

To Innovate Again: Reassessing Students' Strategic Decision-Making in a Simulated Environment

Saltanat Akhmadi
School of Engineering and Digital Sciences
Nazarbayev University
Astana, Kazakhstan
ssalpenova@nu.edu.kz

Mariza Tsakalerou
School of Engineering and Digital Sciences
Nazarbayev University
Astana, Kazakhstan
mariza.tsakalerou@nu.edu.kz

Abstract—This paper investigates the use of simulation-based learning in Engineering Management education. Building on prior research, it explores how students allocate R&D budgets between disruptive and sustaining technologies under dynamic market conditions. Conducted with diverse student groups, the study aims to validate earlier findings, which emphasized disruptive innovations as key drivers of success and highlighted the educational benefits of repeated simulation runs. The research extends previous work by adding a longitudinal dimension, examining how decision-making patterns and learning outcomes evolve over time. The findings confirm consistent trends favoring disruptive technologies across cohorts while revealing some variations in strategies influenced by changing contexts. This study underscores the value of simulation-based learning in fostering critical thinking and preparing students for innovation challenges in SMEs and other STEM fields.

Keywords—game-based learning, simulated environment, decision-making, disruptive innovation

I. INTRODUCTION AND BACKGROUND

This paper presents a study that builds upon previous research investigating the application of game-based simulations in Engineering Management education. In a word, Simulation-based learning, or simulation-based education (SBE) is a transformative approach to enhancing the learning experience in higher education [1], particularly in Science, Technology, Engineering, and Mathematics (STEM) disciplines.

The application of SBE in engineering education has evolved significantly over the past decade, particularly through the integration of gamification and role-playing with experiential learning approaches. It has been observed that many educational institutions have increasingly adopted game simulators and online platforms to create predefined scenarios for problem-solving and decision-making activities. While most simulations have traditionally focused on operational aspects and pedagogical methods, emphasizing instruction techniques and learning activities, the chosen simulation extends this approach by incorporating strategic decision-making elements in innovation management [2].

Engaging students in real-world problem-solving within academic settings often proves challenging. Real-life scenarios are frequently complex, and critical decision points may arise randomly and infrequently, limiting students' exposure to practical problem-solving opportunities. Additionally, the outcomes of real-world decisions can take significant time to be observed, delaying feedback essential to the learning process [3]. SBE addresses these limitations by creating a simulated environment that allows for controlled

experimentation, where specific variables can be adjusted to facilitate learning. By providing immediate feedback and allowing for repeated practice, SBE enhances students' understanding of complex systems and decision-making processes.

The use of SBE is particularly relevant in STEM programs. For example, Engineering Management involves strategic thinking, resource allocation, and innovation management—areas where simulations can provide practical experience in a safe yet challenging environment. Within these simulations, students can experiment with realistic models of infrastructure systems, supply chains, and technology networks, applying classroom concepts [4]. In this way, SBE bridges the gap between theoretical knowledge and practical skills, enabling students to develop the adaptability and critical thinking required in today's rapidly evolving industries.

Despite its advantages, the application of SBE in STEM remains underexplored, with most research focusing on health sciences and other fields that emphasize skill training in controlled settings [5]. Thus, this study aims to contribute to the literature on SBE (and expand the previous research) by examining its impact on Engineering Management education, particularly in the development of strategic decision-making skills. By analyzing data from simulation exercises conducted with master's students, we seek to uncover how SBE influences decision-making preferences.

The simulation employed in this study, the "Innovation Simulation: Back Bay Battery," requires students to allocate Research and Development (R&D) budgets in a fictional company facing realistic market pressures, such as fluctuating demand, delayed feedback, and evolving technology trends. Students are tasked with balancing investments in sustaining innovations, which focus on improving current offerings for existing high-end customers, and disruptive innovations, which aim to capture new markets by providing simpler, more affordable alternatives. This simulated decision-making environment reflects the real-world choices that many large companies and Small and Medium Enterprises (SMEs) face, where limited resources often necessitate strategic prioritization [6].

The choice between sustaining and disruptive innovation is critical for SMEs, which must balance serving established customers with exploring new, underserved markets. While sustaining innovations can be profitable by catering to high-end clients, they may restrict market reach by creating sophisticated products that are inaccessible to a wider audience. In contrast, disruptive innovations introduce simpler, affordable alternatives that can attract previously

neglected customer segments, challenging established market leaders and reshaping market dynamics [7]. Through simulation-based learning, students experience these strategic trade-offs firsthand, building skills to navigate complex decision-making environments. Beyond financial and operational hurdles, SMEs often face psychological and capability challenges that require resilience, problem-solving, and innovative approaches. By immersing students in simulations that replicate real-world business complexities, SBE fosters the entrepreneurial and strategic skills necessary for future managers to drive SME growth in competitive markets [8].

