Design of serious games for teaching industrial engineering methodologies : A design process based on V-model and an application in innovation engineering

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Titre : Conception de jeux sérieux pour l'enseignement de méthodologies du génie industriel : Un processus de conception basé sur le modèle en V et une application en ingénierie de l'innovation

Mots clés : jeu sérieux, méthodologies du génie industriel, modèle en V, processus de conception, ingénierie de l'innovation, Radical Innovation Design

Résumé : Les jeux sérieux (JS) semblent être un format éducatif tout à fait approprié pour s'initier aux méthodologies du génie industriel (GI), car ces dernières consistent à ce que des personnes suivent un processus sous certaines conditions pour aboutir à des performances collectives. Mais les études de conception de JS ont plusieurs limites à ce jour ; l'une d'elles est que les concepteurs comme les enseignants de GI sont sans expertise particulière en conception de jeux. Cette thèse vise à proposer un processus de conception adapté aux JS sur les méthodologies de GI. Nous apportons cinq contributions. Premièrement, nous proposons un langage de conception pour représenter la structure d'un JS de manière hiérarchique. Ensuite, nous proposons un cadre de conception générique pour un JS suivant un modèle en V standard et une approche participative qui permet de définir, vérifier et valider progressivement la structure du JS. Troisièmement, nous proposons un modèle permettant de décomposer une méthodologie de GI en sept catégories d'éléments descriptifs, afin de pouvoir les spécifier en tant qu'objectifs d'apprentissage. Il a été demandé à sept experts de l'utiliser pour décrire douze méthodologies de GI qu'ils connaissent bien. Quatrièmement, nous proposons un modèle en V adapté pour les jeux de GI, qui permet d'expliquer comment les éléments descriptifs d'une méthodologie donnée peuvent inspirer chaque objet de conception du JS.

Notre cinquième et dernière contribution est l'élaboration effective d'un JS en ingénierie de l'innovation, spécifiquement pour enseigner la méthodologie Radical Innovation Design (RID). Douze sessions de conception ont été nécessaires pour suivre le processus de conception du modèle en V. Son scénario de jeu consiste à exprimer et à diminuer les poches de valeur dans le contexte de la mobilité urbaine. Le jeu comprend six épisodes, un plateau de jeu inspiré du processus RID, sept jeux de cartes, des mécanismes de jeu sophistiqués et une notation simple en deux dimensions pour à la fois maximiser l'utilité pour les usagers de la mobilité et les opportunités commerciales pour sa propre entreprise de mobilité. Nous avons organisé deux expériences de validation avec quatre sujets expérimentés et trois novices en matière d'innovation. Les validations ont montré que le jeu offre une expérience d'apprentissage ludique, validant le jeu RID lui-même et, à son tour, validant partiellement le modèle en V adapté. Cette recherche fournit aux concepteurs un processus structuré qui met en relation les éléments de conception du JS et les objets de la méthodologie de GI. La conception complète d'un JS dans le cadre d'une méthodologie d'ingénierie de l'innovation devrait pouvoir être reproduite dans d'autres domaines de GI.

Title: Design of serious games for teaching industrial engineering methodologies: A design process based on V-model and an application in innovation engineering

Keywords: serious games, industrial engineering methodologies, V-model, design process, innovation engineering, Radical Innovation Design

Abstract: Serious games (SGs) seem to be a much appropriate educational format for being initiated to industrial engineering (IE) methodologies as the latter consist for people to follow a common process under some conditions to achieve some collective performances. But the existing SGs design studies have several limitations, especially for designers like IE teachers without game design expertise. This work aims at proposing a design process adapted to SGs on IE methodologies. We make five contributions. First, we propose a design language for representing the structure of an SG hierarchically. Second, we propose a generic design framework for an SG following a standard V-model to define, verify, and validate the SG structure progressively. Third, we propose a template to decompose an IE methodology into seven categories of descriptive elements to be able to specify them as learning objectives. Seven experts were asked to use it to describe twelve IE methodologies they are familiar with. Fourth, we propose an adapted V-model for IE games, explaining how given methodology's descriptive elements can inspire each design object of the SG.

Our fifth and last contribution is the elaboration of an SG in innovation engineering, specifically to teach Radical Innovation Design (RID) methodology. Twelve design sessions were needed to follow the V-model design process. Its gameplay is about expressing and eradicating value buckets on urban mobility. The game comprises six episodes, a game board inspired by the RID process, seven card decks, sophisticated game mechanics, and a simple two-dimensional scoring for fighting at the same time for developing usefulness for mobility users and business opportunity for its own mobility company. We organized two validation experiments with four experienced subjects and three novices in innovation. The validations showed that the game offers a playful learning experience, validating the RID game itself and, in turn, partially validating the adapted V-model. This research provides designers with a structured process that relates SG design elements and IE methodology objects. The complete design of an SG in an innovation engineering methodology should be replicable in other IE domains.

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Résumé

Les jeux sérieux (JS) ont été largement adoptés dans l'enseignement supérieur, car ils peuvent garantir une motivation intrinsèque et fournir un apprentissage en situation. JS semblent être un format éducatif tout à fait approprié pour s'initier aux méthodologies du génie industriel (GI), car ces dernières consistent à ce que des personnes suivent un processus sous certaines conditions pour aboutir à des performances collectives. Mais les études de conception de JS ont plusieurs limites à ce jour ; l'une d'elles est que les concepteurs novices comme les enseignants de GI sont sans expertise particulière en conception de jeux. Cette thèse vise à proposer un processus de conception adapté aux JS sur les méthodologies de GI.

Nous apportons cinq contributions. Premièrement, nous proposons un langage de conception pour les JS, qui organise différents éléments de conception en fonction de la structure hiérarchique des JS. Ensuite, sur la base des objets de conception identifiés, nous proposons un cadre de conception générique pour un JS suivant un modèle en V standard et une approche participative qui permet de définir, vérifier et valider progressivement la structure du JS. Troisièmement, nous proposons un modèle permettant de décomposer une méthodologie de GI en sept catégories d'éléments descriptifs, afin de pouvoir les spécifier en tant qu'objectifs d'apprentissage. Il a été demandé à sept experts de l'utiliser pour décrire douze méthodologies de GI qu'ils connaissent bien. Selon les résultats de la validation, il s'agit d'un outil utile pour décrire brièvement mais suffisamment les méthodologies de GI. Quatrièmement, nous introduisons le langage descriptif proposé pour les méthodologies de GI dans le modèle en V générique pour construire un modèle en V adapté pour les jeux de GI, qui permet d'expliquer comment les éléments descriptifs d'une méthodologie donnée peuvent inspirer chaque objet de conception du JS.

Notre cinquième et dernière contribution est l'élaboration effective d'un JS en ingénierie de l'innovation, spécifiquement pour enseigner la méthodologie Radical Innovation Design (RID). Douze sessions de conception ont été nécessaires pour spécifier les éléments de conception, la disposition et les interfaces du jeu, et créer des prototypes fonctionnels. Son scénario de jeu consiste à exprimer et à diminuer les poches de valeur dans le contexte de la mobilité urbaine. Une poche de valeur est un problème important rencontré par les voyageurs lorsqu'ils se déplacent en ville. Le jeu comprend six épisodes, un plateau de jeu inspiré du processus RID, sept jeux de cartes, des mécanismes de jeu sophistiqués et une notation simple en deux dimensions pour à la fois maximiser l'utilité pour les usagers de la mobilité et les opportunités commerciales pour sa propre entreprise de mobilité. Pour valider le jeu, nous avons organisé deux expériences de validation avec quatre sujets expérimentés et trois novices en matière d'innovation. Tous ces participants ont la motivation d'apprendre le RID car leur expérience de recherche ou de travail est liée à la gestion de l'innovation. Pour rassembler les preuves pour la validation, nous avons adopté trois méthodes: pré- et post-test, entretien et observation non participante. Sur la base de l'analyse des résultats des questionnaires et des commentaires des participants aux expériences, le jeu offre une expérience d'apprentissage ludique et stimule même la motivation des joueurs à poursuivre leur apprentissage du RID, validant le jeu RID lui-même et, à son tour, validant partiellement le modèle en V adapté.

Cette recherche fournit aux concepteurs un processus structuré qui met en relation les éléments de conception du JS et les objets de la méthodologie de GI. La conception complète d'un JS dans le cadre d'une méthodologie d'ingénierie de l'innovation devrait pouvoir être reproduite dans d'autres domaines de GI. Concernant les contributions de cette thèse, certaines limites doivent être mentionnées. Premièrement, la conception de l'ensemble du jeu

RID doit être achevée à l'avenir. Deuxièmement, nous devons consolider la validation des cinq contributions. Troisièmement, pour prouver l'applicabilité du modèle en V adapté, nous devons l'appliquer pour concevoir des JS sur d'autres méthodologies de GI.

Abstract

Serious games (SGs) seem to be a much appropriate educational format for being initiated to industrial engineering (IE) methodologies as the latter consist for people to follow a common process under some conditions to achieve some collective performances. However, the existing SGs design studies have several limitations, especially for designers like IE teachers without game design expertise. This work aims at proposing a design process adapted to SGs on IE methodologies. We make five contributions. First, we propose a design language for representing the structure of an SG hierarchically. Second, we propose a generic design framework for an SG following a standard V-model and participatory approach to define, verify, and validate the SG structure progressively. Third, we propose a template to decompose an IE methodology into seven categories of descriptive elements to be able to specify them as learning objectives. Seven experts were asked to use it to describe twelve IE methodologies they are familiar with. Fourth, we put forward an adapted V-model for IE games, explaining how given methodology's descriptive elements can inspire each design object of the SG. Our fifth and last contribution is the sufficient elaboration of an SG in innovation engineering, specifically to teach Radical Innovation Design (RID) methodology. Twelve design sessions were needed to follow the V-model design process. Its gameplay is about expressing and eradicating value buckets on urban mobility. The game comprises six episodes, a game board inspired by the RID process, seven card desks, sophisticated game mechanics, and a simple two-dimensional scoring for fighting at the same time for developing usefulness for mobility users and business opportunity for its own mobility company. We organized two validation experiments with four experienced subjects and three novices in innovation. The validations showed that the game offers a playful learning experience, validating the RID game itself and, in turn, partially validating the adapted V-model. This research provides designers with a structured process that relates SG design elements and IE methodology objects. The complete design of an SG in an innovation engineering methodology should be replicable in other IE domains.

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Abbreviations

DT	Design Thinking
DRM	Design Research Methodology
DSM	Dependency Structure Modelling
DPS	Design purposes specification
ESM	Eco-ideation Stimulation Mechanism
GM	Game Mechanics
ICT	Information and communications technology
IE	Industrial Engineering
IISE	Institute of Industrial and Systems Engineers
IS	Investigation Strategy
KSB	Knowledge Social Business
LCA	Life Cycle Assessment
LM	Learning Mechanics
MFA	Material Flow Analysis
MRP	Program Evaluation Review Technique
PD	Participatory Design
RID	Radical Innovation Design
RQ	Research Question
SBCE	Set-Based Concurrent Engineering
SG	Serious Game
SGDA	Serious Game Design Assessment
SRS	Software requirements specification
TQM	Total Quality Management
PBL	Problem Based Learning
PERT	Program Evaluation Review Technique
QA	Quality Assurance
UNPC	Usefulness Newness Profitability Concept
USP	Unique Selling Proposition
V&V	Validation & Verification
VB	Value Bucket

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Chapter 1. General introduction

1.1 Context

According to the Institute of Industrial and Systems Engineers (IISE), Industrial engineering (IE) makes any industry better, from automobile manufacturing and aerospace to healthcare, forestry, finance, leisure, and education. IE is the branch of engineering concerned with designing, improving, and installing integrated systems of people, materials, information, equipment, and energy. Industrial engineers utilize their specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles/methods/methodologies/tools (collectively referred to as "**IE methodologies**" in this thesis) of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems[1]. For example, Life Cycle Assessment (LCA) is a widely used IE methodology for assessing environmental impacts associated with all the stages of the life-cycle of a commercial product, process, or service.

These methodologies summarize all the wisdom of predecessors in the field of IE. They can effectively guide industrial practice and provide a solid foundation for further academic research. In order to disseminate IE methodologies, many universities and firms have designed dedicated training courses. However, most of these courses appear as too much theoretical (Glassman and Opengart, 2016). Trainees lack opportunities to apply the knowledge practically, so they may not understand some abstract and complex concepts in IE methodologies. An ancient Chinese proverb says: "I hear and I forget, I see and remember, I do and I understand," clearly indicating that the idea of practice even facilitating the long-term preservation of knowledge (Pérez-Sabater et al., 2011). To make up for the shortcoming of traditional courses, educators adopt an active strategy, "Project-Based Learning (PBL)," which is student-centered and focuses on real-world issues, for creating meaningful teaching and learning experiences (Mesquita et al., 2013; Alves et al., 2016; Lima et al., 2017). However, the researchers also raised some concerns about PBL (Aslanides et al., 2016; Mihic & Zavrski, 2017), like:

① It takes more time for designing, implementing, and administrating PBL curricula;

② Teachers have difficulties designing a system of evaluation that a majority of students will understand;

③ Students with a history of failures generally have a low curiosity level, in consequence they may not be motivated by PBL curricula;

④ PBL curricula have the particular requirement of interest, cooperation and institutional support from various stakeholders in education.

[1] https://www.iise.org/Details.aspx?id=282

Serious Games (SGs) as a new educational format have gained interest in many scholars from diverse fields. According to application areas, SGs can be categorized as shown in Table 1.1 (Susi & Backlund, 2007). This thesis pays particular attention to educational games (higher education) and corporate games (executive education) related to IE methodologies.

Table 1.1: Categorization of serious games (Susi & Backlund, 2007)

Category	Description
Military Games	Games like America's Army[2] are training simulations that are used in the training and recruitment of soldiers.
Government Games	Training and simulation within the government range from a municipal level to a national level. Games may concern a number of different kinds of tasks and situations, like different types of crisis management.
Educational Games	Games designed for students to cultivate their knowledge and practice their skills through overcoming numerous hindrances during gaming.
Corporate Games	Games designed for employees to train skills that their corporations need, like people skills, job-specific skills, and communication skills.
Healthcare Games	• Games for the professional area of doctor training, to teach an operation or to impart specialist knowledge; • Games as a training measure for patients who acquire knowledge about their clinical pictures and possible therapy options.

In literature, SGs are also called edutainment, game-based learning, and applied games. The most common definition of an SG is "a digital game that does not have entertainment, enjoyment, or fun as their primary purpose" (Michael and Chen, 2006). However, some academic researchers extend the concept of SGs to **all processes designed to learn and experiment without necessarily using the support of video games** (Mossoux et al., 2016). We adopt this definition, which means that a serious game can be a board or a sports game.

SGs seem to be useful tools for teaching IE methodologies as they guarantee intrinsic motivation and provide situated learning (Treviño-Guzmán & Pomales-García, 2014; Agustin et al., 2015). Many studies have proved that SGs contribute to developing and sustaining 21st Century skills (Spires, 2008; Romero et al., 2015; Qian & Clark, 2016). Based on the above two reasons, some teachers in IE have combined SGs with PBL (Galvão, 2011; Soo & Aris, 2018), i.e., to create games based on virtual and highly realistic projects. Such games have the pros of PBL courses and make up for some of their cons:

① Compared with PBL curricula, which usually last months, SGs allow students to practice their knowledge in a short duration.

② Game-based learning methods are always attractive, especially for young people.

③ Students practice in a virtual and safe environment. They do not need to worry about failure.

[2] https://www.americasarmy.com/

SGs as educational products have a full lifecycle, including conceptual design, development, validation, deployment, and iterative refinement (Alonso-Fernandez et al., 2017). The design of serious games is actually to define different design elements and form them into coherent game systems (Ma et al., 2020). Considerable research focuses on the design methods for creating effective and playful SGs (Barbosa et al., 2014; Vermeulen et al., 2016; Ismail & Ibrahim, 2017). However, without professional SG designers' help, these methods are difficult to understand for most IE teachers without SG expertise, let alone application. Even if instructors get these general design methods, they still need to spend much time thinking about embedding IE methodologies into SGs. Teachers require precise guidance about how to design and also how to test IE games. Therefore, SG design is still a complicated and time-consuming issue for them.

We try to tackle these difficulties encountered by IE teachers through our research project. This project's general objective is to develop a generic framework that provides a detailed description for designing and validating SGs; then make it to be adapted for the games of IE methodologies teaching.

In the thesis, we have two case studies. The first one is an SG called "**Consortio**[3]," which aims to impart sixty open innovation strategies and let students understand the significance of open innovation for business success. It is a typical IE game that was designed based on a virtual project. We have applied Consortio in an engineering design course to train third-year master students and received positive feedback (Ma et al., 2019). Consortio is used to exemplify and preliminarily validate our proposed design framework.

The second case study is a game on innovation management, more specifically, for teaching **Radical Innovation Design** (RID) methodology. RID is a familiar subject for us and was initiated by our university. It is a novel, complete and well-structured innovative design methodology that prioritizes the improvement of the user experience within a field of activity (Yannou, 2020). The game is a physical board game (Figure 1.1) for RID beginners (students and professionals) designed by ourselves by following the proposed framework. We named it **RID serious game**. Every step of designing and evaluating the RID game is explained in detail in this thesis. We obtained evidence that the game could offer a good learning experience and playing experience by holding two validation sessions to test the game with future potential users. These results serve to validate the proposed framework further.

