

Understanding Systems Engineering Decision-Making Through Game-Based Simulation: Insights from Industry

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Abstract: Learning how Systems Engineers (SEs) make architectural design decisions in real-world settings is challenging due to the involvement of interdisciplinary stakeholders, shifting priorities, and multiple trade-offs often across extended project timelines. While interviews, observations, and participatory sessions provided valuable insights in our research, they fell short of capturing the nuanced decision-making patterns, challenges encountered, and strategies adopted by SEs. To address this gap, we developed “*Decision Pathways*” a board game designed to recreate realistic SE design conditions in a structured and observable environment. *Decision Pathways* is a team-based, one-hour game where participants take on the role of SEs tasked with designing a system architecture. Gameplay involves selecting a knowledge pathway, navigating stakeholder networks, identifying and purchasing knowledge cards within a limited budget, and adapting architectural designs in response to evolving constraints. All decisions are made under time pressure, and the game concludes with each team presenting a physical architecture canvas. The game is structured around the Octalysis framework to ensure player engagement through motivational drivers such as time scarcity, ownership, unpredictability, constraints, and collaborative challenge. Following iterative design refinement and a pilot with 10 cross-disciplinary PhD researchers, the game was implemented with 54 practicing Systems Engineers from high-tech industry. The sessions yielded rich data on decision-making patterns, organization-wide considerations, knowledge identification and use, and team dynamics including the challenges faced and strategies adopted. Participant feedback validated the game’s realism and identified its value beyond research as a training and reflection tool for both novice and experienced SEs. This paper details the conceptual foundations, design methodology, core mechanics, and empirical insights from “*Decision Pathways*.” The research demonstrates how simulation-based board games can effectively support engineering research, professional development, and reflective practice while offering novel perspectives on complex decision environments. The implementation and results gives ideas for broader applications in systems thinking education and engineering design training.

Keywords: Game-Based simulation, Systems engineering, Design decision-making, Octalysis framework, Serious games in engineering

1. Introduction

Architectural design decisions in Systems Engineering (SE) are made under high complexity, involving multiple stakeholders, conflicting priorities, and interdependent trade-offs (Madni and Sievers, 2018). These decisions shape how systems are structured, integrated, and realised (Becker and Walker, 2017). Yet, understanding how SEs make such decisions in practice is challenging. The processes unfold over time, are embedded in collaboration, and shaped by organizational dynamics not easily captured through traditional methods. This gap is also recognised in SE training, where simulation environments like the Experience Accelerator (SERC, 2024) aim to support decision-making under realistic constraints.

In our research, conventional methods like interviews, observations, and workshops provided valuable context but fell short of capturing the dynamic, real-time nature of decision-making. This led us to explore game-based approaches, which offer a structured yet flexible way to simulate complexity and provoke reflection. Serious games have shown promise in engineering education, supporting systems thinking, teamwork, and motivation (Urgo et al., 2021; Núñez-Pacheco et al., 2023; Zourmpakis et al., 2023). While most studies focus on academic settings, their insights offer parallels for professional practice.

Building on this foundation, we developed *Decision Pathways*, a board game that simulates early-stage architectural design in SE. Grounded in motivational principles from the Octalysis framework (Chou, 2016), the game functions as both a research tool and a reflective exercise, enabling deeper insight into how engineers navigate architectural decisions in complex environments.

2. Game Design and Development

Decision Pathways, a serious board game, was developed to investigate architectural decision-making in Systems Engineering (SE) as part of an ongoing research project within the Systems Engineering and Multidisciplinary Design (SEMD) group at the University of Twente.

The game was conducted in a workshop format, serving as the core activity followed by theme-based discussions aligned with our research aims. The primary purpose of the game was to simulate realistic SE decision-making in a controlled setting to support data collection. Earlier methods such as interviews and observations yielded fragmented insights, often influenced by the specific project phase participants were engaged in. The game addressed this limitation by creating a shared, complete design experience that set the stage for richer post-game discussions.