This research extends beyond the foundational study by incorporating a temporal dimension, allowing for the examination of how decision-making patterns and learning outcomes evolve over time. Thus, while the preference for disruptive technologies may persist, the specific strategies employed by students might evolve in response to changing real-world technological environments.

This temporal dimension also provides an opportunity to assess the long-term effectiveness of simulation-based learning in Engineering Management education. By tracking the performance and decision-making patterns of multiple cohorts over several years, the aim is to provide valuable insights into the sustained impact of this pedagogical approach on students' strategic thinking and innovation management skills.

In the following sections, we provide an in-depth analysis of the decisions made by simulation participants, assessing how these experiences influenced their understanding of innovation types, and exploring the implications of SBE for Engineering Management education and curriculum development. This research contributes to the broader discourse on experiential learning in STEM, underscoring the potential of SBE to foster critical thinking, strategic decision-making, and adaptability essential for success in dynamic, innovation-driven industries.

II. DATA AND METHODOLOGY

The "Strategic Innovation Simulation: Back Bay Battery" uses a web-based simulation tool where students are asked to manage a battery company resolving the challenges posed by disruptive technologies. The platform includes a dashboard that replicates a management interface, including financial metrics, R&D investment options, and market feedback. Students progress through various scenarios by making strategic choices between investing in established technologies or exploring disruptive alternatives, observing how these decisions impact company performance and adjusting their strategies in response to the outcomes. This immersive exercise provides insight into the complexities of innovation management and competitive market dynamics. The simulation session followed the same scenario, developed for the previous research [9]. It included six main stages:

1. *Tutorial and setup*, where students are familiarized with the simulation's interface and objectives.
2. *Dashboard overview*, where they can observe current profitability, sales trends, and R&D budgets.

3. *Decision making*, where students decide how to allocate R&D spending between existing technologies and new, innovative options.

4. *Market response*, where they get the simulation updates reflecting the outcomes of their decisions, including sales growth, profitability, and market share.

5. *Adjustments and strategy*, where, based on feedback, students refine their strategies in subsequent rounds, aiming to balance short-term performance with long-term innovation.

6. *Debrief and reflection*, where students participate in a debriefing session to discuss strategies, outcomes, and lessons learned.

As for the previous study, this time participants were randomly selected from a pool of graduate students enrolled in an Engineering Management Master's program. The distribution of the students' background (academic major before the Master's studies) and gender is presented in Fig.1 and represent diverse perspectives skewing more towards Civil and environmental engineering. In terms of gender distribution is balanced, with equal numbers of male and female participants.

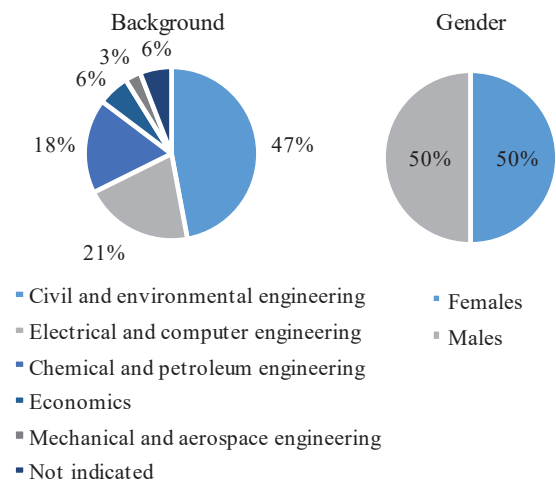


Fig.1. Distribution of the sample by background and gender

Students participated in two runs of the simulations with different difficulty level (the first run was mandatory and the second – voluntary), each run included several attempts. The iterative runs provided sufficient data for an in-depth analysis of how students' decision-making patterns evolved over time.

Thus, in each iteration, students tried the role of senior managers within a fictional company, responsible for determining the optimal timing and scale of R&D expenditures for both established and new (potentially disruptive) technologies. Over a simulated ten-year operational period, students must handle shifts in market conditions for both types of technologies. Players are required to analyze diverse information, extracting critical data, while also trying to achieve specific short-term and long-term performance benchmarks and milestones. Performance is assessed through financial metrics, including unit sales of both technologies, resulting revenue and profits, and market feedback. In addition, participants may encounter real-world delays between their investment decisions and observable outcomes.

Summarizing the results of simulations, Table 1 presents the average cumulative revenue, profit, and unit sales among all the participants in the first run. Notably, it shows increase in all three values compared to the previous (last year) simulation [9].