[3] http://jeuio.rhizome.group/

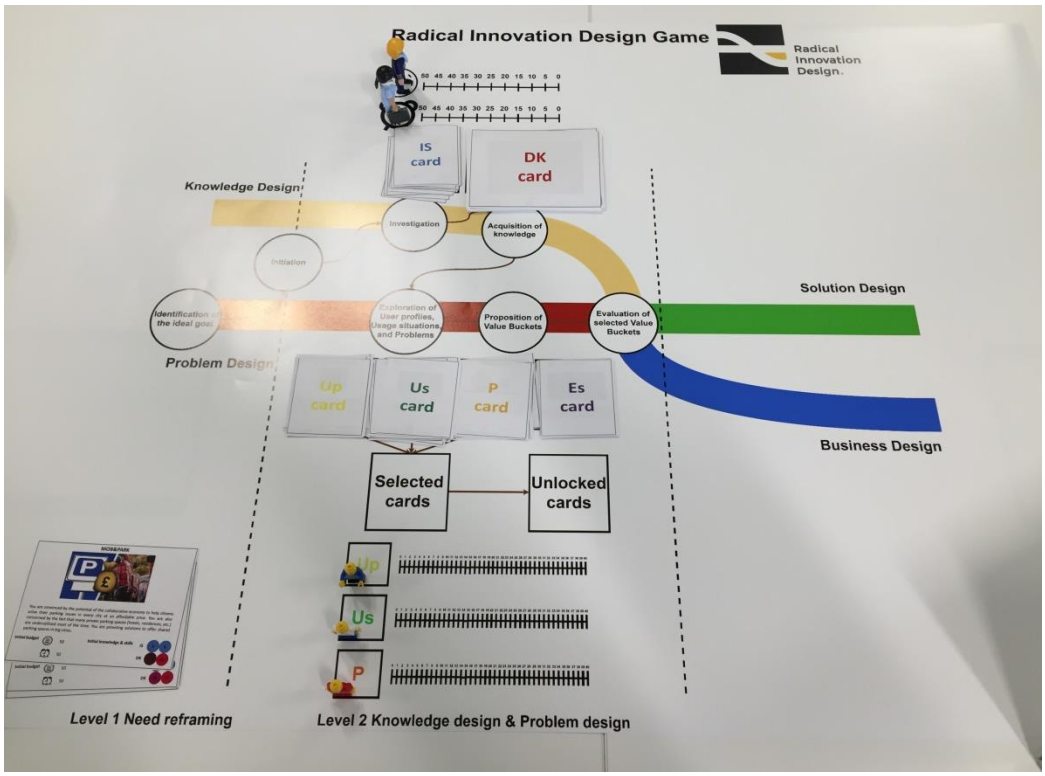


Figure 1.1: The physical product of the RID serious game

1.2 Research process

Our research lasted three years and a half. It is processed within the following four main stages:

Stage one: State of the art analysis and research topic definition (One year)
Our research for SGs was initiated by the need to design a RID game. Thus we defined the research topic as "SGs of teaching innovation processes." The state-of-the-art first aimed to have an in-depth understanding of the research topic, i.e., to find answers for questions like "what is serious gaming," "what should be taught about an innovation process." It helped determine our research project's overall environment and identify a list of challenges and issues in the current practices.

We also found that SG design is a subject worthy of research for industrial engineering education with this preliminary diagnosis. That is why we extended the research scope to "SGs for teaching methodologies used in industrial engineering."

Stage two: Literature review (One year)
As our research is based on interdisciplinary knowledge, a literature review in IE and SG domains is required. This literature review allowed a better understanding of our research's

theoretical basis and led us to generate four research questions. It also allowed following the latest evolution of SG design and evaluation methods, ensuring the performance of our proposed solution to the research questions.

Stage three: New framework proposition (One year)

At this stage, we answered the identified questions step by step and made four core contributions:

① A design language for SGs;
② A V-model based generic design framework for SGs;
③ A descriptive language for IE methodologies;
④ An adapted V-model based design framework for IE games.

Each contribution is elaborated in the next section.

Stage four: Validation (Half a year)

We designed an application based on the proposed framework and validated it with potential future trainees; this is the RID serious game. Series of suggestions for revising the application were collected. Finally, we made conclusions and identified limitations and perspectives of our research.

1.3 Overview of our contributions

Through our research project, we survey the previous studies regarding the SG design. We mainly focus on whether they provide an easy understanding and comprehensive description of the SG design process. The survey reveals a list of limitations in these studies. Based on those, we propose a new solution.

Even though some of the current SG design and evaluation methods can provide clear guidance that encompasses the full life cycle of SGs, they forget to define some special vocabulary used. IE teachers may not be familiar with the terms that are widely adopted in the SG domain, like “game mechanics,” “framing,” and “learning mechanics.” To ease the understanding of our proposed framework, we first proposed a design language for SGs. It defines and exemplifies all the components that constitute an SG system.

All the design processes of SGs we have identified in the literature start planning game testing after generating functional prototypes. Designers need to review the design purpose specification to develop a testing plan, which takes extra time. These processes often test the entire game system rather than validate the small components that make up the system in advance, hindering defect tracking. The traditional V-model (Rook, 1986) emphasizes the importance of planning validation as early as conceptual design activities and verifying each intermediate product. Also, the V-model has been popularly used in IE. For the above reasons, we proposed a generic SG design framework based on the V-model, which offers a concrete illustration of the work packages, expected outcomes, and participants of each design stage.

Before adapting the proposed design framework for IE games, we should understand how to describe a given IE methodology so as to efficiently define the game's design purpose and embed the knowledge. To address this issue, we put forward a descriptive language for IE methodologies, which serves as a template for teachers to name and categorize the main features of an IE methodology so as to specify precise pedagogical and game design objectives and validate them. Experts validated the language through experimenting with several methodologies.

Our research's last contribution integrates the previous two contributions, which is a dedicated V-model based design framework for SGs of IE methodologies teaching. This framework explains how each descriptive element of a given IE methodology can facilitate different SG objects' design. Taking advantage of the framework, we designed the first version of the RID serious game. We received very positive feedback from users who tested the game, proving that our framework can be applied directly into practice.

1.4 Dissertation structure

In Chapter 1, the research is justified, and details about the research context, research process, and core contributions are given. In Chapter 2, a literature review on the research areas concerning our thesis research is explained. In Chapter 3, the research approach and research questions are introduced. From Chapters 4 to 7, each of them answers a research question separately. Chapters 8 and 9 describe the process to design and validate the RID serious game. Chapter 10 provides a general discussion about our four contributions, while the conclusion, limitations, and perspectives are also outlined. Finally, some of the remaining research outcomes are presented in Appendices.

Chapter 2. Serious games and 21st-century teaching

Chapter 2 presents a literature review relevant to the scope of our research, which consists of three parts:

- *The relationship between serious gaming and 21st-century education;*
- *Existing studies that focus on serious games (SGs) design and evaluation;*
- *SG applications in the field of industrial engineering (IE).*

The chapter concludes the limitations of previous studies on SGs design, which leads us to identify a research gap that "there is no appropriate methodology to support novice designers for designing SGs used in IE."

2.1 Teaching Practice in the 21st-century

2.1.1 Introduction

To understand the significance of serious gaming as an innovative teaching method for 21-st century teaching and learning, especially for higher and executive education, we present a related literature review in this section. The notion of "21st-century learning and teaching" can be seen as the current overall education vision. Many educators advocate it as a collective response to the challenges posed by the rise of information and communications technology (ICT) in traditional classrooms (Chai &Kong, 2017). According to Jerald (2009), three specific kinds of knowledge and skills have been identified as required for success in 21st-century society and workplaces:

- *Traditional knowledge and skills in school subjects*. The educational content traditionally taught in the school curriculum, like mathematics, science, and language arts, will never be outdated. They will not be replaced by a series of new skills required by the times. In fact, a solid academic foundation is essential to the success of post-secondary education and training (Hysa, 2014).
- *Practical literacies*. Beyond knowledge acquisition, students must develop the abilities to apply their knowledge to solve real-world problems relevant to reading, math, science, civics, and technology (Jerald, 2009).
- *Broader competencies*. They refer to a set of in-demand skills to adapt to today's world trends from automation to globalization and corporate change. A survey of the Conference Board (2006) reveals that the four most important are: critical

thinking and problem-solving, applying information technology, collaboration and teamwork, and creativity and innovation. The cultivation of these competencies seems to be closely correlated to higher education and executive education.

Teaching methods are principles and strategies employed by teachers to enable student learning (Shinn, 1997). The traditional teaching methods make students learn by memorization but not understanding. They emphasize theory without any practical and real-life situations (Nurul Mostafa Kamal, 2019). Thus these methods are no longer sufficient to develop students' broader competencies, especially those requiring long-term practice. That is why some innovative methods like *Embodied Learning*, *Learning by doing Science*, and *Gamification of Learning* have emerged (Bidarra & Rusman, 2017). Table 2.1 describes the characteristics of traditional teaching and innovative teaching and makes a comparison (Nurul Mostafa Kamal, 2019). Serious gaming is a perfect pedagogical tool with all the advantages of innovative teaching methods and combines the above three methods. SGs allow students to learn in teams and in a fun way and apply their knowledge in a virtual world with high authenticity.

Table 2.1: Comparison between traditional and innovative teaching

(Nurul Mostafa Kamal, 2019)

Traditional approach	Innovative approach
Teacher-centered learning	Student-centered learning
Mass instruction (one size fits all)	Mass customization with instruction to fit individual student needs
One pace applies to all students	Flexible pacing based on student abilities
Classroom and school building	Distributed learning possible from any place
Facts and recitation	Critical thinking in real-world contexts
Individual student performance	Collaboration and dialogue among students between students and teachers
Textbooks	Up-to-date primary information resources
Activities prescribed by teacher	Activities determined by learners
Individual task	Working in teams
Apply known solution to problems	Find new solutions to problems
No link between theory and practice	Integrating theory and practice
Summative approach	Diagnostic approach

The next subsection introduces the SGs applied in higher and executive education and their value for both teachers and learners.

2.1.2 Serious games in higher and executive education

Various studies have shown that SGs have positive effects on complex skills learning (Younis & Loh, 2010; Giessen, 2015; Haoran, 2019; Westera, 2019), which evokes the booming of the

SGs industry. SGs have vast application areas like scientific exploration, health care, emergency management, city planning, engineering, and politics (Mayer et al., 2014). They have also been integrated into higher and executive education programs. In the following, we will focus on two successful SGs adopted by the world's top universities.

Entrepreneurship Simulation: The Startup Game (Figure 2.1) is a computer-based and role-playing game created by the Wharton School of the University of Pennsylvania that supports up to 86 students to experience simultaneously (Mollick, 2020).

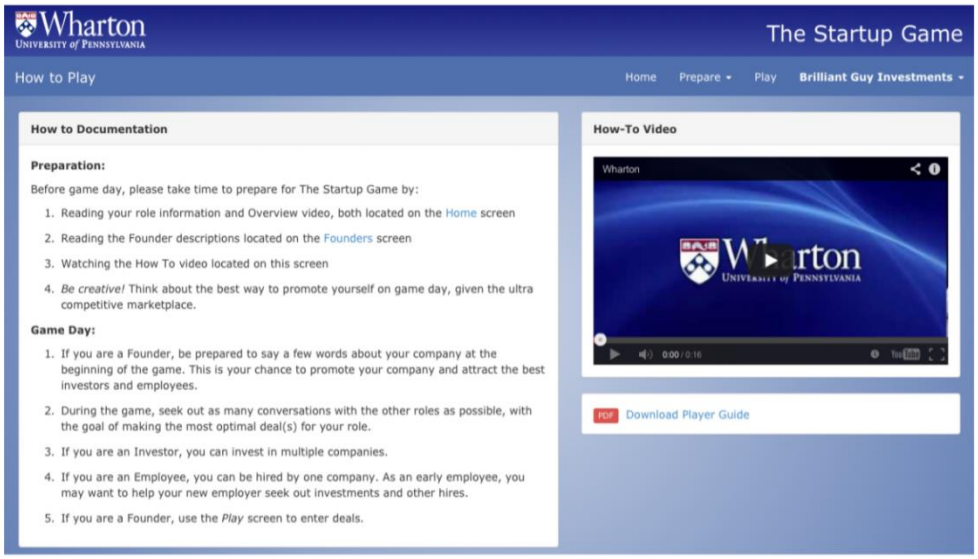


Figure 2.1: Interface of The Startup Game[4]

The game is dedicated to cultivating the skills of entrepreneurship, leadership, and strategic decision-making. When playing the game, students can take the roles of founders, investors, or potential employees who must deal with the many complexities of negotiating deals to make their startup a success. The users of The Startup Game include business students and professionals.

The CheckiO (Figure 2.2) is a new approach that offers engaging challenges and fun tasks for practicing Python and JavaScript programming languages (Fernandes et al. 2017), which is designed for both beginners and advanced programmers. It is an adventure game in which the player is required to explore mysterious islands in the sea. The player needs to use coding skills to complete all the tasks of building the first island before exploring the second island.

[4] https://simulations.wharton.upenn.edu/startup-game/

Figure 2.2: CheckiO used for teaching computer programming[5]

In Table 2.2, we present more examples of SGs which are categorized by name, topic, and primary reference. These games are designed for higher or executive education, and real users have validated them. We deliberately chose those with distinct themes to show the wide range of applications of SGs.

Table 2.2: SGs designed for higher education and executive education

Name	Topic	Primary reference
CyberCIEGE	Cyber security	[Irvine et al., 2005]
Recursive Algorithms	Applied informatics	[Rossiou, E. & Papadakis, S., 2007]
Sorting Game	Sorting algorithms	[Hakulinen, 2011]
Table Mystery	General chemistry	[Boletsis & McCallum, 2013]
Digital IL game	Information literacy	[Guo & Goh, 2014]
AbcdeSIM	Emergency care	[Dankbaar et al, 2016]
RPG Sims	Language acquisition	[Franciosi, 2016]
Escape game	Research methods	[Clarke et al., 2017]
CheckiO	Programming	[Fernandes et al. 2017]
Dogs of War	History	[Bunt et al., 2019]
Ser é Investigador	Self-regulation	[Samaniego Ocampo, 2019]
The Startup Game	Entrepreneurship	[Mollick, 2020]

Because of SGs' unique benefits, more and more educators have changed their attitude towards SGs, from resisting to admiring (Demirbilek, 2010). The research of Zhonggen (2019) reports eight beneficial influences brought by SGs:

- Promote learners' overall understanding of scientific concepts,
- Acquire cognitive abilities,

[5] https://checkio.org/

- Increase the positive impact of learning and improve the teaching of sciences,
- Provide flexible learning methods,
- Improve learning outcomes,
- Promote social-cultural education from the perspective of cognition and motivational influence and team opinions,
- Improve cross-cultural communication skill,
- Improve professional learning based on script collaboration and learner satisfaction.

However, not all SGs can produce expected learning outcomes and exciting gaming experience for players. A classic example is the game Math Blaster, which is nicknamed "Math Disaster" by players (Foster et al., 2013). This game is usually marked as dull due to excessive emphasis on math exercises and neglect of entertainment. Designers should follow adequate design and evaluation methodologies to avoid failures. Thus, we conduct a literature review in the next section to understand the existing methodologies for developing and validating SGs.

2.2 Serious games design and evaluation

2.2.1 Introduction

Serious games (SGs) as educational products have a full lifecycle, including conceptual design, development, validation, deployment, and iterative refinement (Alonso-Fernandez et al., 2017). Design methodology and evaluation methodology are two intertwined research areas in the field of SG. The design of SGs is to define different serious game elements (Mitgutsch & Alvarado, 2012) and form them into coherent game systems. Evaluation is to assess the effectiveness of SGs concerning their designated purpose. To understand the tasks in the SG design and validation process and who should be recruited to execute them, we conducted a literature review about SGs design methodologies and evaluation methodologies. To collect useful information, we used five online academic databases: IEEE Xplore, ACM Digital Library, Springer, SAGE journals, and Sciencedirect. When searching for literature, we used the following keywords: "serious game/educational game/game-based learning" plus "design framework/model/methodology" or "evaluation framework/model/methodology." We found that current studies on design/evaluation methodologies of SGs are almost all based on digital games (except [Corrigan et al., 2015]), not physical board games. The reason is that most researchers consider the SG as "a digital game that does not have entertainment, enjoyment, or fun as its primary purpose (Michael & Chen, 2006)." However, our previous research (Ma et al., 2019) showed that most of the existing SGs for teaching *Creativity* and *Innovation* are physical board games. It is still not known whether the methodologies for digital SGs are adapted to board games.

2.2.2 Design methodologies for serious games

SG design is a complex subject, as there are broad contextual aspects (Table 2.3; Braad et al., 2016) to consider. The effects of many design choices are uncertain under different conditions and even more so in conjunction with other design choices. To remedy this complexity, various frameworks/models/methodologies that describe design and development processes have been proposed, and in this subsection, we will discuss some of them. The classification results of design frameworks/models/methodologies are also different according to distinct criteria. In the thesis, we use two classification criteria.

Table 2.3: Contextual aspects that influence the SG design (Braad et al., 2016)

Contextual aspect	Explanation
Context of design	The context that the design process takes place. Designers should be aware that the values of their own design context will affect the game design. These values may include liberty, justice, enlightenment, privacy, security, friendship, comfort, trust, autonomy, and sustenance (Van Den Hoven & Weckert, 2008).
Context of use	The situation in which the game is meant to be used. The design should also encompass surrounding activities. For example, suppose a game is to be used in the classroom. In that case, at least the briefing session and the debriefing session need to be designed.
Audience	A serious game's targeted audience is an essential source of design requirements: gameplay, look-and-feel, and suitable technology need to be in tune with future players.
Purpose	The intention (cognitive, skill-based, and affective; Kraiger et al., 1993) for designing the game. A serious game's purpose is another source of design requirements: gameplay and other content and interactions in the game need to support the overall purpose of the game.

General vs. Customized

The first classification criterion is "topic," that is, does the design framework/model/methodology serve a specific type of SGs?