Grounded in insights from our industrial partner, the game simulates design pressures through a realistic scenario, knowledge acquisition pathways, architectural planning under budget constraints, evolving conditions, and uncertain information sources. It retains the complexity of SE work while enabling structured observation of decision-making, knowledge strategies, and team dynamics. By engaging participants in stakeholder complexity, incomplete knowledge, and trade-offs under constraints, the game creates conditions that surface authentic decision-making behaviours for analysis. The format is both cooperative and competitive: teams collaborate internally while aiming to produce the most effective architectural solution.

Participants design a system architecture in response to a scenario by acquiring stakeholder knowledge and managing constraints such as time, budget, and evolving conditions. There is no single correct solution; teams must make trade-offs, justify decisions, and relate their approach to real-world SE practices. The game promotes reasoning and negotiation, and encourages participants to reflect on their own decision-making practices. Gameplay follows structured phases: scenario briefing, rule explanation, knowledge exploration, decision rounds, introduction of constraints, architecture finalisation, presentations, and concluding reflection.

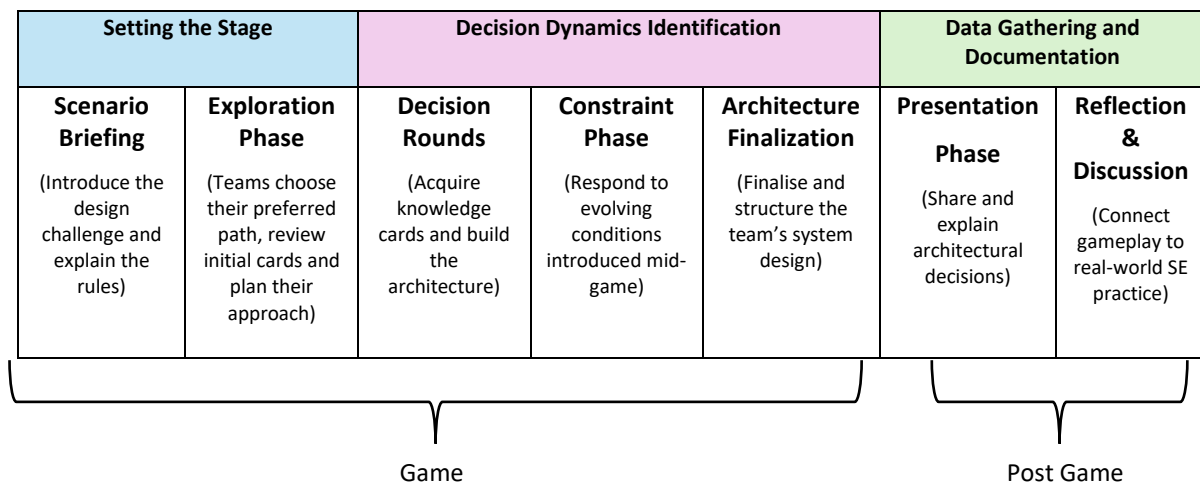


Figure 1: Decision Pathways Game Flow

The development process included two major stages: development and final design. The game evolved through multiple design cycles, informed by insights from the partner company to ensure realism and industrial relevance. Key elements refined included the scenario, card-based stakeholder knowledge, the distinction between people and process pathways, and the integration of time and budget constraints. The final design incorporated the Octalysis Framework's eight psychological drivers (Chou, 2016) to align gameplay with decision-making themes. While other models such as Kapp (2012) or Zichermann and Cunningham (2011) exist, Octalysis offered a practical structure and had been used by one author in a prior context (Pessoa, 2023).

The game was piloted with 10 PhD researchers at the University of Twente to test structure, clarity, and realism. Conducted as a 90-minute workshop, it included briefing, gameplay, and debriefing. Two teams of five used printed materials stakeholder maps, knowledge and constraint cards, budget tokens, and architecture canvases to complete the full cycle from selecting a knowledge path to presenting a final design.