TABLE 1. AVERAGE CUMULATIVE REVENUE, PROFIT AND UNIT SALES AMONG ALL THE PARTICIPANTS

	Current	Previous
Average cumulative revenue (\$ million)	3,088.3	2,737.7
Average cumulative profit (\$ million)	219.8	112.5
Average unit sales	47.2	42.4

III. RESULTS AND DISCUSSIONS

The findings of the current study largely align with those of previous research, confirming earlier insights on the role of disruptive versus sustaining technologies in revenue and profit growth. Specifically, we observed that investments in disruptive innovations significantly drove revenue and profit growth. As it is shown in Table 2 the highest growth rates are observed from disruptive technologies. Conversely,

investments in sustaining technologies were associated with revenue and profit decreases, underscoring their limitations for achieving aggressive financial expansion. In comparison to the previous study, in general, improvement across all values was observed.

Interestingly, current results show significant improvement in the revenue and growth rate compared to the last-year run (although conducted among different groups of students). As in the previous study, a closer look at the individual plays across repeated runs was taken (Fig. 2). Thereby, the first student played seven time in the first mandatory run and five times in the second optional one. The cumulative profits and revenues achieve indicate the learning process at plays 1 and 2 (run 1) and some change in the strategy which led to negative results in play 6. With the defined strategy this student showed stable high results in run 2 despite the changes in the difficulty level. Student 2 also demonstrates ascending learning curve with the continuous increases of cumulative profits and revenues across the plays, although experienced more disturbing adaptation to the increased difficulty level in the run 2.