Based on the "topic," we can divide all of them into two categories: general and customized ones. Vermeulen et al. (2016) derived a DISCO model of SGs for teachers by involving them actively in the design process. It is a general model that can guide teachers to define explicit design purposes and better plan learning activities in their SGs. Marfisi-Schottman et al. (2010) proposed a 7-step general design method. This method states the roles of multiple stakeholders in serious game design, besides teachers and students. These two studies mainly focus on the conceptual design phase of SGs but say nothing about the development and the validation. Aslan (2016) put forward two methodologies, "GAMED" for designing digital SGs and "IDEALLY" for measuring the quality of the game design. The former provides a detailed illustration of the complete design process for SGs; the latter lists more than 100 indicators to evaluate the software quality as well as the learning quality of SGs.

In addition to the general design approaches described above, there exist some methodologies for serving specific types of SGs. Szczesna et al. (2012) proposed a design methodology for SGs that aims at cognitive behavior therapy. It provides guidelines for describing game scenarios based on cognitive-behavior techniques. Cano et al. (2016) put forward a methodology for the design of SGs for children with hearing impairments. It focuses on collecting and analyzing the needs of the hearing impaired and evaluating game prototypes.

Theoretical vs. Practical

The second classification criterion concerns "theoretical vs. practical." The theoretical framework/model/methodology often provides a series of heuristic suggestions for the SGs design, which requires related deep expertise for users. For instance, Song & Zhang (2008) proposed a model that combined the active learning environment, flow experience, and motivation. This model consists of seven basic requirements for the active learning environment, nine dimensions of flow experience, and four essential strategy components for motivation. Only by fully considering these aspects can game designers design effective and engaging SGs. The three-layer reflection model by El Arroum et al. (2020) was proposed to help designers group the series of considerations from both the world of gaming (time and score) and pedagogy (skills to be developed in the game and related assessment) to create an efficient learning synergy. Marne et al. (2012) put forward a generic conceptual framework, the six facets of serious game design (Figure 2.3). These facets involve two categories of expertise (pedagogical and game design), which must be considered when developing SGs. The model can not only help organize and simplify work but also analyze existing SGs.

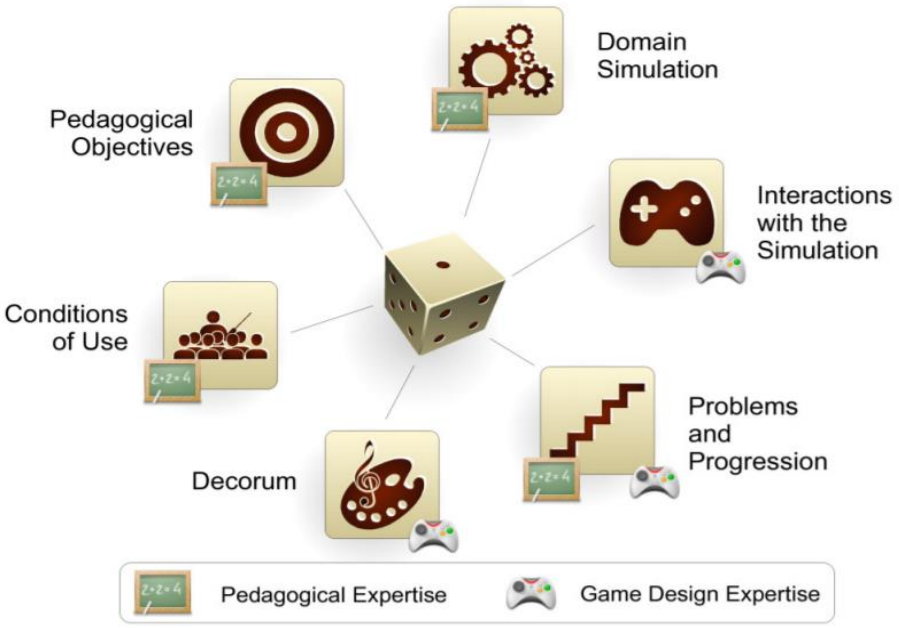


Figure 2.3: Graphical representation of The Six Facets of Serious Game Design

The practical framework/model/methodology that involves a set of steps and diagrams to elaborate on the design process. Such frameworks/models/methodologies are of considerable significance to novice SGs designers. The design framework of Saavedra et al. (2014)

describes work packages from the "Requirements Stage" to the "Continuous Improvement Stage." It is founded in the traditional software engineering paradigms and complemented by co-design as well as competency-based approach. Following the framework, they have developed applications for teaching elementary school math. Play Your Process (PYP) is a method for designing business process-based digital games (De Classe et al., 2019). As shown in Figure 2.4, the method starts with analyzing the business process context (which process to teach) and mapping process elements with game design elements. Each game element is then designed and implemented. The evaluation is also taken into account by the PYP method. There are three aspects of evaluation of a business process-based SG:

1) The design team performs the first evaluation, aiming to check whether all stated requirements are developed in the game.

2) Process actors are responsible for the second evaluation, which intending to check whether the game represents the process.

3) The last evaluation is conducted with the target audience. It aims at evaluating the gaming experience and whether the game shows a comprehensive process to external users.

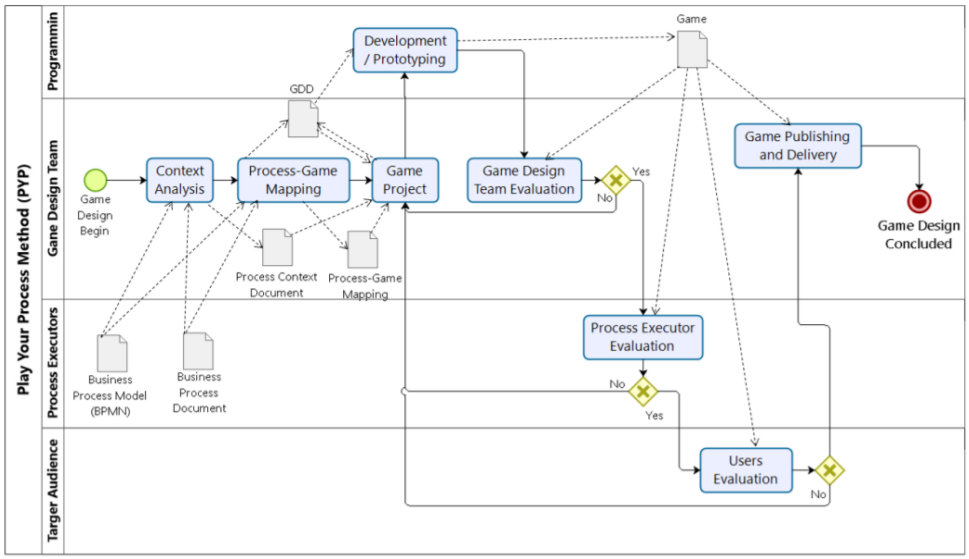


Figure 2.4: Steps of the PYP method (De Classe et al., 2019)

Table 2.4 briefly introduces the other six practical design methodologies/models/frameworks. Each of them clarifies an exhaustive process consisting of different stages.

Table 2.4: Practical design methods for SGs

Ref.	Contribution
[Mariais et al., 2012]	A methodology that promotes the design of learning role-play game (LRPG) scenarios: how to collect, share, and operate LRPG scenarios and components.
[Barbosa et al., 2014]	A design methodology that facilitates the integration of educational content while keeping the fun factor of SGs.

[Carvalho et al., 2015]	A design model "ATMSG" based on the activity theory: supports a systematic and detailed representation of SGs; depicts how game elements contribute to the desired pedagogical goals.
[Corrigan et al., 2015]	A design methodology for stimulating collaborative learning and enhancing communication in SGs. It also describes how to plan playtests and use the results of the tests to improve SGs.
[Ismail & Ibrahim, 2017]	A framework based on participatory design theory. It clearly illustrates the role of students and teachers in the various game design phases.
[Silva, 2020]	A methodology to design SGs that facilitate communication between design team members. It illustrates all the main steps needed to define the learning mechanisms, which starts with the choice of the topic of the game and ends with the user experience.

To understand the general design process of SGs, we analyzed the commonalities of these methodologies and extract 20 typical design stages (Table 2.5). Each design stage may have several names. For example, the stage "teaching objectives" can also be called "learning objectives" or "educational problems."

Table 2.5: Definition of the design stages

Design stage	**Definition**
User/Player profile	Determine the targeted audience other stakeholders.
Instructional activities	Define the relationship between SGs and other teaching activities.
Teaching objectives	Provide a detailed description of ambition in terms of knowledge and competencies.
Collect other design purposes	Listen to stakeholders and understand their expectations about game playing.
Specification document of the design purposes	Write a report for summarizing of all design purposes defined.
Quality assurance (QA #1)	Evaluate the quality of the previous report and the process for gathering design purposes.
Define the game type	Choose a game genre which determines the main gameplay, such as adventure game, puzzle game, or role-playing game.
Define game elements	Generate game ideas for each element: story, game mechanics, information, aesthetics, and framing. Each element must reflect design purposes.
Evaluation design	Consider how to evaluate: player performance during the gameplay; learning outcomes after the gameplay.
Scenario specification	Describe each game scenario that constitutes the whole game.
Architecture definition	Describe the logical relationship between different game scenarios.
Specification document of game ideas	Write a report that summarizes all game ideas.

Quality assurance (QA #2)	Evaluate the quality of game ideas and the process for generating game ideas.
Design prototypes	Design digital or physical prototypes for testing game ideas. The SGs designers explain design requirements to software engineers with the help of prototypes.
Software requirements specification (SRS)	Write a report to explain the functional/non-functional requirements for the software.
Quality assurance (QA #3)	Evaluate the quality of the previous report and the requirements engineering process.
Game programming	Design game software for fulfilling all requirements.
Software test	Test whether the software meets all functional requirements.
Goal validation	Test the game with users: confirm that all design purposes have been achieved; collect feedback for improving the game.
Deployment	After rounds of iterative design, the game is officially used in teaching activities.

2.2.3 Evaluation methodologies for serious games

Emmerich & Bockholt (2016) stated the advantages of a structured evaluation of SGs. For game developers, it advances the dissemination of SGs and improves future designs. For game researchers, the assessment of SGs not only helps them understand the impact of SGs on players but also develops guidelines for designing effective SGs. The intermediaries, those who have to support the use of SGs in their field of work, can get justification that SGs are useful tools. Moreover, for users, SGs evaluation can provide them with a better play and learning experience since it improves the designs of SGs. In addition to those design methodologies that cover evaluation, numerous dedicated methodologies have been put forward in the literature to measure educational effectiveness of SGs.

In general, we can classify all existing evaluation methodologies from two perspectives: the time point of assessment (when to assess), and the content of assessment (what to assess).

When to assess

The evaluation methodologies applied are distinct depending on the stage of the SGs development life cycle. There is usually a difference between formative and summative assessments. Formative assessment is carried out during the development stage. This kind of evaluation is conducive to the further development of the SG. Summative assessment takes place after the development stage. It emphasizes on the quality of the final product and the way to apply the product better. In literature, there are several methodologies which concern with the time point of assessment. For example, the famous Analysis Design Development Implementation Evaluation (ADDIE) framework (Molenda, 2003) covers both formative and summative evaluation. This framework claims that SGs development is not a sequential process; each development stage needs several iterations. The quality of the game is gradually improved thanks to these repetitions. Another popular summative assessment method is “pre-

test/training/post-test." (Mortara et al., 2013; Iten &Petko, 2016; Newbery et al., 2016) It serves to evaluate the quality of SGs by comparing the player's performance in a particular aspect before and after using the game. Mortara et al. (2013) offered 12 multiple-choice quiz questions about Japanese culture to players before and after the game session. The game effectiveness is measured by contrasting the answers given by players.

What to assess

Many methodologies focus on the content of the assessment. Wouters et al. (2013) provided a meta-analysis method to evaluate the cognitive and motivational effects of SGs. More specifically, this method investigates whether SGs are more effective in terms of learning and more motivating than conventional instruction methods. Through testing the short-term and long-term retention of knowledge, we can assess the cognitive effects of an SG (Tawadrous et al., 2017). Some researchers recommend using physiological or behavioral indicators such as eye tracking (Alkan & Cagiltay, 2007) and skin conductance (Jerčić et al., 2019) to measure the motivation of players during gameplay objectively. Players' motivation reflects whether the game can provide a flow experience; neither cause anxiety nor make them bored. Flow describes a state of complete immersion or engagement in an activity and refers to the optimal experience (Figure 2.5; Csikszentmihalyi, 2014).

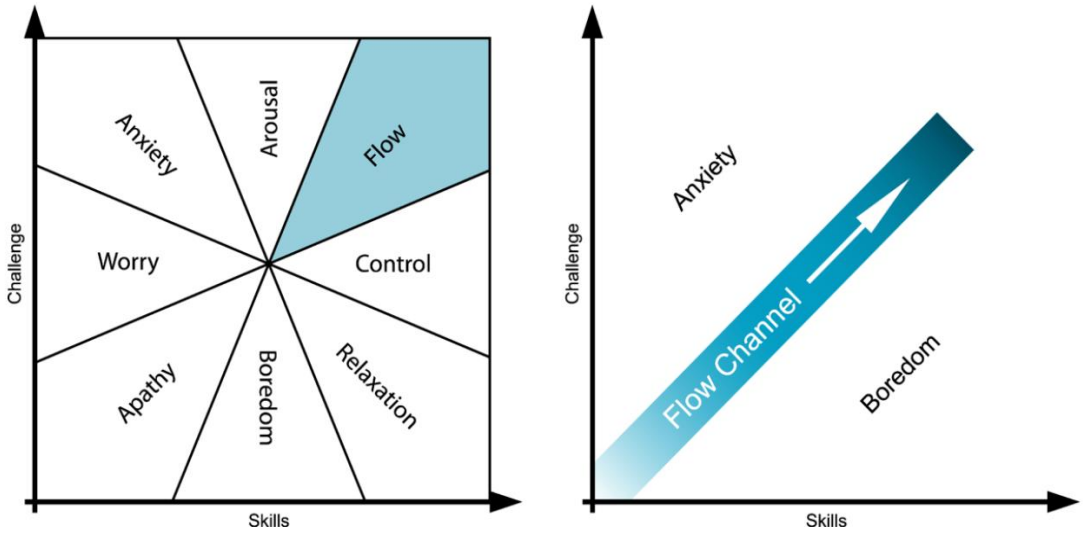


Figure 2.5: Flow model (Csikszentmihalyi, 2014)

After gameplay, the survey or questionnaire is used to measure subjective motivation (Doukianou et al., 2014; Evans et al., 2015). The Serious Game Design Assessment (SGDA) Framework (Mitgutsch & Alvarado, 2012) is one of the few methods that a priori analyze the game system itself. The SGDA framework emphasizes the cohesiveness and coherence between different SGs design elements. It starts with determining the game purpose and then analyzing the relevance between other elements and game purpose. Besides the game purpose (a), the SGDA framework identifies six critical components of the formal conceptual design of the game system: (b) content & information, (c) mechanics, (d) fiction & narrative, (e) aesthetics & graphics and (f) framing (Table 2.6). This framework causes our great attention since it is a template tool that states the principles and components of an a priori satisfactory

SG design. These components must be intimately bound up with the game purpose. Only when all the game design elements reflect the design purpose well can the game achieve the desired effects.

There also exist other ways of dividing design elements. Lameras (2015) distinguished design elements into game attributes and learning attributes. Game attributes have been broadly understood as a way to summarize game rules (Lundgren & Bjork, 2003). Learning attributes are mechanics that facilitate learning in games. This classification is not detailed enough to use it to break down and further analyze SGs. Cheek et al. (2015) researched on the SGs for health behavior change. Thus, they classified serious game design elements into four categories: elements contributing to enjoyable play experience, elements relating to the accessibility of online content, elements of the therapeutic relationship, and elements producing learning activities. Obviously, the "therapeutic relationship" elements are not necessary for all SGs. Neither of Lameras (2015) and Cheek et al. (2015) addressed one common design element, "narrative". Compared with these two studies, the SGDA framework is more comprehensive and universal. Therefore, in the thesis, we adopt it as the basis to distinguish and define SG essential elements. We find that the SGDA framework does not clarify relationships between high-level elements (e.g., design purposes; Slimani et al., 2016) and low-level elements (e.g., game mechanics; Slimani et al., 2016). Namely, it cannot guide novice designers to derive relevant low-level elements from the established design goals.

Table 2.6: Serious game essential elements defined by the SGDA framework

(Mitgutsch & Alvarado, 2012)

Design elements	Explanation & Assessment criteria
Design purpose	The intention of a designer to design the game.
Content & Information	The information or data offered and used in the game. All of the given information should be valid, easily approachable and fact-based.
Mechanics	The methods invoked by agents for interacting with the game world, general rules, in-game challenge, learning curve, and reward system.
Fiction & narrative	The created fictional space, relationship between story and game purpose.
Aesthetics & Graphics	The audiovisual language used in the game and its impact on the player.
Framing	The framing of other elements in terms of the target group, their play literacy and the broader topic of the game.

2.2.4 Discussion

In this section, we have provided a literature review of the existing SG design and evaluation methodologies. We discuss the strengths and limitations of the methodologies mentioned based on four criteria:

1) Comprehensiveness: does the study cover all the design stages listed in Table 2.5 and crucial SG design elements?
2) Practicality: does the study provide practical and concrete guidance for each design stage?
3) Adaptability: does the study can be easily adapted for all kinds of SGs?
4) Particularity: does the study have any uniqueness compared to others? For example, some methodologies introduce the participatory design approach.

This analysis should help us understand the limitations of current research to envisage the difficulties encountered by novice SG designers when applying these methodologies.