Facilitators observed the session, made notes, and collected data through audio recordings and sticky notes. Participants engaged with trade-offs and stakeholder reasoning, showing clear understanding of the design challenge. Feedback led to refinements in instructions, visuals, canvas layout, and constraint timing, informing the version later implemented with 54 practicing systems engineers in industry.

3. Decision Pathways Board Game

As the game was designed to mirror real-world SE architectural decision-making, it includes components that reflect typical SE work conditions while embedding motivational design principles from the Octalysis framework. As shown in Figure 1 (game flow), players move through a sequence: understanding the scenario, choosing a knowledge path, acquiring knowledge cards, designing the architecture, and finally reflecting on their choices. Each element serves both a gameplay function and a motivational purpose, as outlined below:

- The game begins with an *imaginary company profile and design scenario* that provides players with clear context and purpose. This frames the challenge and supports the core drive of **epic meaning and calling**, as teams step into the role of Systems Engineers solving a realistic architecture problem.
- A key setup feature is the *Organisational Stakeholder Map*, which visually represents internal and external actors. Each stakeholder links to two colour-coded knowledge cards aligned with distinct pathways: the *people pathway* (orange), representing informal, experience-based knowledge (e.g., preferences or routines), and the *process pathway* (blue), representing formalised sources (e.g., documentation or logs). This dual-path design introduces **curiosity, unpredictability, and early trade-offs** in knowledge strategy.
- Teams are given a *fixed budget of 20 coins* to purchase stakeholder knowledge. This constraint, combined with a *60-minute time limit*, pressures teams to prioritise and manage uncertainty reinforcing **scarcity & impatience** and **loss & avoidance**. Not all knowledge cards are equally useful; some are detailed, others vague or misleading. This variability requires strategic adaptation, further engaging **unpredictability and curiosity**.
- Midway through the session, *constraint cards* are introduced. These simulate disruptions such as organisational shifts, compliance issues, or conflicting requirements. Teams must adapt their evolving architecture and rethink decisions on the fly, reinforcing **unpredictability**, and encouraging reflective, adaptive decision-making.
- As teams work toward a solution, they use the *architecture canvas* to visualise their final design. This shared space externalises reasoning and links stakeholder knowledge to design choices supporting **ownership & possession, creativity & feedback**, and a sense of accomplishment. Players often refer to the canvas as “our system,” highlighting engagement and collaboration.
- Additional materials like *stationery, tokens, and printed instructions* support gameplay and help externalise thinking. The structured flow and completion of the architecture contribute to a sense of progress, aligning with **development & accomplishment**. Team-based play naturally encourages role division (e.g., card reader, budget manager), activating **social influence and relatedness** through shared decision-making and negotiation.
- The game’s open-ended format, with no single correct solution, allows for creativity and diverse approaches. Final presentations provide space for **empowerment of creativity & feedback**, as participants explain their logic and reflect on decisions supporting both learning and professional insight.

The Octalysis framework helped ensure the game was structured and engaging while reflecting the realities of SE decision-making. Rather than applying it as an overlay, we used the core drives to shape key aspects of the game from the outset from time pressure and resource limits to team interaction and design ownership. This alignment of gameplay mechanics with motivational patterns made the experience meaningful in both learning and professional contexts.

The game is designed as a one-hour session for teams of 2–6 players. For a given design scenario, participants collaboratively build a physical system architecture using fragmented knowledge, while managing time, budget, and evolving constraints. Success depends on strategic choices: selecting knowledge paths, navigating stakeholder networks, acquiring and applying relevant cards, and adapting designs under pressure. Each team ends with a completed architecture canvas. While primarily intended for group play to encourage discussion and role division, the game can be played solo though this may reduce key dynamics such as negotiation and collaborative reasoning.