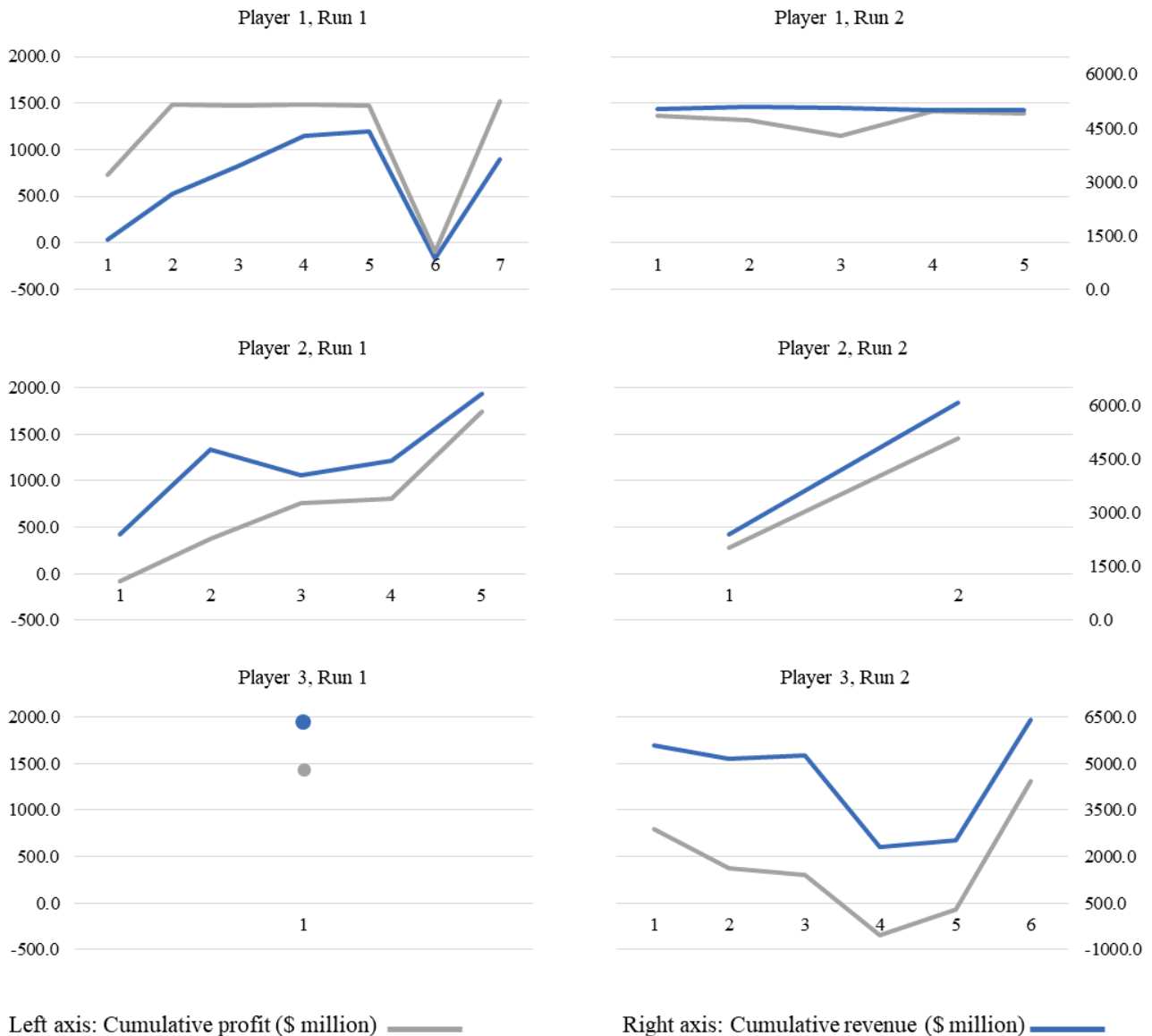


Fig.2. Cumulative revenue, profit and unit sales among selected participants in two runs

TABLE 2. AVERAGE REVENUE AND PROFIT GROWTH RATES

	Current	Previous
Average revenue growth rate (sustaining)	-14%	-16%
Average revenue growth rate (disruptive)	269%	202%
Average profit growth rate (sustaining)	-9%	-13%
Average profit growth rate (disruptive)	316%	130%

Student 3 (although they played only one game in run 1) demonstrated a more unstable performance with the less successful plays and strategies at runs 4 and 5 but was able to stabilize the outputs and even achieve some of the highest results.

Notably, students 3 and 2 obtained the highest cumulative profit among their group in one of their plays (\$1,748 and 1,428 million, and codes 34 and 10 in the entire group, respectively); both of them are female students, with backgrounds in Electrical and Computer, and Civil and Environmental Engineering respectively. Student 1 (3 in the general group) demonstrated stable performance but landed 7th in the ranking of the group (Table 3).

TABLE 3. BACKGROUND AND GENDER OF TOP-7 PLAYERS WITH THE HIGHEST CUMULATIVE PROFIT (\$ MILLION)

Code	Background	Gender	Cumulative profit (\$ million)
Student 34	Electrical and computer engineering	F	1,748
Student 10	Civil and environmental engineering	F	1,428
Student 26	Civil and environmental engineering	M	1,417
Student 21	Electrical and computer engineering	M	1,348
Student 12	Economics	F	1,252
Student 22	Chemical and petroleum Engineering	F	1,252
Student 3	Civil and environmental engineering	M	1,203

Thus, the educational value of simulation-based learning can be observed, as the simulation provided an engaging, hands-on experience that successfully bridged theoretical knowledge with practical application. The dynamic scenarios, combined with feedback from each attempt, fostered an adaptive learning process. Students refined their decision-making skills by responding to evolving challenges, thus enhancing overall learning outcomes. However, conclusions on the learning curve remain inconclusive due to the limited dataset gathered in this study.

Although stronger results were achieved, these gains cannot be attributed to accumulated experience across runs, as different students participated in each session. This limitation suggests an opportunity for future research: a longitudinal study tracking the same participants across

multiple years within a master's program could offer deeper insights into long-term learning curves and strategic growth.

IV. CONCLUSIONS

In conclusion, this study reaffirms the significant advantages of disruptive innovation as a strategic lever for driving revenue and profit growth. The simulation demonstrated the transformative potential of disruptive technologies to reshape market dynamics and provide a competitive edge. While sustaining technologies are essential for maintaining operational stability, their limited capacity to fuel substantial growth further emphasizes the strategic value of prioritizing disruptive innovations, particularly in the context of small firms.

This study emphasizes the critical role of simulation-based learning as an innovative and practical pedagogical approach, effectively bridging theoretical frameworks with real-world applications to enhance student learning and skill development.

However, it may not be limited only to the educational environment. The simulation's focus on strategic R&D allocation makes it relevant in SMEs and large companies, too as innovation-driven firms predominantly rely on internal knowledge development and R&D as critical drivers of their success [10]. Beyond skill development simulations are incorporating adaptive, real-time decision-making scenarios and complex system modeling and serve as a practical instrument for enhancing innovation management, bridging the gap between theoretical knowledge and practical application. Their immersive and dynamic nature promotes the development of adaptive learning, critical thinking, and systemic problem-solving, making them invaluable for organizations aiming to strengthen their innovation capabilities in an increasingly complex and competitive environment [11].

Nevertheless, despite the compelling learning outcomes observed, conclusions about students' learning curves remain tentative due to the limited dataset and varying participant groups across runs. Future research could address this limitation through longitudinal studies tracking the same participants across multiple simulation iterations within a master's program, providing deeper insights into long-term learning trajectories. Additionally, future studies might incorporate pre- and post-simulation surveys to assess participants' innovation capabilities and the impact of simulation-based learning on their strategic skills [12].

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