Table 2.7: Strengths and limitations of the existing design processes of SGs

Ref.	Strengths	Limitations
[Song & Zhang, 2008]	• Point out the relationship between motivation, flow, and effective learning environment in SGs. • Provide some heuristic suggestions to create a flow experience and stimulate players' motivation.	• Lack of the description of the design process of SGs. • Lack of a description of who should be involved in the design process and their tasks.
[Marfisi-Schottman et al., 2010]	• Provide a list of design tasks should be accomplished. • Describe the participants who should join the design process as well as their roles.	• Contain a special step "searching for reusable software components", which makes it not applicable to board games. • Lack of the description of how to plan and how to conduct the evaluation of SGs. • Lack of the definition of some terms in the description of the method (e.g., game model and game scenario).
[Mariais et al., 2012]	• Offer an authoring tool for describing game scenarios.	• Only suitable for role-playing games. • Only explain the different aspects (rules, actors, and functions) to be considered in describing role-playing game scenarios but does not explain the specific process.
[Marne et al., 2012]	• Point out the six aspects to cover when designing SGs. These aspects can be used to verify the integrity of the game design. • Provide some concrete examples for each aspect.	• Lack of the description of the design process of each aspect. • Lack of the description of the SG evaluation.
[Szczesna et al., 2012]	• Provide main guidelines of designing psychology SG based on cognitive-behaviour techniques.	• It is a customized design methodology that cannot be directly used to design SGs in other fields. • The design process is incomplete, as it lacks many stages in Table 2.3.
[Barbosa et al., 2014]	• Simplify the design process: distribute learning contents to different game levels and then select	• Lack of the description of the whole design process.

	learning mechanisms (quizzes, puzzles, etc.) to impart these contents.	• Lack of description of essential design elements, like, game mechanics and story.
[Saavedra et al., 2014]	• Provide a detailed description of the design process of digital SGs. • Offer a clear description of the inputs and outputs of each design stage.	• Lack of description of the participants who should join the process. • It does not explain how to evaluate the outputs of each stage. • Only suitable for digital SGs.
[Carvalho et al., 2015]	• Provide an approach for defining and analyzing the game sequence based on the activity theory. • Provide a taxonomy of SGs components.	• Only focus on the game structure without explaining how to design specific SGs components. • Lack of description of the SGs evaluation.
[Corrigan et al., 2015]	• Provide a comprehensive description of the tasks in the design process.	• The description of the design process is based on an SG for supporting the implementation of airport collaborative decision-making, which may hinder people who lack relevant knowledge to understand. • Lack of guidance on how to complete the tasks of each stage.
[Aslan. 2016]	• Provide a comprehensive and detailed description of design tasks, processes, participants. • Provide a taxonomy of SGs components.	• Only suitable for digital SGs. • Although the output of each design stage is described, it is not stated how to validate these outputs.
[Cano et al., 2016]	• Provide a comprehensive description of how to design of serious games for children with hearing impairments.	• It is also a customized methodology that cannot be directly used to design SGs in other fields. • Only suitable for digital SGs.
[Ismail & Ibrahim, 2017]	• Provide a suitable participatory design process for primary school educational game design. The roles of each participant are clearly stated.	• Lack of the detailed description of design tasks; • Lack of the description of the outputs of each design stage.
[Vermeulen et al., 2016]	• Point out the five aspects (domain model, objectives, interaction, screenwriting, and usage context) to cover when designing SGs.	• Only suitable for digital SGs. • Lack of the detailed description of the whole design process.

[De Classe et al., 2019]	• Provide a comprehensive description of the design process. • Use existing games to illustrate each design stage.	• Lack of the description of how to validate the inputs and outputs of each design stage. • Only suitable for SGs that have related business processes.
[EI Arroum et al., 2020]	• Emphasize the importance to develop corresponding evaluation activities for each design purpose.	• Lack of the detailed description of the design process.
[Silva, 2020]	• Provide a detailed description of how to define learning mechanics and game mechanics for SGs.	• Only focus on game mechanics and learning mechanics. • Lack of the detailed description of design tasks and participants.

Table 2.7 shows most of the design methodologies we have discovered do not provide a straightforward and easy to follow instruction, which describes every task of the design process. Even if some methodologies succeed in proposing such descriptions, novice designers without game design expertise cannot effortlessly understand them. Most of these design methodologies were put forward based on digital SGs, restricting their use for designing board games. Only two of them clearly describe the people who need to be recruited in the design process and their responsibilities. The validation (evaluation) activities are only planned and performed after generating a functional prototype. The lack of validation of the outputs of each design stage has led to so many failed SG applications (Catalano et al., 2014). Although some existing design methodologies mentioned SG's evaluation, they only answer "what to evaluate" but do not point out "how to evaluate." Novice designers who follow a particular design methodology need to discover a matching evaluation methodology, which takes extra time. Based on the literature review of SGs evaluation methodologies, we find that each methodology usually focuses on only one object. For example, the SGDA framework evaluates the game system, while Mortara et al. (2013) measure knowledge retention. A comprehensive evaluation methodology for SGs with precise instructions is still lacking.

2.3 Serious games in industrial engineering

2.3.1 Introduction

In this thesis, we pay particular attention to serious games (SGs) in industrial engineering (IE), both for higher education and executive education. These games deliver up-to-date knowledge in a fast-changing world and broader professional skills, which help design, analyze, improve, and install systems integrating people, materials, information, equipment, and energy (IISE, 2018).

According to the study of Despeisse (2018), SGs have been commonly applied in the IE domain, especially in supply chain management, innovation management and production planning. IE games bring at least three benefits to engineering students and professionals: 1) allow practicing theoretical knowledge in a simulated safe environment; 2) permit them to reflect on the impact of their decisions; 3) foster the development of skills such as leadership, teamwork, and communication. In the following, we take SGs in innovation and creativity as examples to illustrate what IE games look like.

2.3.2 Serious games in innovation and creativity

To identify the existing SGs in creativity and innovation, we first used the Design Society Database (www.designsociety.org). By searching the keyword "serious game," 84 papers

were found. Among these papers, there were 20 papers about specific SGs. However, only three of them concern SGs for teaching innovation processes (Boks & McAloone, 2009; Becker & Wits, 2014; Libe et al., 2020). The remaining papers focus on different topics, for example, "project management," "user experience design," and "design communication." To find more relevant SGs, we used the Google search engine to do the same search and then found another seven games. All the games identified are multiplayer board games except "innovation makers" which is a single-player digital game (Table 2.8).

Table 2.8: The panel of serious games on innovation and creativity

Name of the game	Reference	Type of the game
Creativ'	[Gharbi, n.d.]	Multiplayer & board game
Innovation maker	[Innovation Makers, n.d]	Single player & digital game
Eco-board game	[Boks and McAloone, 2009]	Multiplayer & board game
Crossroads	[Bogers and Sproedt, 2012]	Multiplayer & board game
Set-Based Concurrent Engineering (SBCE)	[Kerga *et al.*, 2012]	Multiplayer & board game
Product development process game	[Becker and Wits, 2014]	Multiplayer & board game
Consortio	[Jeu IØ, 2016]	Multiplayer & board game
Business Innovation Game	[Van Oudenhove, 2017]	Multiplayer & board game
Creanov	[Diaz, 2017]	Multiplayer & board game
Lino	[Libe et al., 2020]	Multiplayer & board game

Consortio is one of the existing SGs in IE, used as a case study in Chapters 4 and 5 to explain our contributions. It is part of the "*Meilleures pratiques d'affaires*" (i.e., best business practices acknowledged by) of the Ministry of Economy, Science and Innovation of Quebec (MESI). Consortio is a collaborative board game for teaching open innovation strategies (Figure 2.6).

Figure 2.6: The game board and game cards of Consortio

The open innovation cycle (Figure 2.7) prescribed that the game has four successive game levels: research, design, prototype, and deployment (Jeu IØ, 2016). Each of levels is corresponding to the different stages of development of one innovation project in reality.

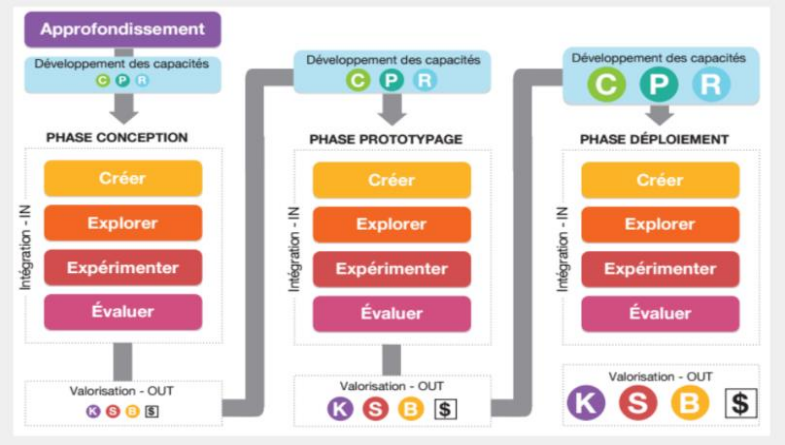


Figure 2.7: Open innovation cycle used in Consortio

The game designers recommend that at least two groups play it together, with four to six members in each group. In the game, players of a group constitute a food consortium, and each of them represents an organisation (Figure 2.8a) within the consortium. The consortium's goal is to develop new products based on the "Super freezing technology" to generate maximum value. Each organisation also comes with a personal business background, a budget (represented by the virtual currency) and an individual challenge. Players cannot ignore the goal of the consortium while completing personal challenges. At each turn of the game, the consortium must make a decision on the open innovation strategies (using virtual currency to "purchase" open innovation strategies, e.g., Figure 2.8b) to be put in place according to multiple factors (e.g., available budget, individual challenges, and innovation capacity of the consortium).

(a) Character card *(b) Open innovation strategy card*

Figure 2.8: Game cards

The designer evaluates the consortium's performance by measuring the three kinds of value (Knowledge, Social, and Business) created by the consortium. The group with the best performance will be the final winner.

- **Knowledge**: Level of knowledge acquired during the open innovation cycle (client experience and new ideas);
- **Social**: Level of social links established between partners, communities and outside organizations (community of start-ups and user community);
- **Business**: Business value released during the open innovation cycle (new products and services, new processes, cost reduction and sales).

2.4 Conclusion

In this chapter, we present a literature review that helps us aware that serious gaming is an innovative teaching approach that meets the requirements of 21st-century education. Thanks to SGs' advantages, more and more educators are using SGs in their teaching activities. According to Theodosiou & Karasavvidis (2015), it is evident that pedagogical experts should be actively involved in SGs design to ensure teaching effectiveness. However, it is hard to directly engage educators like IE teachers in the SGs design process as they lack gaming expertise. They require guidance to better understand through comprehensive methodologies. Unfortunately, the existing studies, which have several limitations (see subsection 2.2.4), cannot meet their needs. IE teachers need a methodology with the following characteristics:
1) Provide a detailed and precise description of tasks and expected outcomes in each design stage. All terms from the field of SG must be defined and exemplified.
2) Provide a description of the participants who should join the design process and define their roles.
3) Provide methods to evaluate the outcomes of each design stage.
4) Provide methods and tools to evaluate the play and learning experience of the game.

More importantly, in the 50 years since the term "serious game" appeared (Abt, 1987), no previous study has investigated the design and evaluation methodology of SGs in the field of industrial engineering. Without the guidance of these customized methodologies, SG design is still a time-consuming and complicated process.

This thesis aims to fill the research gap that there is no appropriate methodology to support novice designers for designing SGs used in IE. The next chapter introduces the research questions developed based on the identified gap and our research approach. We fill this gap in four steps and present related results in Chapters 4, 5, 6, and 7.

Chapter 3. Research approach

This chapter presents the research approach for this PhD thesis. First of all, the limitations of previous research are stated. Then four research questions and the research scope are defined. After this, the research method is described.

3.1 Limitation in previous research

As discussed in Chapter 2, previous studies on serious game (SGs) design and evaluation have several limitations, summarized as follows.

Limitation A

First, the existing SG design methodologies are difficult to understand for novice designers without gaming expertise. These methodologies usually directly employ some common vocabulary (e.g., game mechanics, game level, game challenge, etc.) in the field of serious gaming. However, these terms are unfamiliar to non-specialists. Therefore, to master these methodologies, for novices, the first step is to conduct a literature review to understand each term's definition, which costs time. As a user-friendly methodology, each term should be clearly explained and exemplified.

Limitation B

Second, most design methodologies are not comprehensive; some ignore essential design stages, while others do not mention a series of SG design elements. For example, EI Arroum et al. (2020) only answer how to validate the game but do not clarify the specific design process. Silva's (2020) research pays particular attention to game mechanics (GMs) and learning mechanics (LMs), but so nothing about the story, aesthetics, etc. These studies are beneficial for experienced people in SG design, but they may bring some confusion to novices, "is mastering LMs and GMs enough to design SGs?"

Limitation C

Third, most design methodologies fail to provide essential details. We believe a self-sufficient methodology should include the information about:

- What are the different stages of SG design?
- What are the work packages, expected deliverables, and participants of each stage?
- How to complete each stage?
- How to validate the intermediate results of each stage?
- How to validate the entire game?

Limitation D

The last and most crucial point is that no research has focused on SG design in the field of industrial engineering (IE). Teachers require an adapted SG design methodology to guide them to integrate better the knowledge they want to teach into the game. This methodology can shorten the duration of game design while ensuring the quality of the game. In addition to proposing such a methodology, we must also provide means to an IE teacher to express his/her knowledge about what can be taught into identifiable items. However, to the best of our knowledge, there is no research that has answered this apparently basic question.

3.2 Research scope and research questions

Based on the limitations summarized in the last section, we develop the following research questions (Table 3.1):

Table 3.1: Formalization of research questions

Limitation	Research question
A	Research question 1
B and C	Research question 2
D	Research question 3
	Research question 4

Research question 1: What are the invariant elements that make up a serious game? How to describe and structure them?

Before developing a comprehensive and concrete SG design solution, the game system's elements should be identified and defined. Although these elements have been discussed in the literature, there is no research to organize them systematically. The first research question aims to address this issue.

Research question 2: What is a comprehensive and easy-to-understand design methodology of serious games for novices? How to design and validate serious games based on such methodology?

Research question 2 seeks to propose a generic design solution that adapts to all kinds of SGs. This solution should have the following characteristics to make up for the shortcomings of existing design and evaluation methodologies of SGs:

- Provide precise definitions of all objects related to the design of SGs;
- Provide a detailed and clear description of tasks, expected outcomes, and participants of each design stage;
- Provide instructions on how to validate the outcomes of each design stage;
- Provide comprehensive guidance that covers the design and evaluation of SGs.

Research question 3: How to describe and structure all relevant objects for a given industrial engineering methodology?

In this thesis, we are particularly interested in SGs at the service of any IE methodologies. We have the ambition to make the training of IE methodologies more professional and to promote it in companies and universities. To be able to design solutions for SGs in IE, we must be able to describe and manipulate the descriptive elements or structural components of an IE methodology. Research question 3 is used to gain an understanding of a description of IE methodologies. It intends to provide a language for describing and structuring the objects of IE methodologies.

Research question 4: How to design effective serious games that balance fun and learning to teach industrial engineering methodologies?

Research question 4 attempts to combine the first three questions' contributions. Through answering this question, we expect to generate an adapted design solution for IE games.

The above four research questions define our research scope as "the design of SGs for teaching IE methodologies." This scope covers two research areas (Figure 3.1): **serious gaming** and **IE methodologies**. Each area further consists of several research objects. The overlapped part of the two research areas is our main research subject.

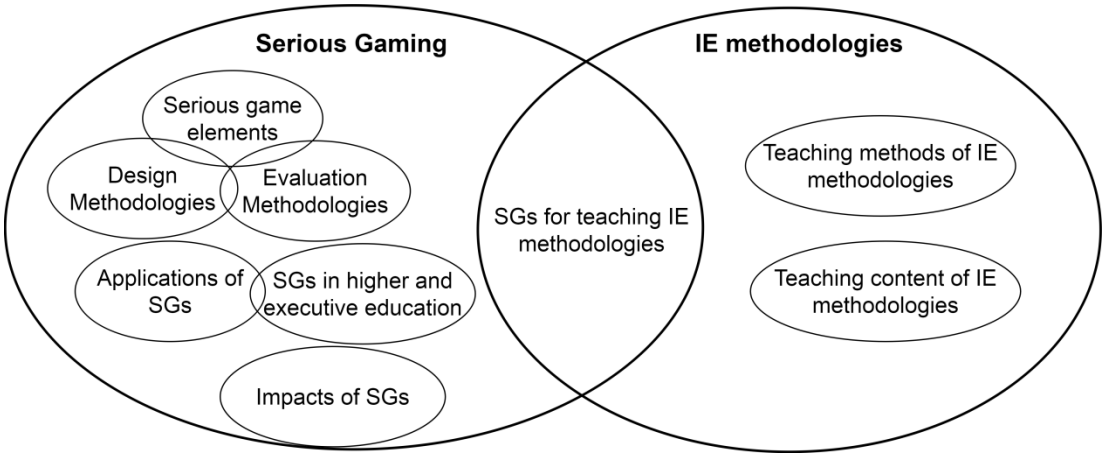


Figure 3.1: Research scope of the thesis

3.3 Arrangement of contributions

Contributions address the following areas that have been obtained by answering the four research questions in this thesis:

- Structuration of SG design elements (associated with RQ 1): a design language for SGs;
- Design and evaluation methodologies of SGs (associated with RQ 2): a generic V-model based design framework for SGs;

- Clarification of the teaching content of IE methodologies (associated with RQ 3): a descriptive language for IE methodologies;
- SGs for teaching IE methodologies (associated with RQ 4): an adapted V-model based design framework for IE games;
- SGs for teaching IE methodologies (associated with RQ 4): an SG application designed for teaching Radical Innovation Design (RID) methodology.

Figure 3.2 explains the relationships between five contributions. The first contribution defines different design elements of SGs, which are then adopted to develop a generic design framework for SGs (the second contribution). The third contribution offers invariant descriptive objects of IE methodologies, which serve as an input to the generic V-model to generate an adapted V-model. Finally, based on the fourth contribution, we design an SG for teaching RID (the fifth contribution). We introduce these contributions in turn in Chapters 4 to 9.