A typical session moves through a series of phases that reflect key parts of SE project work. It starts with a short briefing on the design scenario, followed by phases where teams explore knowledge paths, collect information, deal with constraints, and develop their architecture. The session ends with a presentation and reflection. Each phase has a set time and is simulating aspects of SE decision-making. The sections below explain each phase step by step, linked to the visuals in Figure 2 (numbers in the text * correspond to the numbers in the figure).

3.1.1 Briefing (0–5 mins)

The session begins with a short introduction where the facilitator presents the scenario. This is done using a brief presentation and a printed handout that participants can refer to. Participants are told they will act as Systems Engineers, working in teams to design a system architecture within the given time and budget.

The facilitator then explains the structure of the game, including its components (*1-5). One of the first choices teams must make is selecting a knowledge path (*2): either the people path (orange) or the process path (blue). The people path represents informal, experience-based knowledge such as stakeholder preferences, team culture, or hallway conversations. The process path focuses on formal sources like documentation, reports, emails, and system logs. This early decision shapes the team's starting point, as it determines which set of knowledge cards they receive. However, participants are informed that their paths remain flexible later in the game.

The briefing also covers how to read the stakeholder map (*1), use the knowledge cards (*3,4), manage the fixed budget of 20 coins per team (*5), and work with the architecture canvas (*7) to build and present their design. Basic rules are introduced, and each component is detailed. Participants are encouraged to ask questions to ensure the game mechanics are clear. Once the rules are understood, teams begin reading the scenario and discussing how they might approach the challenge. This leads into the exploration phase, where they receive their first set of knowledge cards (*4) and begin working through the scenario.

3.1.2 Exploration Phase (5–15 mins)

Teams receive a set of five pre-selected knowledge cards based on their initial choice of the people or process path, marking the start of the exploration phase. They begin by reviewing the content of the cards to identify useful information, spot connections to the design scenario, and determine which elements might guide their next steps.

During this phase, teams typically spread out the cards, divide reading tasks, and highlight key points or stakeholder references (*6). Some teams begin sketching rough ideas on paper or directly on the architecture canvas, while others focus on discussing what kind of architecture might be feasible given the information they currently have. Early roles such as timekeeper, card reader, or design lead often emerge organically as the group starts organising its thinking.

The exploration phase is intentionally open-ended, with no prescribed structure for how teams must proceed. This flexibility allows participants to define their own approach to navigating the design challenge from the outset. While their initial cards are drawn from one pathway, teams are free to switch between the people and process paths in later phases and can access any available knowledge card (*3) using their remaining budget.



Figure 2: Decision Pathways Board Game (Numbers in the figure correspond to the gameplay phases described in Section 3.)

3.1.3 Decision Rounds (15–60 mins)

In the main phase of the game, teams decide which additional knowledge to acquire and begin constructing their architecture using the stakeholder map, knowledge cards, budget coins, and architecture canvas. Stakeholders (*3) represent internal and external actors, each linked to two knowledge cards one from the people path (orange) and one from the process path (blue). Cards are uniquely numbered and assigned a budget cost (*5). Teams may select any card at any time, using their remaining coins to access knowledge aligned with their evolving strategy.

A key design element emerges here: people and process cards have different costs, which teams discover only after choosing a path. This prompts reassessment of budget use and strategy. Not all cards are equally valuable, some offer clear insights, while others are vague or less relevant. This variability introduces uncertainty and requires teams to judge whether a card is worth the cost. The resulting trade-offs stimulate strategic decision-making under pressure.

As teams gather more knowledge, they begin shaping their architecture. Some cluster cards by stakeholder (*6); others sketch layouts or trace reasoning paths. The game supports varied working styles. Teams build, test, and revise ideas, often adjusting direction as new insights emerge.

3.1.4 Constraint Phase (30–50 mins)

Midway through the session, teams face a new challenge through the introduction of constraint cards, which simulate real-world disruptions such as stakeholder changes, compliance issues, or resource limitations.

