It also allows students to use state-of-the-art facilities to perform a series of tasks and compete with other users for the best performance.

in college, and (4) factors contributing to low student involvement in the semiconductor field. Each interview lasted approximately 20 to 30 minutes. The transcriptions were analyzed using thematic analysis with MAXQDA.

Results: The interview findings suggested that *rewarding learning experiences and interest* were the most crucial motivators for studying semiconductors. Specifically, four participants mentioned they decided to study semiconductors because they enjoyed learning the various concepts involved in semiconductor manufacturing and fabrication. One participant noted that the state-of-the-art facility he saw during his internship inspired him to continue his studies in semiconductor manufacturing. Additionally, three participants highlighted the *importance of early exposure to the field*, either from high school or family members, in deciding to study semiconductors. However, when discussing barriers, participants often compared semiconductor engineering to software engineering. They cited several disadvantages, including *limited access to learning resources* (e.g., YouTube tutorials, Discord communities) and *limited hands-on lab experience* due to the expensive equipment required for semiconductor fabrication. This makes it difficult for students to actively engage with the material. Furthermore, one graduate student mentioned the *delayed outcome visibility* in semiconductor work as a significant challenge:

"In software, you can see your results quickly. In hardware, it takes a significant amount of time to see results. You have to go through a step called 'tape out,' where you send the design to a factory and wait for months to see the final results."

Design Implications: Building upon our findings and prior literature on STEM education, we derive design interventions to motivate aspiring engineering students: Introducing young students to semiconductor-related topics early on [3, 5]; ensuring easy access to content via the web [1]; offering hands-on learning experiences through 3D interactive contents [12, 19]; enhancing interest in the field by showcasing state-of-the-art facilities [16]; enabling students to immediately see the feedback [4]; and creating a rewarding learning experience through gamification [17, 18].

3 CHIPQUEST: DESIGN ELEMENTS

Gamification Targeting K12 Students: Gamification has become a widely adopted educational strategy, supported by extensive empirical evidence showing its effectiveness in engaging and motivating young students in STEM fields [8, 17, 18]. A systematic literature review by Majuri et al. [14] suggested that educational games include several key elements: missions and quests (e.g., learning tasks), progress indicators (e.g., levels, progress bars), evaluation and feedback mechanisms (e.g., rewards, leaderboards), competition and cooperation, as well as storytelling and simulation. In line with this approach, we integrated these game elements into our solution to create an immersive learning experience, as illustrated below.

Mission & Hands-On Activities: In semiconductor manufacturing, mastering the multiple steps—from wafer preparation and oxidation to metallization and packaging—is crucial [15]. However, as revealed in our interviews, this complex process can overwhelm learners. To address this challenge, ChipQuest integrates mini-games that break down the overarching missions into smaller, manageable goals, guiding players through the eight steps of semiconductor engineering using virtual avatars [13]. Moreover, to enhance realism and provide a hands-on experience, we have developed a 3D interactive virtual game. In this virtual environment, users utilize cutting-edge facilities and equipment, fostering active learning experiences [12].

Pedagogical Agent & Storytelling: Pedagogical agents have been shown to enhance learning engagement, particularly in e-learning environments where social interaction may be limited [6, 9–11]. In particular, agents capable of displaying emotions are recognized for their ability to improve learning experiences [6, 23]. Additionally, employing narrative storytelling and clear instructions is crucial when teaching complex concepts like semiconductor fabrication. In line with these findings, ChipQuest integrates an animated pedagogical agent. Throughout the game, this agent delivers instructions and interactive feedback using animated verbal and non-verbal cues, thereby promoting engagement and fostering empathetic learning connections.

Evaluation & Competition: Based on insights gathered from interviews with industry engineers, ChipQuest integrates essential performance metrics into its evaluation system: the speed of chip production and cost efficiency [15]. Players are tasked with optimizing these metrics and can assess their performance on a leaderboard displayed at the end of each session. This element closely simulates real-world challenges faced by engineers, thereby enhancing the game's educational value with practical knowledge.

4 FUTURE WORKS

ChipQuest integrates educational gaming principles to provide an engaging and educational experience that simulates semiconductor manufacturing processes while fostering learning through interactive guidance, performance assessment, and competitive motivation. Future work will focus on conducting a user study to evaluate the effectiveness of ChipQuest, involving multiple participants including K-12 students and educators. This study aims to assess its impact on student learning outcomes and gathers feedback on user experience. The insights gained from the user study will inform us on how to refine and optimize the game's educational effectiveness.

REFERENCES

[1] Patricia Ananga and Isaac Kofi Biney. 2017. Comparing face-to-face and online teaching and learning in higher education. *MIER Journal of Educational Studies Trends and Practices* (2017), 165–179. https://doi.org/10.52634/mier/2017/v7/i2/1415

[2] Burkacky, Ondrej and Kingsbury, Ulrike and Pedroni, Andrea and Poltronieri, Giulietta and Schrimper, Matt and Weddle, Brooke. 2022. How semiconductor makers can turn a talent challenge into a competitive advantage. https://www.mckinsey.com/industries/semiconductors/our-insights/how-semiconductor-makers-can-turn-a-talent-challenge-into-a-competitive-advantage Accessed: 2024-6-1.

[3] Nancy DeJarnette. 2012. America's children: Providing early exposure to STEM (science, technology, engineering and math) initiatives. *Education* 133, 1 (2012), 77–84.