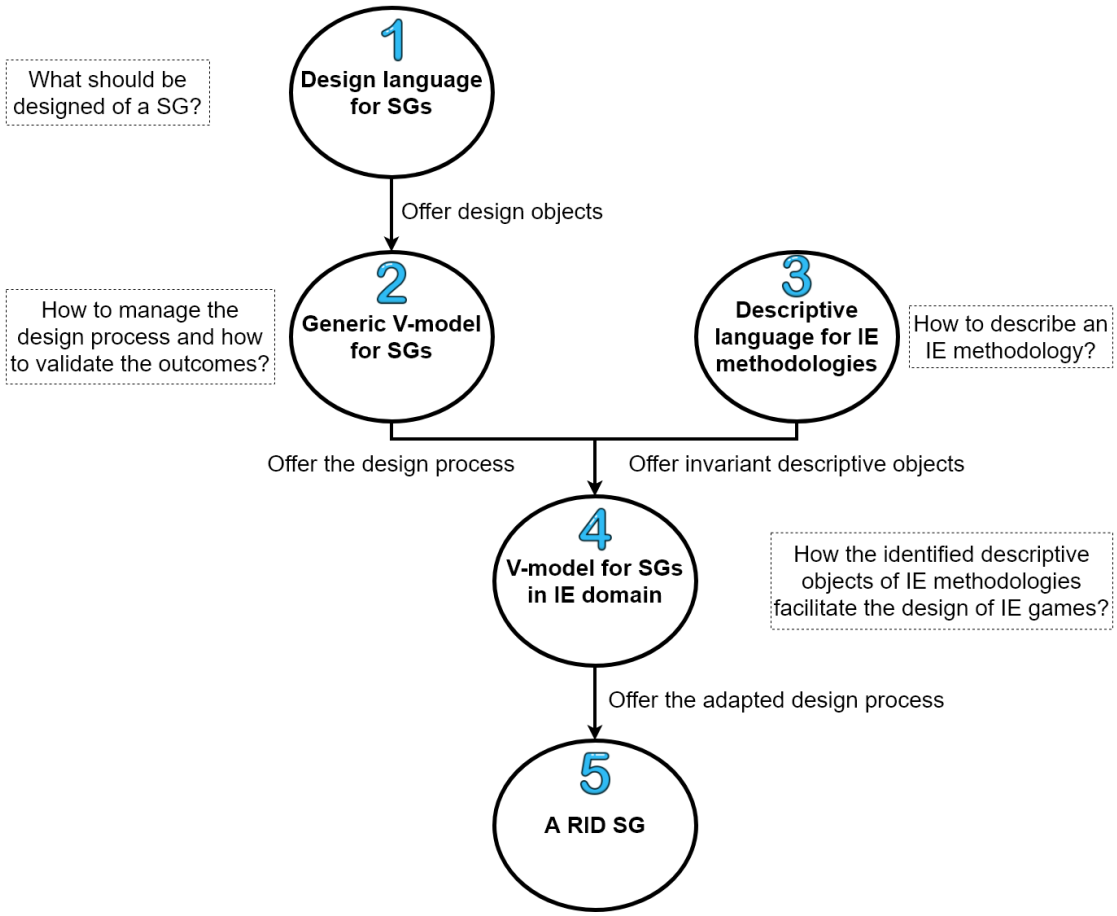


Figure 3.2: The logical relationship of the five contributions

3.4 Research method

The structure of our research is based on the Design Research Methodology (DRM). The

DRM framework aims to support engineering and industrial design research (Blessing & Chakrabarti, 2009). It consists of four main stages:

- Research Clarification (RC). At this stage, researchers formulate a realistic and worthwhile research goal through searching and reading the literature that influences task clarification and product success.
- Descriptive Study I (DS-I). After defining a clear research goal, researchers conduct an in-depth literature review to identify and clarify in more detail the limitations in the literature. Furthermore, empirical data analysis and logical reasoning are also conducive to the definition of the problem.
- Prescriptive Study (PS). The researchers propose prescriptive models (e.g., solution, method, and tool) based on their increased understanding of the problem.
- Descriptive Study II (DS-II). At this stage, researchers conduct empirical studies to evaluate the impact of developed support. Through analyzing the evaluation results, researchers further investigate how to improve the tool.

Bless & Chakrabarti (2019) claimed that the stages in DRM are not linear. The stages can be carried out iteratively or parallelly. Figure 3.3 shows the four research stages linked with their related basic means and deliverables.

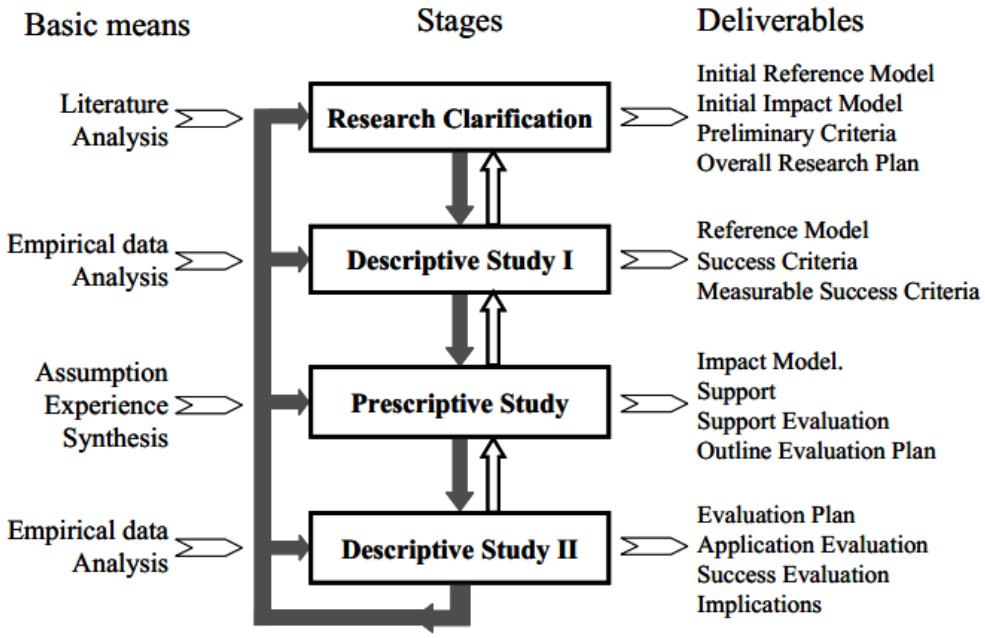


Figure 3.3: DRM framework: stages, basic means and deliverables

(Blessing & Chakrabarti, 2009)

Figure 3.4 presents the research method applied in this thesis, which is developed from DRM. However, we do not adopt all the DRM objects and tools, like the initial impact model. As mentioned before, we have the intention to disseminate the use of SGs for teaching IE methodologies. On this premise, we start the research.

The **RC** is based on the state of the art. This analysis led to identifying a research gap: "there is no adapted design framework for IE games to reduce their design process's complexity and time consumption." To fill the gap, the last three research questions are defined.

The **DS-I** is carried out by a detailed literature review and observations. The review covers some relevant areas, like SGs design, SGs evaluation, teaching methods of IE methodologies. The observations aim to understand existing SGs for teaching IE methodologies and the educational content of IE methodologies. For example, the observation of a lecture course on RID helps us know all the knowledge and competencies that should be taught to students to enable them to use the RID process. Taking advantage of this stage, the first research question has been identified. We think it is mandatory to be clear about the objects that constitute SGs before designing.

During the **PS** stage, we compare the existing design and evaluation methodologies of SGs and analyze the commonalities of IE methodologies, which result in the first four contributions.

At the **DS-II** stage, two case studies are employed to validate our contributions. The first case study is Consortio. We use the proposed design language and generic design framework to describe Consortio comprehensively and to reasonably reverse its design process. The second case study is the RID game, which is designed based on the adapted V-model. We invite future potential users to test it and obtain evidence that the game could offer a good learning experience and playing experience. These results serve to validate the RID game itself and validate the proposed framework further. Finally, IE experts help us test the descriptive language on nine relevant methodologies and prove the effectiveness of the proposed framework.

3.4 Conclusion

This chapter defines research questions and outlines how the research is conducted. Our study aims to understand how to design and validate SGs for teaching IE methodologies. The next chapter details the process for answering the first research question and reports related findings.

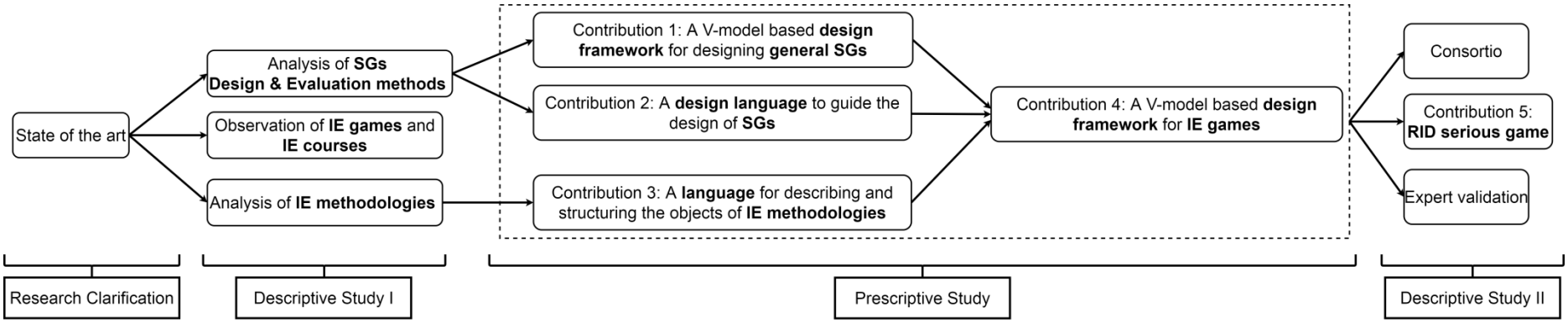


Figure 3.4: Research method

Chapter 4. Design language for serious games

This chapter aims to answer the first research question that "What are the invariant elements that make up a serious game (SG)? How to describe and structure them?" We propose a design language for SGs, which organizes different SG design elements based on the game system's hierarchical structure. The game Consortio is employed to illustrate the proposed language.

4.1 Introduction

A prerequisite for designing SGs is to understand the design objects and structure of them. In this chapter, we define a set of generic design objects of SGs based on state of the art. Then, we make decomposition of an existing innovation game (Consortio). Respecting the hierarchical structure of an SG, we develop a series of derived terms that allow us to build a design language for SGs. The language includes and organizes all the design objects we have discovered so far, which answers the thesis's second research question. In the next chapter, we will take advantage of the design language to put forward a V-model design framework of SGs. The design objects identified will be utilized to explain the design tasks and expected deliverables of each stage.

When designing an SG, no matter which method adopted, the ideal product is a holistic game system that offers a playful learning experience. Different game elements make up the game system. We can treat design elements as a set of building blocks or features shared by SGs. In Chapter 2, we have discussed different ways of decomposing a game system. The acknowledged SGDA framework proposed by Mitgutsch & Alvarado (2012) identifies six essential components of the formal conceptual structure underlying an SG: *design purposes*, *information*, *story*, *game mechanics*, *aesthetics*, and *framing*. Compared with the studies of Lameras (2015) and Cheek et al. (2015), the SGDA framework provides an exhaustive list of design elements to help novice designers understand SG's composition. Although most of the researchers adopt it only to analyze SGs, in this thesis, we employ the SGDA framework as the backbone objects for establishing an SGs design language.

SGs are highly complex systems with many different game elements that could affect their effectiveness (Wilson et al., 2016). An SG has its internal architecture, which determines the arrangement of and relations between design elements. Understanding the architecture of SGs is conducive to planning the design process and facilitating the integration of game elements.

In the field of SGs, a game is usually considered to be composed of different *game levels*

(Coenen et al., 2010; Barbosa et al., 2014; Furuichi et al., 2014; Thillainathan & Leimeister, 2014; Chua, 2017). The game level is a section or part of a game. For each level, players have different tasks to overcome as a way to advance in the game. The alternative terms of game levels are episodes, minigames, and game scenarios. Decomposing the entire game system's design into the design of and merging several game levels is beneficial to reduce the design complexity and the integration of educational content in the game.

Through extensive knowledge of existing SGs (Hannig et al., 2012; Coenen, 2013; Katsaounidou et al., 2019; Libe et al., 2020), we find that a game level may further consist of one or more *game challenges*. For example, the innovation board game "Lino" developed for elementary pupils by Libe et al. (2020) has seven game levels. The beginning game level requires players to complete two game challenges. First, they have to read all the "dream cards," which describe different innovation topics. The second one is to select a dream card and start to generate innovative ideas.

Section 4.2 defines and exemplifies the design objects of SGs. A design language for SGs is proposed in section 4.3. The last section makes a summary of the chapter.

4.2 Design objects of serious games

In this section, the definitions adopted for the generic SG design objects are introduced. Then, we generate some derived terms based on this set of generic objects by considering the three systematic layers of an SG: *game system layer*, *game level layer*, and *game challenge layer* (Table 4.1). An open innovation game "Consortio" (see Chapter 2 for more details) serves as an instance to support the illustration of them.

Table 4.1: Design layers of SGs

Design layer	Explanation
Game system	The game is treated as a coherent and consistent system.
Game level	Game levels are a series of spaces, or rooms, with connections in video games (Schell, 2008). We define game levels as the different sections or parts that constitute the pathway that players can follow as they play a game. A game may consist of one or several game levels.
Game challenge	A task that requires a player's mental or physical effort to complete successfully (Adams, 2014). Each game level may contain one or several game challenges.

4.2.1 Generic design objects of serious games

We propose eight generic design objects, five of which are from the SGDA framework: *design purposes*, *story*, *gameplay*, *information*, and *aesthetics*.

Three novel objects are *design constraints*, *evaluation*, and *game props*. First of all, SGs are expected to perform in a predefined usage situation. *Design constraints* shape the usage situation and help narrow choices when creating a game. Second, *evaluation* is regarded as a fundamental object because it is a significant way to provide feedback concerning the choices made by a player or the player's performance. It has an essential impact on player satisfaction. Third, *game props* are artifacts at each design layer and are closely linked to other design objects. For example, game cards as one kind of game props can carry information and realize the gameplay. The definitions are presented in the following, along with the explanation based on Consortio.

1) Design purposes

Design purposes: The intention of a designer to design the serious game (Mitgutsch & Alvarado, 2012). There exist three types of intentions (Michael & Chen, 2005): "spread a message" (inform people about a subject), "educate" (learning by doing), and "train" (coach people about a subject with a virtual training before a real doing).

Example: The topic of Consortio is open innovation. The purpose of the game contains three serious aspects and one fun aspect. Those three serious aspects are: make players 1) learn different strategies of open innovation, 2) understand how the benefits of open innovation can help businesses address their challenges, and 3) become aware of the importance of the preparation of the company and its partners (strategy and maturity) in the choice of open innovation strategies (Jeu IØ, 2016). The fun aspect is to provide a good experience for players while ensuring achieving the other serious aspects. The game also wants players to unfold imagination and answer the question about the future that "If you have to implement strategies of open innovation, what will they be?"

2) Design constraints

Design constraints: A list of pre-assumptions of the game. They describe targeted users and when, where, and how users will apply the game.

Example: Consortio targets a significant group of professionals whose work involves marketing, R&D, and human resources. This game also aims at training students from an engineering school or business school. These people have the motivation to learn open innovation. The designers planned to use the game in one-day (Introduction: 1h30; Game session: 4~6 h) open innovation training (Jeu IØ, 2016). All users need to register for training and then experience the game under the guidance of the trainer (Figure 4.1).

Figure 4.1: Open innovation training with Consortio at CentraleSupélec

3) Gameplay

Gameplay: A set of certain core game mechanics that determine a game's overall rules.

Game mechanics are usually regarded as low-level SG design objects (Slimani et al., 2016). We use the term "gameplay" to refer to the higher-level object corresponding to them.

Example: The gameplay of Consortio is:
① Players should play the game in group and they need discussion and negotiation.
② Every player should play a specific game role with a personal mission.
③ Players should play the game with a game board and manipulate cards and counters.

4) Evaluation

Evaluation: Determination of the way for evaluating players' performances. Based on the evaluation results, the game provides feedback to players to keep their engagement and motivation (Johnson et al., 2017).

Example: The designers of Consortio created a scoring system according to three value indicators KSB (see subsection 2.3.2). Whenever players buy an open innovation strategy card, they can benefit from the value generated by this card. The value of the card is quantified and converted into three scores corresponding to KSB. The group with the highest score will be the final winner.

5) Story

Story: The game's whole background story (Kazoo, 2015). It consists of five aspects. *Setting:* The location of the action.

Characters: The individuals that the story is about.
Plot: The actual story around which the entire game is based.
Conflict: A challenge or problem that drives the action of the story.
Solution: The solution to solve the problem or challenge.

Example: The story of Consortio (Figure 4.2) is about an open innovation project (*plot*). Different organizations (*characters*) are involved in the "SUPERGEL" food consortium (*setting*). Its objective (*conflict*) is to develop a line of frozen ready meals using the new super freezing technology developed by the C.R.A.M.P.: a fictive research centre and a member of the consortium. To achieve the objective, consortium needs to select and implement appropriate open innovation strategies to create maximum value (*solution*).