Three constraints are introduced during this phase, spaced approximately 5–7 minutes apart. The facilitator reads each constraint aloud, and all teams receive the same one simultaneously. Teams are given a short window to respond by revising their architecture, reconsidering prior decisions, or acquiring new knowledge. Some constraints require removing a card, shifting priorities, or integrating new requirements; others introduce ambiguity or conflicting information. This phase often sparks intense discussion as teams adapt their strategies to meet evolving challenges.

Introduced during the final 30 minutes of gameplay, constraints test teams' adaptability under pressure, mirroring the shifting conditions of SE work. Some teams use their remaining budget to acquire new cards, while others rework their designs using existing knowledge.

3.1.5 Architecture finalization (ongoing)

As teams gather knowledge and respond to constraints, they begin shaping their final architecture using the canvas (*7), which represents both the system design and the reasoning behind it. The canvas is open-ended: teams may draw component layouts, list design features, map stakeholder priorities, or trace knowledge connections. This flexibility mirrors how design logic unfolds in SE practice. Teams revisit earlier decisions, check alignment with scenario goals, and identify gaps or contradictions.

This phase often triggers creative reasoning. As teams integrate information and respond to constraints, discussions become more strategic. Final disagreements are resolved, and decisions are finalised. Some teams divide tasks for example, one member sketches others review cards while others collaborate on every part of the layout. By the end, each team produces a completed canvas that reflects their design logic, knowledge use, and responses to the challenges encountered during the game.

3.1.6 Presentation phase

At the end of the one-hour gameplay, each team presents their final architecture using the canvas they developed (*7). Presentations are informal but focused, typically lasting around five minutes per team. Teams explain their design choices, use of knowledge cards, and responses to constraints. While there is no single correct solution, facilitators may ask questions to probe reasoning or challenge trade-offs. The "winning" team is selected based on overall coherence, creativity, and alignment with scenario goals.

This phase allows teams to reflect on their design process, compare strategies, and discuss how knowledge was used or interpreted. Despite starting from the same scenario, teams often arrive at different solutions, showing SE diversity.

Facilitators also recorded observational notes throughout gameplay, capturing how teams interpreted the scenario, engaged with knowledge, responded to constraints, and collaborated. These notes supported post-game reflections and offer insight into participant strategies.

3.1.7 Reflection and discussion (post game)

After presenting their final architecture, teams move into a structured reflection phase, where participants reflect on the game with SE practices. Facilitators guide the discussion using predefined themes: organisational-wide knowledge thinking, knowledge identification and use, and stakeholder alignment, each rooted in prior research. Participants are encouraged to link game reflections with their own work experiences.

This phase supports research data. As participants reflect on their reasoning and collaboration strategies, researchers gain insight into SE behaviour under pressure backed by audio recordings for further analysis. Participants also use sticky notes (*8) to reflect on the challenges encountered.

Together, the game phases create a realistic simulation of SE decision-making. From scenario to reflection, each element aims to keep participants engaged while surfacing how they handle knowledge, constraints, and collaboration, supporting both learning and empirical observation.

4. Implementation and Insights from Industry Sessions

The Decision Pathways supported simulated reflection for participants and research data collection. From the participant perspective, the goal was to simulate realistic SE decision-making and promote systems thinking by engaging with stakeholder complexity, navigating incomplete knowledge, and making trade-offs under constraints. From the research perspective, the sessions aimed to verify the game's structure and realism and provided a controlled, observable environment to study how SEs engage with knowledge, constraints, and team decision dynamics.