[4] Michael L Epstein, Beth B Epstein, and Gary M Brosvic. 2001. Immediate feedback during academic testing. *Psychological reports* 88, 3 (2001), 889–894. https://doi.org/10.2466/pr0.2001.88.3.889

[5] Garry Falloon, Maria Hatzigianni, Matt Bower, Anne Forbes, and Michael Stevenson. 2020. Understanding K-12 STEM education: A framework for developing STEM literacy. *Journal of Science Education and Technology* 29 (2020), 369–385. https://doi.org/10.1007/s10956-020-09823-x

[6] Malliga K Govindasamy. 2014. Animated Pedagogical Agent: A Review of Agent Technology Software in Electronic Learning Environment. *Journal of Educational Multimedia and Hypermedia* 23, 2 (2014), 163–188.

[7] H.R. The United States Congressional Report. 2022. The CHIPS and Science Act of 2022. https://www.commerce.senate.gov/services/files/592E23A5-B56F-48AE-B4C1-493822686BCBRequired Accessed: 2024-4-30.

[8] Rui Huang, Albert D Ritzhaupt, Max Sommer, Jiawen Zhu, Anita Stephen, Natercia Valle, John Hampton, and Jingwei Li. 2020. The impact of gamification in educational settings on student learning outcomes: A meta-analysis. *Educational Technology Research and Development* 68 (2020), 1875–1901.

[9] Yanghee Kim and Amy L Baylor. 2006. A social-cognitive framework for pedagogical agents as learning companions. *Educational technology research and development* 54 (2006), 569–596. https://doi.org/10.1007/s11423-006-0637-3

[10] Yanghee Kim and Amy L Baylor. 2016. based design of pedagogical agent roles: A review, progress, and recommendations. *International Journal of Artificial Intelligence in Education* 26 (2016), 160–169.

[11] Nicole C Krämer and Gary Bente. 2010. Personalizing e-learning. The social effects of pedagogical agents. *Educational Psychology Review* 22 (2010), 71–87.

[12] Richard Lamb, Pavlo Antonenko, Elisabeth Etopio, and Amanda Seccia. 2018. Comparison of virtual reality and hands on activities in science education via functional near infrared spectroscopy. *Computers & education* 124 (2018), 14–26.

[13] Edwin A Locke and Gary P Latham. 2019. The development of goal setting theory: A half century retrospective. *Motivation Science* 5, 2 (2019), 93.

[14] Jenni Majuri, Jonna Koivisto, and Juho Hamari. 2018. Gamification of education and learning: A review of empirical literature. In *Proceedings of the 2nd international GamiFIN conference, GamiFIN 2018.* http://ceur-ws.org/Vol-2186/paper2.pdf

[15] Gary S May and Costas J Spanos. 2006. *Fundamentals of semiconductor manufacturing and process control.* John Wiley & Sons.

[16] Sasha Nikolic, Christian Ritz, Peter James Vial, Montserrat Ros, and David Stirling. 2015. Decoding Student Satisfaction: How to Manage and Improve the Laboratory Experience. *IEEE Transactions on Education* 58, 3 (2015), 151–158. https://doi.org/10.1109/TE.2014.2346474

[17] Margarita Ortiz-Rojas, Katherine Chiluiza, and Martin Valcke. 2019. Gamification through leaderboards: An empirical study in engineering education. *Computer Applications in Engineering Education* 27, 4 (2019), 777–788. https://doi.org/10.1002/cae.12116

[18] Margarita Elizabeth Ortiz Rojas, Katherine Chiluiza, and Martin Valcke. 2016. Gamification in higher education and stem: A systematic review of literature. In *8th International Conference on Education and New Learning Technologies (EDULEARN).* Iated-int Assoc Technology Education A& Development, 6548–6558. https://doi.org/10.21125/edulearn.2016.0422

[19] Veljko Potkonjak, Michael Gardner, Victor Callaghan, Pasi Mattila, Christian Guetl, Vladimir M Petrović, and Kosta Jovanović. 2016. Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education* 95 (2016), 309–327. https://doi.org/10.1016/j.procs.2015.12.224

[20] Aida Damanpak Rizi, Antika Roy, Rouhan Noor, Hyo Kang, Nitin Varshney, Katja Jacob, Sindia Rivera-Jimenez, Nathan Edwards, Volker J. Sorger, Hamed Dalir, and Navid Asadizanjani. 2023. From Talent Shortage to Workforce Excellence in the CHIPS Act Era: Harnessing Industry 4.0 Paradigms for a Sustainable Future in Domestic Chip Production. arXiv:2308.00215 [cs.CY]

[21] S. Brugmans, O. Burkacky, K. Mayer-Haug, A. Pedroni, G. Poltronieri, T. Roundtree, B. Weddl. 2024. How semiconductor companies can fill the expanding talent gap. https://www.mckinsey.com/industries/semiconductors/our-insights/how-semiconductor-companies-can-fill-the-expanding-talent-gap Accessed: 2024-6-1.

[22] SIA. 2022. America Projected to Triple Semiconductor Manufacturing Capacity by 2032, the Largest Rate of Growth in the World. https://www.semiconductors.org/emerging-resilience-in-the-semiconductor-supply-chain/ Accessed: 2024-4-30.

[23] Anne M Sinatra, Kimberly A Pollard, Benjamin T Files, Ashley H Oiknine, Mark Ericson, and Peter Khooshabeh. 2021. Social fidelity in virtual agents: Impacts on presence and learning. *Computers in Human Behavior* 114 (2021), 106562. https://doi.org/10.1016/j.chb.2020.106562