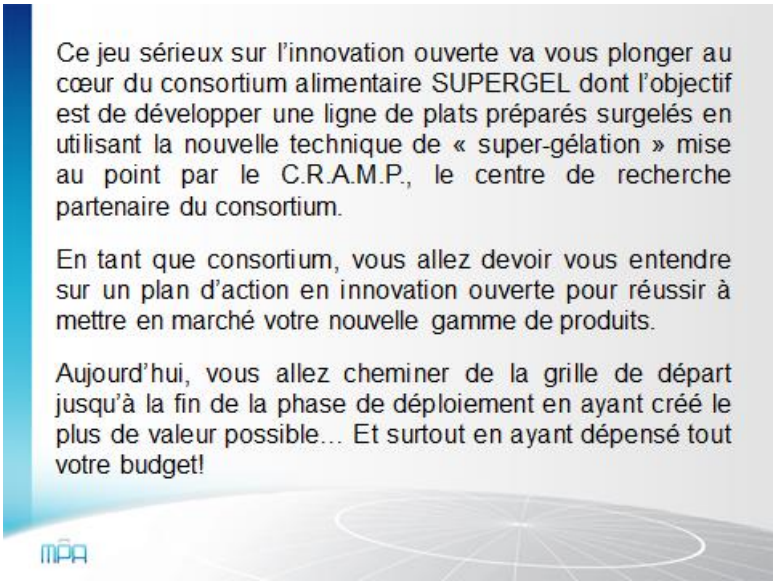


Figure 4.2: The story of Consortio (Jeu IØ, 2016)

6) Information

Information: The information or data offered and used in the game (Mitgutsch & Alvardo, 2012). For SGs, all information needs to directly or indirectly promote the achievement of design purposes, not just for fun.

Example: Consortio provides information about the definition and significance of open innovation and also examples of open innovation projects. These pieces of information are provided by the trainer using an hour of screen presentation. Game cards offer players information about their characters in the game and different open innovation strategies (Figure 4.3a; Figure 4.3b).

(a) Character "Clic Express"

(b) Open innovation strategy "Living Lab"

Figure 4.3: Game cards of Consortio

7) Aesthetics

Aesthetics: The audiovisual language used in the game (Mitgutsch & Alvardo, 2012). For board games, aesthetics are reflected in the visual appearance of game props.

Example: The aesthetics of Consortio shows in the appearance of game cards (Figure 4.3) as well as the game board (Figure 4.4). The game board is square, and each side of it corresponds to a game level. Each of levels is corresponding to the different stages of development (research, design, prototype, and deployment) of one innovation project in reality. The counters for the indicators KSB are located in the middle of the board to remind players' mission.

Figure 4.4: The game board of Consortio

8) Game props

Game props: The various specialized parts, pieces, and tools (e.g., coins, game board, scoreboard, and game cards) used for board games (Magerkurth et al., 2004). All game designers utilize props to achieve the design purposes, whatever it is an entertainment game or a serious game (Stenros, 2007; Ampatzidou & Gugerell, 2018; Sim et al., 2019). Game props are the design artefacts that derived from all the other design objects to make the game a reality.

Example: Consortio uses main three kinds of game props:

① Game cards: open innovation strategy cards, game character cards, and perturbation cards. The perturbation cards offer players rewards or penalties caused by their previous decisions. If one group did not choose open innovation strategy card "Charter on intellectual property", then they will probably lose all of the concepts and prototypes (Figure 4.5). In reality, a wrong decision may lead to huge economic losses.

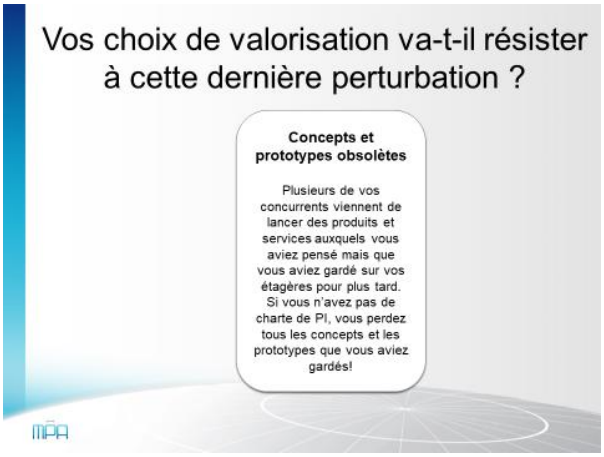


Figure 4.5: Perturbation card "outdated concepts and prototypes"

② Game board (Figure 4.4). The game board embodies the entire process of Consortio. It provides a platform to place game cards.

③ Scoreboard (Figure 4.6). The scoreboard is used to record the scores gained by a group in each game level and the total score.

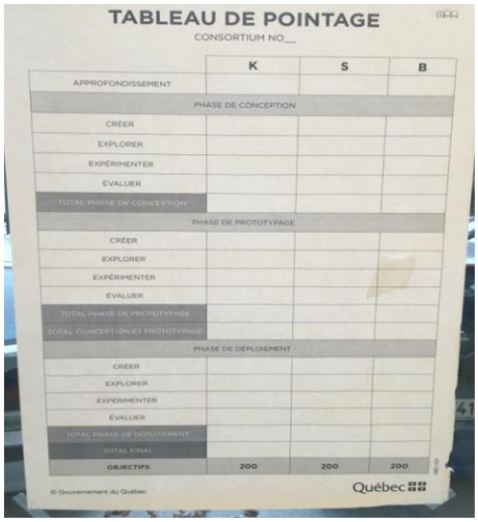


Figure 4.6: Scoreboard of Consortio

4.2.2 Derived design objects of serious games

The above eight generic design objects define a template for designers to fill when designing a new SG. We generate a series of derived vocabulary (Table 4.2) to distinguish the same design objects in the three systematic layers. By doing so, we can understand how the design objects evolve as the design process progresses when a hierarchical approach is applied to design SGs. These derived terms will be used in Chapter 5 to describe a V-model based design framework of SGs.

Table 4.2: Derived design objects of SGs

Design layer / **Generic objects**	**Game system**	**Game level**	**Game challenge**
Design purposes	Design purposes of the game	Design purposes of the game level	Design purposes of the game challenge
Design constraints	Design constraints of the game	Design constraints of the game level	Design constraints of the game challenge
Gameplay	Basic gameplay	Gameplay of the game level	Gameplay of the game challenge
Evaluation	Evaluation in the game	Evaluation in the game level	Evaluation in the game challenge
Story	Story frame	Story of the game level	Story of the game challenge
Information	Information of the game	Information of the game level	Information of the game challenge
Game props	Game props required by the basic gameplay	Game props required by the gameplay of the	Game props required by the gameplay of the

		game level	game challenge
Aesthetics	Aesthetics of the game props required by the basic gameplay	Aesthetics of the game props of the game level	Aesthetics of the game props of the game challenge

Most derived terms can be easily understood with the help of the definition of generic design objects. Here we only add some additional explanation.

1) Game system layer

Story frame: A brief write-up sums up game's story.

Example: See the example of generic object "story."

2) Game level layer

Gameplay of the game level: The description of how players interact and how players interact with game props at a particular game level.

Example: The first game level of Consortio is "Research." The gameplay of this level is "*Players in one group need to discuss and then purchase open innovation strategy cards by using a limited budget. They should collect as much data as possible to understand their open innovation project fully. The time limit is 15 minutes*."

Design purposes of the game level: Expression of the design purposes that each game level needs to achieve.

Example: The design purpose of the first level of Consortio is to help players understand the open innovation strategies (Figure 4.7) used in the research phase.

Figure 4.7: Open innovation strategy "Benchmark and positioning"

Story of the game level: The story taking place at the game level. It adds more details to the story frame from the five aspects: setting, plot, character, conflict, and solution.

Example: The story of the first game level of Consortio is "*The food consortium has been established. At the beginning of the innovation project, the consortium conducts research to understand the market and customer needs*. "

Design constraints of the game level: Pre-assumptions related to the game level. For instance, the predefined duration of one game level.

Example: In order to ensure that the duration of the entire game session does not exceed the specified time. The designer of Consortio has set a time limit for each game level.

Information of the game level: Outline of the information contained in the game level.
Every piece of information should associate with at least one design purpose. The mean of providing information at a certain game level needs to be defined.

Example: To define the information of the first game level of Consortio, the designer needs to determine all the open innovation strategies that the level shows to players. Besides, they need to decide further which aspects (e.g., definition and example) of these strategies to introduce.

Evaluation in the game level: Determination of the way for evaluating players' performances in a specific game level.

Example: At the end of each level, the trainer employs the "hidden data" (Figure 4.8) to evaluate players' performances and to indicate the best choices of open innovation strategies at a given game level. These data model the value generated by each strategy based on the KSB indicators.

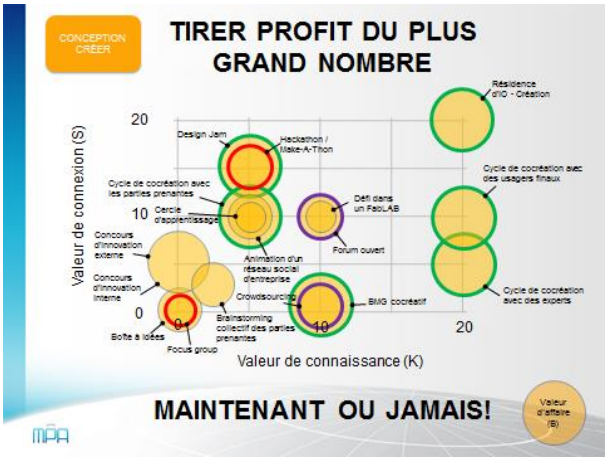


Figure 4.8: The hidden data used to evaluate open strategies

3) Game challenge layer

Gameplay of the game challenge: The description of how players conquer the game challenge. It is developed and elaborated on from the gameplay of the game level.

Example: The first game level of Consortio consists of three game challenges:
① Each player should read and understand all the open innovation strategies cards that are useful in the research phase.
② Each player chooses suitable cards according to the personal challenge.
③ Different players of a group negotiate to make choices that satisfy the interests of multiple organizations.

Information of the game challenge: The detailed information that should be provided to players to complete the game challenge. It is expanded based on the information outline in the relevant game level.

Example: The designer needs to define precise texts that appear on game cards and the game board. As shown in Figure 4.7, the designer of Consortio provides clear definition of "Benchmark and positioning" and explains its significance.

4.2.3 Other design objects of serious games

In addition to the design objects introduced above, some particular objects only appear in a specific design layer.
1) Game type

Game type: A game type is a specific category of games related to similar basic gameplay (Grace, 2005). For example, action, adventure, puzzle, and role playing.

Every game has a game type. This term is only used in the *game system layer* to illustrate how to derive the basic gameplay.

Example: Consortio is related to four game types:
① Role playing: The game provides eight different characters (Figure 4.3a) for players to choose.
② Cooperative: Although the players represent different organizations, they need to form a consortium and strive for the same goal.
③ Board game: Players are asked to play with a board and a lot of game cards (Figure 4.4).
④ Strategy and resource management: Each group of players needs to consider the budget and other factors to make a decision through discussion.

2) Game mechanics

Game mechanics: The rules and procedures that guide the player and the game response to the

player's moves or actions (Boller, 2013). The gameplay of a game challenge may employ one or several game mechanics. To help novice designers understand the commonly used game mechanics, we establish a "Game mechanics space. (Appendix A)" This space contains more than 70 different game mechanics. Each is defined and exemplified.

We adopt the "game mechanic" in the game challenge layer as the elementary component that makes up the gameplay of each game challenge.

Example: Based on our analysis of Consortio (Ma et al., 2019), the game uses seven game mechanics in the first game level (Table 4.3).

3) Learning mechanics

Learning mechanics: It is the dynamic operation of learning, relying on learning theories and pedagogical principles. This includes the components (e.g., specific goals, tasks, activities, methods) that constitute learning strategies, instructions or processes that are affected by the learning environment (Arnab et al., 2015). The learning mechanic guides the selection of game mechanics for achieving relevant design purposes.

Example: The following table describes the learning mechanics used in the first game level of Consortio.

Table 4.3: Game mechanics and learning mechanics used in Consortio

Game mechanic	Learning mechanic	Explanation
Collaboration	Participation Action/Task Plan Tutorial Feedback Reflect/Discuss	Negotiation between players
Selecting/Collecting		Cards selection
Tutorial		PPT presentation
Time pressure		Time controlled by trainer
Feedback		Counters of KSB Trainer's feedback
Resource management		Budgets
Branching choices		Choose cards

4) Framing

Framing: The framing of other elementary components in terms of the target group, their play literacy and the broader topic of the game (Mitgutsch & Alvardo, 2012).

"Framing," the *game challenge layer*'s design object, emphasizes the importance of developing game challenges of appropriate difficulty based on the targeted users' play literacy.

Example: The trainers of Consortio always combine the game with an academic course. They adjust the content and duration of the course based on the players' knowledge of open innovation. The play literacy needed to master the game is very basic because the trainer clearly explains the game rules before playing. The difficulty increases from level to level, realized by the game mechanics "time pressure." Players need to make decisions in less and less time.

4.3 Building a design language for serious games

Based on the design objects mentioned in section 4.2, in this section we propose a design language for SGs. In the design language, an SG system has three layers: game system layer, game level layer, and game challenge layer (Figure 4.9).

The game system layer design focuses on defining the *System layout & Interfaces* (i.e., the game levels that compose a system and the relationship between them) and designing the common objects throughout the game based on the predefined design purposes and design constraints. The outcomes of the game system layer will be used as the input of the game level layer.

When designing the game level layer, we define the *Level layout & Interfaces* (i.e., the game challenges that compose a level and the relationship between them) of a specific game level and the common objects throughout this game level. The related results are useful to specify the design objects of different game challenges of the game level.

The intermediary product of the design objects related to gameplay, story, evaluation, and information is gradually enriched as the layer goes down. The objects related to design purposes and design constraints are gradually decomposed and distributed. The same design purpose may be associated with multiple game levels.

Inspired by Arnab et al. (2015), we find that matching game mechanics and learning mechanics is a concise means to relate ludic elements and teaching objectives within the SG. This is why the learning mechanic is introduced into the *game challenge layer* and linked with the game mechanic.

The design language for SGs also provides instances for some design objects (e.g., game props and aesthetics), which help illustrate each layer's upshots.

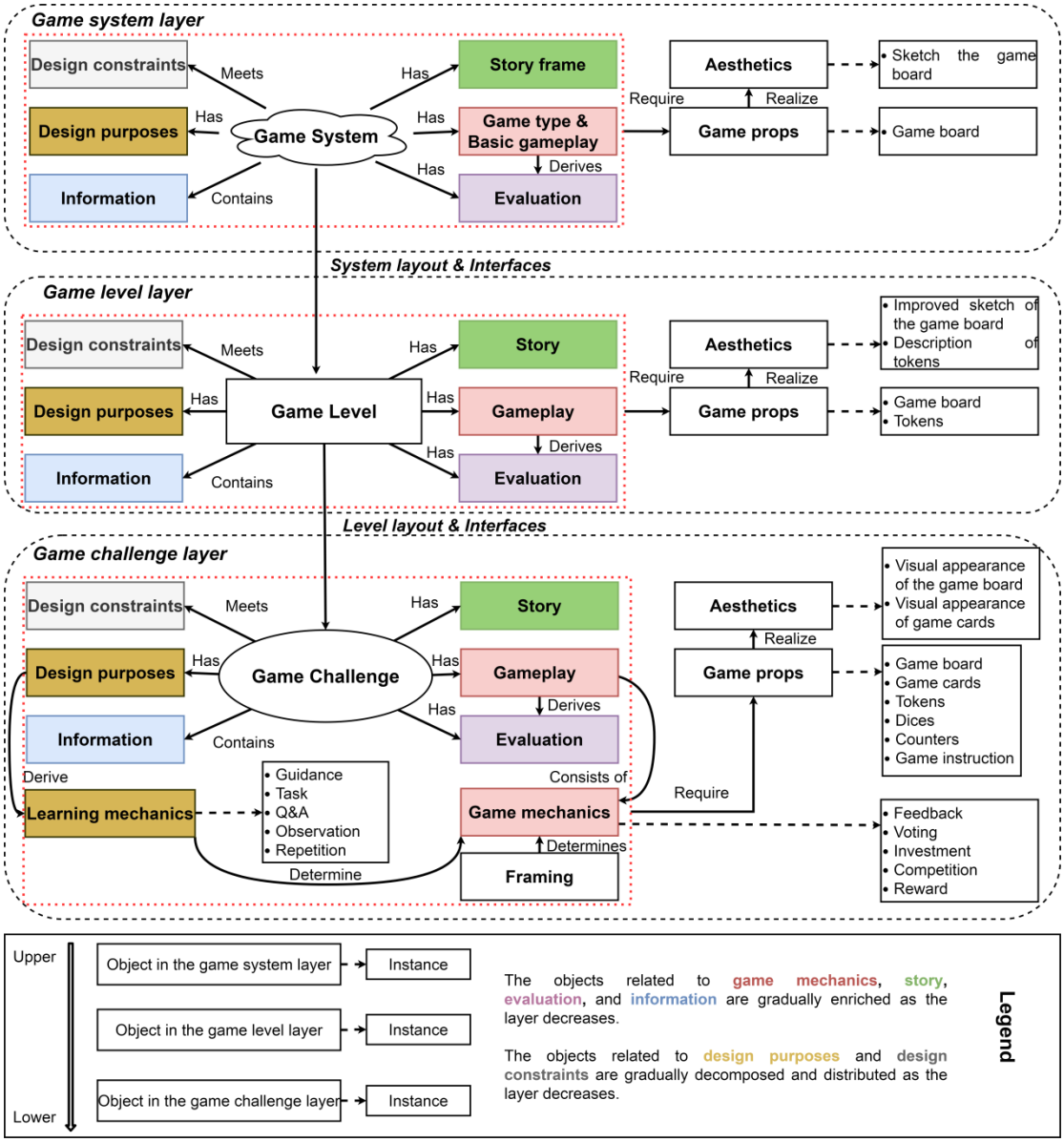


Figure 4.9: Graphical representation of a design language for serious games

4.4 Conclusion

This chapter proposes a design language for SGs, which describes and structures the design objects that make up an SG. There are eight generic design objects, and considering the hierarchical structure of the SG system, we derive a series of supplementary design objects.