The game was implemented with 54 practicing Systems Engineers from a high-tech industry between December 2024 and March 2025. Sessions were conducted in small groups, each facilitated and followed by a structured post-game discussion. Participants consistently noted the game's resemblance to real-world SE challenges, describing it as structured, realistic, and engaging with several calling it "fun but intense." Many valued the opportunity to reflect on their decision-making styles in a simulated yet familiar setting. Each session followed the gameplay flow described in Section 3 and Figure 1, progressing through seven phases: briefing, exploration, decision rounds, constraint phase, architecture finalisation, presentation, and reflection. This structure enabled consistent yet flexible engagement and supported observation of behaviours such as knowledge navigation, trade-off reasoning, and team dynamics elements often difficult to capture in long-term, distributed SE projects.

Data collection included facilitator observations, team architecture canvases, sticky notes, and audio recordings. Analysis followed a thematic approach based on four predefined themes developed during game design: organisation-wide knowledge thinking, knowledge identification, knowledge use, and stakeholder alignment. These themes also framed the guided post-session reflections. Audio data were reviewed to extract decision-making challenges and strategies, triangulated with in-game observations and artefacts. Emergent patterns such as negotiation strategies and trade-off reasoning were compared against the predefined themes. These analytical methods supported interpretation of observed behaviours and decision patterns during gameplay.

Several design patterns emerged across sessions. Some teams focused on internal stakeholders, others prioritised external perspectives. Interpretation of knowledge also varied: some trusted formal documentation, others relied on stakeholder input or informal cues. These choices often reflected team preferences or established decision habits. When constraints were introduced, some teams revised their architecture quickly, while others struggled to adapt without major rework. These differences revealed how rigid or flexible decision strategies played out in a simulated yet realistic design environment.

Facilitators documented how participants engaged with the game, interpreted components, collaborated, and responded to constraints. These observations confirmed that the mechanics functioned as intended and reflected typical SE decision behaviours. In post-game discussions, participants compared the experience to real projects, noting parallels such as knowledge gaps, stakeholder pressures, and conflicting needs. These insights affirmed that the game successfully surfaced relevant SE decision-making patterns.

The sessions revealed how teams manage fragmented knowledge, make trade-offs, and collaborate under pressure. Beyond outcomes, the game functioned as a reflective tool, prompting participants to consider how such decisions unfold in their actual work. This aligns with the game's original aim to serve both as a structured

simulation for research and a means to mirror SE complexity. Participants' spontaneous reflections, negotiation dynamics, and varied design approaches suggest that the game effectively surfaced common decision challenges and strategies. By making these patterns visible in a compressed, observable format, the game fulfilled its dual role of fostering reflection and generating insight into SE practice.

We conducted a thematic analysis of qualitative data from audio recordings, facilitator notes, and artefacts such as architecture canvases and sticky notes. The analysis was guided by four predefined themes organisation-wide knowledge thinking, knowledge identification, knowledge use, and stakeholder alignment established during game development. Transcripts of post-game discussions were coded using a hybrid approach: deductive coding identified data aligned with predefined themes, while inductive coding captured additional insights such as negotiation strategies and team adaptation behaviours. Coding was performed by two researchers, with regular discussions to ensure consistency. Triangulation across data sources supported the validity and helped surface recurring decision-making behaviours and team dynamics reflective of real-world SE practice.

5. Reflections on the Decision Pathways Game

The implementation of Decision Pathways offered valuable insight into how participants engaged with a simulated SE environment. Observations and reflections indicated that teams perceived the game as a realistic design challenge, prompting deep reasoning and collaboration. The balance between realism and playability was well received; participants found the scenario and stakeholder layout reflective of actual SE conditions, while the format maintained focus within time limits. Some teams welcomed greater complexity, while others appreciated the clarity, suggesting the design supported flexible engagement across experience levels.

Teams demonstrated structured reasoning throughout gameplay, discussing which knowledge to acquire, how to interpret it, and how to reflect it in their system design. The architecture canvas helped externalise logic and trade-offs. Rather than focusing on winning, many teams approached the game as a collaborative exercise, mirroring real-world working styles. Reflection began informally during gameplay and deepened in the post-game discussion. Participants drew clear parallels with project work, especially in handling incomplete knowledge, shifting requirements, and internal alignment. For many, the game mirrored their team dynamics and decision-making habits. They saw value in the game not only for research, but also as a tool for training, onboarding, and team learning. The tangible materials and structured format helped surface abstract thinking in a practical, engaging way.