Comparing with the SGDA framework, our language contains three new design objects: evaluation, game props, and design constraints. In this design language, each design object is connected to the relevant systematic layer, making novice designers easily understand design objects' evolution as the design layer goes down. In the next chapter, we use the proposed language for developing a generic V-model based design framework for SGs.

Chapter 5. Proposition of a V-model based generic design framework for serious games

This chapter aims to answer the second research question: "What is a comprehensive and easily understandable design methodology of serious games (SGs) for novices? How to design and validate serious games based on such methodology?" We start by introducing the V-model (Validation & Verification model) and the participatory design (PD) approach. Then we justify our intentions for the introduction of the standard V-model and PD in the SG design process. Finally, we propose a generic design framework for SGs built based on the V-model and the SG design objects identified before. The proposed framework also integrates the PD method.

5.1 Literature review

The V-model (Validation & Verification model) has been primarily proposed by Paul Rook (1986) in the context of software development. It is a modified version of the Waterfall model (Balaji & Murugaiyan, 2012). The standard V-model (Figure 5.1) presents the typical sequence of development activities on the left and the corresponding sequence of testing activities on the right. Basically, it provides a systematic roadmap from project initiation to product obsolescence like the Waterfall model.

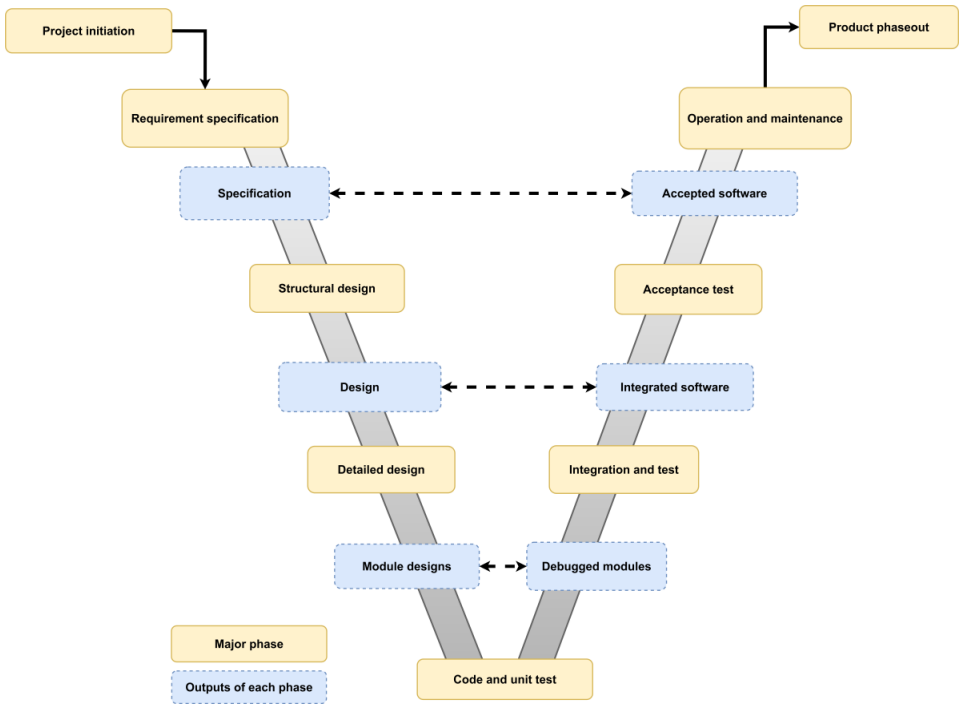


Figure 5.1: The standard V-model produced by Rook (1986)

But, the V-model also demonstrates the relationship between the development and testing activities and describes the outputs that have to be produced during product development. Table 5.1 defines each activity and introduces its outputs.

Table 5.1: Description of the activities in the V-model based on Rook (1986)

Development activity	**Definition**	**Outputs**
Requirement specification	Collect the requirements of the system by analyzing users' needs. This activity is related to determining what the ideal system must perform.	A complete, validated specification of the required functions, interfaces and performance for the software product. A detailed project plan.
Structural design	Understand and detail the complete hardware and communication setup for the product under development.	A complete, verified specification of the overall software architecture, control structure and data structure for the software product, along with such other necessary components as draft user's manuals and test plans.
Detailed design	Break down the system into modules with different functionalities and define the data transfer and communication between them. Detailed design of each module.	A complete, verified specification of the control structure, data structure, interface relations, sizing, key algorithms and assumptions for each program component.
Code and unit test	Choose the suitable programming language and code the system modules. Test each module and eliminate bugs.	A complete, verified set of program components.
Testing activity	**Definition**	**Outputs**
Integration and test	Test the coexistence and communication of the internal modules within the software.	A properly functioning software product.
Software acceptance test	Test the software in the user environment to ensure the satisfaction of users.	A software product accepted by users.
Maintenance	Deliver updates that meet the new needs of users.	Software updates.

Software projects widely adopt the V-model for its four main advantages (Munassar & Govardhan, 2010; Krishna et al., 2012):

1) Simple and easy to use;

2) Minimization of risks and better plannability. The test plan and documentation are developed early before prototyping;

3) Improvement of product quality through integrated quality assurance measures;

4) Cost estimation is relatively easy due to the repeatability of the process.

Before it was developed, software testing activities were envisaged only after the design stage with few possibilities to backtrack. Without the V-model, the software design consequences would be dramatic, as the validation part often lasts and costs twice the design part (Awedikian & Yannou, 2014). The V-model allows us to envision the validation activity as soon as the corresponding design part is proposed; consequently, one can say that the two parts are co- or concurrently designed.

In recent decades, the standard V-model has been refined and extensively used in industry, especially in the system engineering domain for improving the cost effectiveness of complex systems as experienced by the system owner over the entire life of the system, from early design to retirement (Osborne et al., 2005). The V-model is used to visualize the system engineering focus, particularly during the development stages. It highlights the need to define verification plans during requirements development, the need for continuous validation with the stakeholders, and the importance of continuous risk and opportunity assessment (SE Handbook Working Group, 2011). Ferreira et al. (2014) utilized it for eliciting business process requirements in cloud design, i.e., to derive logical architectural models from executing in the different cloud layers from a process-level perspective instead of the traditional product-level perspective. Vasić & Lazarević (2008) offered a standard industrial guideline for mechatronic product design based on the V-model to overcome classical sequential product design procedures and domain isolated product development (i.e., over-the-wall syndrome) with substantial cost and time reduction.

We propose four reasons to justify the introduction of the standard V-model in the serious games (SGs) design process:
1) All the design processes of SGs (see section 2.2) we have identified in the literature start planning game testing after generating functional prototypes. Designers need to review the design purposes specification to develop a testing plan, which takes extra time. In the V-model, test designing and planning happen well before “coding” activity (to transpose in SG context). This should save much time.
2) All the design processes of SGs we have discovered often directly test the entire game system rather than validating the small components that make up the system in advance, hindering defect tracking. In the V-model, units undergo testing before being assembled into modules. If errors are found, the programmer will improve the code and retest.
3) Although the existing design processes specify each design stage work packages and expected outputs, but few of them mention the validation and verification of these outputs (Aslan, 2016). This may lead to the downward flow of the defects. In the V-model, every intermediate product needs to be verified and validated, which guarantees the quality of the design.
4) SGs design is still a complex issue because we need to consider multiple objects (see chapter 4) when designing. However, the existing design methods cannot answer how to design these objects separately and assemble them. The V-model can provide a hierarchical

design scheme for orchestrating these SG elements. From the top layer to the low layer, each game element's specification becomes more affluent, and the relationship between game elements becomes apparent.

5.2 Participatory design

Participatory design (PD) is the process during which consumers take an active role and co-create value together with the company (Spinuzzi, 2005). More and more SGs designers adopt it for significant interactive content creation (Tobar-Muñoz et al., 2016; Plumettaz-Sieber et al., 2019). Potential users and other stakeholders are invited to design and also test the game. However, there exist difficulties of fit between PD and serious game design. Khaled & Vasalou (2014) argue that "serious game design complicates the notion of involving users as co-designers, as serious game designers must be fluent with both domain content and game design." Indeed, when users participate in other products' design, they know well about the product and just need to express their product-related needs and feedback their feelings about using the product. However, SGs' users (objects be trained) usually cannot clearly express their expectations for a serious game. First of all, they are not familiar with the content that the game wants to teach, and they also lack SG vocabulary to organize their views. Therefore, there may be communication problems between professional SG designers and co-designers.

To solve these problems, we must provide co-designers with clear guidance to understand the game's topic and master commonly used terms in SG design during PD sessions. Additionally, the game's design purposes, design progress, and expected outcomes of the session should be introduced. Thanks to the documentation produced at each stage of the V-model, it is convenient to extract the necessary information for developing guidance. That is why we integrate the PD approach into our proposed design framework for SGs.

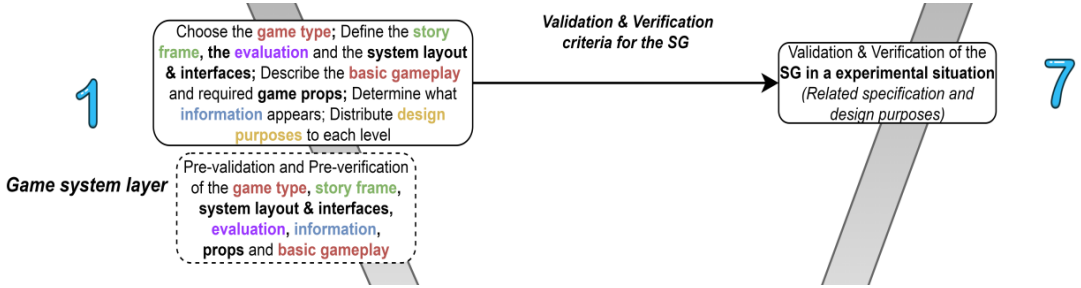
5.3 A generic V-model based design framework for serious games

The generic V-model based design framework (Figure 5.2) is proposed on the basis of the three systematic layers and various design objects of an SG. It combines the original V-model and participatory design approach, which provides a practical and progressive way to design SG elements. As the design phase proceeds, the description of each game element becomes more specific.

The framework separates an SG design process into three phases: the conceptual design phase (stage 0~3 in Figure 5.2), the detailed design phase (stage 4 in Figure 5.2), and the validation & verification phase (stage 5~8 in Figure 5.2). The detailed design phase bridges the other two phases. The conceptual design phase includes four SG development stages, and each stage requires designers to perform related ***conceptual design*** (which is named as "development" in [Rook, 1986]), ***pre-validation***, ***pre-verification*** (which is named as

"verification" in [Rook, 1986]) activities. We originate the pre-validation activities and introduce them to the V-model to evaluate the quality of game ideas generated during the conceptual design phase. The game idea refers to the description of any SG design objects. The quality of a game idea is the degree to which the idea possesses a desired set of characteristics: acceptability, challengeability, engageability, effectiveness, etc. (Aslan, 2016). The validation & verification phase consists of four game testing stages corresponding to the game design stages. In the game testing stages, the design team should accomplish several ***validation activities*** and ***verification activities***. In Rook (1986), these two types of activities are collectively referred to as testing activities. Table 5.2 defines the format of the V-model and describes as well as exemplifies all the activities in the V-model.

Table 5.2: Description of the activities in the proposed framework

<table>
<tr><td>Example</td><td colspan="2"> 

The conceptual design stage “1” and the corresponding validation & verification stage “7” are used as examples.</td></tr>
<tr><th>Activity</th><th>Definition</th><th>Explanation</th></tr>
<tr><td>Conceptual design</td><td>The tasks related to the description of the SG design objects</td><td>During the conceptual design stage “1,” designers need to describe the game system layer’s SG design objects with respecting the design constraints and design purposes, and then record results. For example, they should determine whether their game is a puzzle, adventure, or role-playing game.</td></tr>
<tr><td>Pre-verification</td><td>The tasks related to evaluating whether the documentation accurately reflects the game ideas generated of each conceptual design stage</td><td>The people who involved in the conceptual design activity of stage “1” are asked to check whether the documentation completely and accurately reflects the game ideas.</td></tr>
<tr><td>Pre-validation</td><td>The tasks related to evaluating whether the generated game ideas of each conceptual design stage are conducive to achieving the design purposes</td><td>The verified documentation generated during stage “1” is sent to the relevant stakeholders to collect their feedback. For example, to understand whether the selected game type helps achieve design purposes and attract potential users.</td></tr>
<tr><td>Verification</td><td>The tasks related to evaluating whether the prototype meets the specifications</td><td>Designers need to check if the prototype meets the specification of the game system generated during stage “1”.</td></tr>
<tr><td>Validation</td><td>The tasks related to conducting game testing with potential users</td><td>Potential users are invited to test whether the entire game system has achieved all the established design purposes during stage “7.”</td></tr>
</table>

To adequately implement this V-model design in Figure 5.2, we propose seven types of participants should be involved in the SG design team. Each of them is named and defined in Table 5.3. There are two categories of participants: fixed members and co-designers. Fixed members are designers and technical writers that participate in every design stage. The former is responsible for completing the game design, and the latter needs to record the outcomes. Co-designers can be teachers, experienced SG designers, potential users, pedagogical experts, and game players. They are invited at certain stages to share ideas for improving the learning experience and the gaming experience of SGs.

Table 5.3: Members of an SG design team

Type	Member	Role
Fixed members	***Designers*** 	They are the fixed members of the design team who participate in every stage of serious game design. They are usually the initiators of serious game projects.
	Technical writers 	Their mission is to record the participants' comments, game ideas proposed, and decisions reached during PD sessions. After sessions, they are asked to write formal specification documents.
Co-designers	***Teachers*** 	They should provide expertise about the state of the art in pedagogies for teaching the subject of the SG, which helps define the expected learning experiences. Teachers help the design team understand the learning subject.
	Experienced serious game designers 	They act as co-designers to provide insights and guide novice designers during PD sessions.
	Potential Users 	They are the game's targeted group, who may be (un)familiar with the subject taught. They are invited to PD sessions for game ideas generation and voting. Users join the SG experiments and provide feedback for improving the game.
	Pedagogical experts 	These experts have a deep understanding of the subject matter knowledge involved in the game and also familiar with a variety of effective teaching approaches. They help evaluate the feasibility of design purposes and guide the team to choose useful game ideas based on their teaching experience.
	Game players 	They are the people who have a rich gaming experience, making it possible for them to come up with interesting game ideas. Game players are invited to test the playability of the game. If the player is familiar with the subject to be taught, he can even evaluate the game's effectiveness.

Once the design team is formed, they can begin to follow the process shown in Figure 5.2 to design and validate the SG. The illustration of the V-model adopts the same coloring method as the design language for SGs. While the design team works on the V-model's left side (stages 0 to 4), team members first define the game's design purposes and, based on them to specify the entire game system, game levels, and game challenges. Finally, a functional prototype is made based on the specifications. Each stage has its intermediate outcomes, which should be pre-verified and pre-validated. During the conceptual design phase, the team should plan verification and validation activities based on the specifications generated in each stage. While the design team works on the V-model's right side (stages 5 to 8), team members need to refine the validation plan and then conduct all the validation and verification activities to determine whether the game achieves designated design purposes.

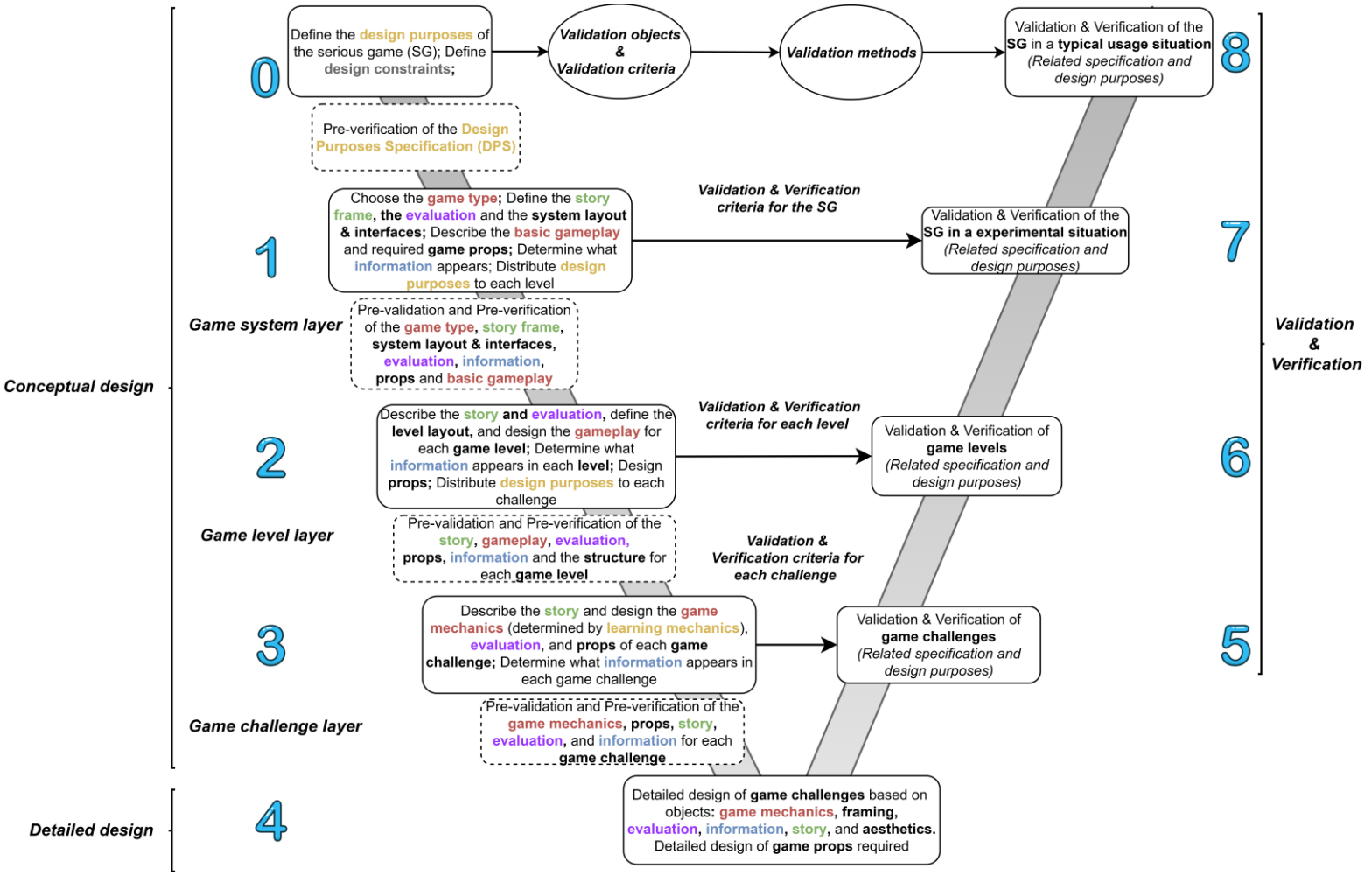


Figure 5.2: Generic V-model for SG design

Table 5.4 describes each stage in detail from three perspectives: work packages, expected deliverables, and participants. We use G-V <n> (n from 0 to 8) to represent the stages in the generic V-model.