Several Octalysis drives were actively experienced during gameplay. Scarcity and Impatience were triggered by the 60-minute time limit and fixed budget, which pressured teams to prioritise and make quick decisions under uncertainty. Ownership and Possession emerged in how teams referred to the architecture canvas as "our system" and defended their decisions during presentations, reflecting a sense of control and commitment. Social Influence and Relatedness surfaced through natural role division teams appointed timekeepers, budget managers, and design leads mirroring real-world SE collaboration. Empowerment of Creativity and Feedback was seen in how teams interpreted knowledge differently, adapted to evolving constraints, and creatively justified their designs. Unpredictability and Curiosity were sparked by the varied content of knowledge cards some clear, others vague or misleading which pushed teams to reassess decisions and adapt strategies throughout the game.

One participant noted:

"The design game workshop is an exercise in system-level design and would be a good conversation starter on SE ways of working. It triggers reflection on how to approach design questions. It has an attractive example case and is well-prepared with game cards and an overall storyline, including last-minute changes in boundary conditions. I really enjoyed playing it and would love to see it as part of regular training material." - Senior SE, high-tech industry, NL.

These experiences suggest that the Octalysis-based design supported both engagement and reflection, surfacing complex decision behaviours in collaborative settings. Participants viewed the game not just as an activity, but as a realistic simulation of SE practice. Its structured format supported decision-making under constraints, encouraged team dialogue, and revealed reasoning strategies. The game offered participants a chance to think, act, and reflect like Systems Engineers in a setting that was controlled and authentic. It shows promise not only as a research tool, but also for professional learning, training, and team development.

6. Conclusion and Future Potential

Decision Pathways was developed to address the research challenge of exploring SE decision-making without relying on extended industry access or fragmented observations. It also provided participants with a structured, collaborative space to engage with SE complexity. Though initially designed for research, the game quickly proved to be a valuable learning and reflection tool, prompting insights into design strategies, collaboration, and decision-making patterns. A key takeaway was the value of shared, hands-on experience in revealing hidden aspects of decision-making. The game's physical format encouraged participants to think aloud, explore trade-offs, and engage with abstract constraints in a tangible way, bridging research aims with practical SE challenges more effectively than interviews or post-hoc reflections. The Octalysis framework shaped both the game's design and player experience. Its motivational drivers, integrated from the outset, made gameplay purposeful and engaging, and offered a lens to understand not just what players did, but why certain mechanics resonated. Although created for research, participant feedback highlighted its broader value as a reflective and developmental tool. Many reported increased awareness of their reasoning, team dynamics, and working styles, noting its potential for onboarding, training, and team learning. Grounding the game in real-world SE conditions made it feel authentic. While these insights stem from a context, they suggest directions for adaptation and testing elsewhere. The open-ended gameplay supported flexible use beyond its original research intent. Looking ahead, the game can be adapted to other settings, such as academic programmes, digital formats, or industries with similar decision-making structures. While the current implementation involved a specific industrial context with a limited but diverse participant group, the core structure and thinking behind Decision Pathways show promise for broader application. Although recurring patterns were observed, generalisability remains a direction for future work. We view the game's transferability not as a fixed outcome, but as potential that requires contextual validation. Nonetheless, the game's value extends beyond observing decisions it also supports how decisions are made, shared, and reflected upon in practice.

Ethics Declaration: This study was conducted in accordance with institutional ethical standards for research involving human participants. Participants received an information sheet and provided written consent for the use of anonymised gameplay artefacts and audio reflections. Participation was voluntary, without incentives, and no personal or sensitive data were collected.

AI Declaration: After the development OpenAI was used to improve language clarity and format references. All content and analysis are the author's own.

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