Table 5.4: Description of the generic V-model

<table>
<tr><th>Stage</th><th>Activity</th><th>Work package</th><th>Expected deliverable</th><th>Participant</th></tr>
<tr><td rowspan="4">G-V <0></td><td rowspan="3">Conceptual design - Determination of design purposes</td><td rowspan="3">• Define what the players should experience during the game;
• Define what the players should learn after playing the game;
• Define the design constraints (time, resources, usage situations, etc.).</td><td rowspan="3">A design purposes specification (DPS) document which clearly defined expected learning and gaming experiences of the game as well as constraints.</td><td> 
Define design purposes</td></tr>
<tr><td> 
Set the requirements for the gaming experiences</td></tr>
<tr><td> 
Write the DPS document</td></tr>
<tr><td>Pre-verification</td><td>• Check the DPS document to ensure it records all the design purposes accurately.</td><td>A formal and explicit verification, with additional comments.</td><td> 
Check every design purpose</td></tr>
</table>

G-V <1>	Conceptual design - Game System Layer	• Choose a *game type* (adventure, puzzle, etc.); • Describe the *story frame*, the *evaluation*, the *basic gameplay*, and required *game props*; • Plan the *system layout & interfaces* and link each game level with related *design purposes*; • Determine the *information* conveyed by the system; • Define the validation objects, criteria, and methods for the system.	A high-level specification document which illustrates all the design objects of the game system layer.	 Choose the game type, define the story frame, the information, the evaluation, the basic gameplay, game props, and system layout  Write the high-level specification document
	Pre-verification - Game System Layer	• Check the high-level specification document to ensure it records all the results accurately and completely.	A formal and explicit verification, with additional comments.	 Check the document
	Pre-validation - Game System Layer	• Evaluate the attractiveness of the *story frame*, *game type*, *game props* and the *basic gameplay*; • Evaluate the effectiveness of the *basic gameplay* for achieving design purposes.	Evaluation results for improving the high-level specification document.	 Read the specification and provide feedback

G-V <2>	Conceptual design - Game Level Layer	• Detail the design objects for each game level based on the high-level specification; • Plan the *level layout* of each game level and link each game challenge with related *design purposes*; • Define the validation objects, criteria, and methods for each level.	An intermediate-level specification document which describes the design objects of each game level as well as level layout & interfaces.	 Describe the design objects of the game level layer, and define the structure of game levels  Write the intermediate-level specification document
	Pre-verification - Game Level Layer	• Check the intermediate-level specification document to ensure it records all the results accurately and completely.	A formal and explicit verification, with additional comments.	 Check the document
	Pre-validation - Game Level Layer	• Evaluate the attractiveness of the description of design objects of each game level; • Evaluate the effectiveness of the *gameplay of each game level* for achieving design purposes.	Evaluation results for improving the intermediate-level specification document.	 Read the specification and provide feedback
G-V <3>	Conceptual design - Game Challenge Layer	• Describe relevant design objects for each game challenge; • Define the validation objects,	A low-level specification document.	

		criteria, and methods for each challenge.		 Describe the design objects of the game challenge layer
				 Write the low-level specification document
	Pre-verification - Game Challenge Layer	• Check the low-level specification document to ensure it records all the results accurately and completely.	A formal and explicit verification, with additional comments.	 Check the document
	Pre-validation - Game Challenge Layer	• Evaluate the attractiveness of the description of design objects of each game challenge; • Evaluate the effectiveness of the *gameplay of each game challenge* for achieving design purposes.	Evaluation results for improving the low-level specification document.	 Read the specification and provide feedback
G-V <4>	Detailed design	• Design a functional prototype (physical & digital) to implement each game idea.	A functional prototype which allows for game testing	 Design a prototype

G-V <5>	Verification - Game Challenge Layer	• Check whether the prototype consistent with the low-level specification document.	A corrected prototype	 Check the prototype with the low-level specification
	Validation - Game Challenge Layer	• Organize experiments to test whether each game challenge has achieved the corresponding design purposes.	An improved prototype	 Test game challenges and provide feedback
				 Further improve the game
G-V <6>	Verification - Game Level Layer	• Check whether the prototype consistent with the intermediate-level specification document.	A corrected prototype	 Check the prototype with the intermediate-level specification
	Validation - Game Level Layer	• Organize experiments to test whether each game level has achieved the corresponding design purposes.	An improved prototype	 Test game levels and provide feedback

				 Further improve the game
G-V <7>	Verification - Game System Layer	• Check whether the prototype consistent with the high-level specification document.	A corrected prototype	 Check the prototype with the specification
	Validation - Game System Layer	• Organize experiments to test whether the whole game has achieved the all design purposes.	An improved prototype	 Test the game system and provide feedback
				 Further improve the game
G-V <8>	Validation	• Test whether the game can achieve all the design purposes in a typical usage situation shaped by design constraints.	A mature product	 Test the game and provide feedback
				 Further improve the game

The proposed design framework is not a sequential process. The design team may need to perform each activity introduced above one or more times to get satisfactory results. It is essential to mention that each validation & verification stage has been preliminarily planned as early as their related conceptual design stages. For example, when conceptually designing game challenges, designers also need to consider organizing SG experiments to test whether each game challenge achieves the relevant design purposes. They should first derive "what to evaluate" based on design purposes and select suitable validation methods to collect data during SG experiments.

In Table 5.4, each conceptual design stage contains a pre-validation activity, which requires pedagogical experts to evaluate the generated game ideas' effectiveness. However, when designers themselves have a high level of teaching expertise, they can ensure the gameplay's effectiveness. In this case, there is no need to invite other experts for pre-validation. Users of the design framework can apply it flexibly according to their own situations.

5.4 Conclusion

This chapter introduces a hierarchical design scheme for SGs based on the SG objects defined before, which associates the participatory design approach and the standard V-model. The generic V-model makes up all the limitations of previous research identified in Chapter 2. It covers the full life cycle of SGs. The proposed framework emphasizes the importance of pre-validation and pre-verification activities to guarantee the quality of SGs. It also clearly states the work packages, expected deliverables, participants of each stage.

The proposed framework is expected to be employed as a heuristic tool for SG designers, especially novices. The initiators for SG design can first hire the right participants (Table 5.3) to form a design team according to their needs and then follow the generic V-model to design and validate a game on the subject of their concern (Figure 5.2 and Table 5.4).

In the next chapter, we explore the invariant objects for describing industrial engineering methodologies. The results of Chapter 6 and the generic V-model proposed in this chapter will serve as inputs to produce an adapted V-model for SGs of teaching industrial engineering methodologies in Chapter 7.

Chapter 6. Descriptive language of industrial engineering methodologies

This chapter aims to answer the third research question that "How to describe and structure all relevant objects for a given industrial engineering (IE) methodology?" We first introduce the detailed research process, which consists of four main stages. The outcomes of each stage are reported. Taking advantage of this research, we identify seven invariant objects of IE methodologies to build a language for describing IE methodologies. Finally, IE experts validate this language.

6.1 Introduction

In the previous chapter, we have proposed a generic V-model for designing serious games (SGs). The tasks and expected outcomes of each design stage are clearly defined. In this thesis, we are particularly interested in SGs at the service of any kind of industrial engineering (IE) methodologies. To be able to design solutions for SGs in IE, we must be able to describe and manipulate the design elements or structural components of an IE methodology. Then, we have to answer a research question, "how to describe and structure all relevant objects for a given industrial engineering methodology?" By identifying the invariant objects of IE methodologies and then introducing them into the generic V-model, we can develop a customized V-model for the games in the field of IE. To address this issue, we offer a descriptive language for IE methodologies in this chapter. The proposed language is especially useful for formulating the design purposes of IE serious games.

Section 6.2 describes the overall research process to create the descriptive language of IE methodologies. A literature review of IE disciplines and relevant methodologies is presented in section 6.3. Sections 6.4, 6.5, and 6.6 introduce results produced at each research stage. The last section makes a summary of the chapter.

6.2 Research process

This section explains how we generate, refine, and then validate the descriptive language. Figure 6.1 describes the whole research process, consisting of four main stages: a literature review of IE methodologies, creation, refinement, and expert validation. The results of each stage are detailed in sections 6.3 ~ 6.6.

The research starts with a literature review of IE methodologies, which aims to recognize the

diverse disciplines in IE and the methodologies employed by these disciplines. IE covers about twenty main disciplines (Wikipedia[6]). Each discipline has its research topics, and therefore different methodologies are applied. In section 6.3, we introduce six of them as well as related methodologies.

After understanding the existing IE methodologies, the next step is to generate the first version of the descriptive language. We performed of first ground experiment with the Radical Innovation Design (RID) methodology (Yannou, 2015) used for innovation management. We therefore designed a textbook along with Professor Yannou (Appendix B) for RID to describe and structure at best all its related objects. The hypothesis was that the resulting textbook, which provides an adequate descriptive language of RID, could also serve as a starting point for creating a generic descriptive language of IE methodologies. Five categories of objects naturally emerged at this point.

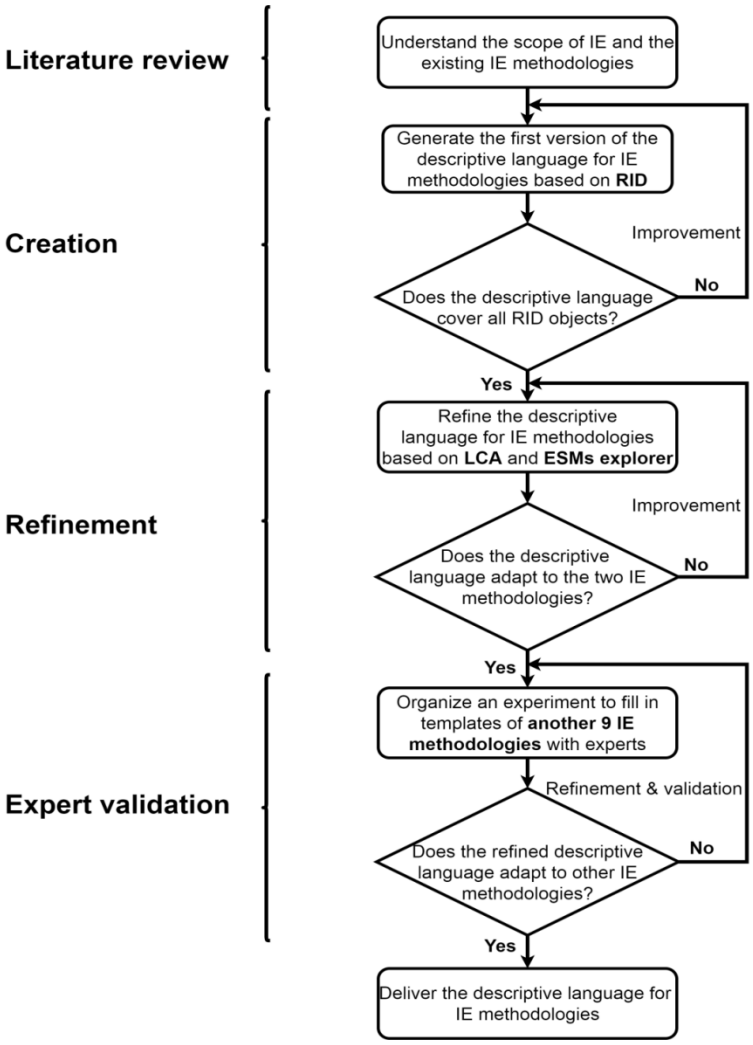


Figure 6.1: Research process for resulting in a descriptive language of IE methodologies

[6] https://en.wikipedia.org/wiki/Industrial_engineering#cite_note-11

This first experiment resulted in five categories: *Process description(s)*, *Performance*, *Competencies*, *Principles*, and *Methods & Tools* (see Table 6.1).

Table 6.1: The initial template for the descriptive language of IE methodologies

Object category	Detailed object
Process description(s)	
Performance	
Competencies	
Principles	
Methods & Tools	

The third stage is a refinement, during which, the first version of the descriptive language was practiced and improved on the Life Cycle Assessment (LCA) methodology (ISO 14040; ISO 14044) and the Eco-ideation Stimulation Mechanisms (ESMs) explorer (Tyl et al., 2016). LCA counts as the most accepted and widely used environmental assessment methodology of products and services (Curran, 2015). It is included in the 14000 series of environmental management standards of the International Organisation for Standardisation (ISO), in particular, in ISO 14040 and ISO 14044. In view of its popularity, we considered it as a good example to refine the descriptive language. Compared with LCA, ESMs explorer is a relatively novel IE methodology designed to support eco-innovation effectively. It was selected as there is one relevant expert in our intimate environment. As preparation, we first defined the five elementary objects of the descriptive language. We explained the proposed language to the two experts of LCA and ESMs explorer based on these definitions. After ensuring that they fully grasped the descriptive language, we asked them to fill in the template (Table 6.1) and put forward suggestions to improve it. Two new categories, "Concepts" and "Objective of the methodology," were then recommended by experts to complete the five existing ones. Indeed, the most crucial information of presenting an IE methodology is its objective, which answers the question, "What problem can this methodology solve?" and which was forgotten with the initial RID example. We also noticed that experts preferred to distinguish between "Concepts" which are general structuring notions and methods and tools which are more procedural knowledge.

To validate the refined descriptive language, i.e., whether it helps define any IE methodologies simply and effectively, we organized experimentation in the last stage, which involved several experts familiar with a series of selected IE methodologies (one expert per methodology). These experts come from our IE research department to get quick and rich feedback. Above all, we contacted the experts by email to explain our intentions and the descriptive language briefly. We held separate meetings with every expert willing to participate in the experiment. A supplementary document was provided to the expert at the beginning of the meeting, consisting of three parts: a detailed explanation of the proposed language, two examples based on LCA and ESMs explorer, and an improved template (Table 6.2) to define his/her designated methodology. After reading the document, the expert was asked to complete the description within half an hour.

Table 6.2: The improved template for the descriptive language of IE methodologies

Object category	Detailed object
Objective of the methodology	
Process description	
Performance	
Competencies	
Principles	
Concepts	
Methods & Tools	

To further validate the usability and the completeness of the descriptive language, we decided to conduct structured interviews. At the end of each meeting, we asked three qualitative validation questions to experts:

- Q1: *Do you feel at ease to provide sufficient materials about the IE methodology under each of the seven categories? If not, please explain why.*
- Q2: *Do you feel confident that most of the knowledge about this methodology has been listed based on the descriptive language? If not, please explain why.*
- Q3: *Do you think this practice has brought you some value? And that this simplified IE methodology identity card could be used to introduce an IE methodology to learners briefly?*

6.3 Literature review

To understand the scope of IE and the methodologies applied, we conducted a literature review. The IE methodologies identified will be used as samples for creating, refining, and validating the descriptive language.

The origin of the IE profession can be traced back to the Industrial Revolution. It has become an engineering occupation that concerns with the optimization of complex processes, systems, or organizations by developing, improving and implementing integrated systems of people, money, knowledge, information, equipment, energy and materials (Salvendy, 2001). IE as a broad research area has many sub-disciplines, some very common of which are introduced below. To our best knowledge, all top universities offer the curriculum related to these sub-disciplines to students who want to earn the "Master of Science (MS)" diploma[7]. After reviewing the six sub-disciplines, we enumerate twelve IE methodologies. Table 6.3 shows the major issues addressed by the six disciplines. As interpreted in section 6.3, we selected RID, ESMs explorer, and LCA deliberately to establish and ameliorate the descriptive language. We randomly selected the remaining nine methods, and then experts confirmed their representativeness in related fields. Because of their diversity and representativeness, we believe that these methodologies represent a reasonable sample.

[7] https://en.wikipedia.org/wiki/Industrial_and_production_engineering

Eco-design is an integrative ecologically responsible design discipline (Charter, 2018). The main goal of eco-design is to anticipate and minimize negative environmental impacts throughout a product life cycle (Sakao, 2007). A relevant discipline of eco-design is **eco-innovation**. Based on OCED (2009), "Eco-innovation can be understood and analyzed according to its targets (the main focus), its mechanisms (methods for introducing changes in the target) and its impacts (the effects on environmental conditions)." It not only focuses on environmental impacts but also on social impacts – which induces a change of the functionalities required to the new product and consequently a change of its business model (Carrillo-Hermosilla et al., 2010). The significant differences between eco-innovation and eco-design have been discussed in Cluzel et al. (2016). We will not elaborate on them here.

The improvement of IE performance is the current chief issue. **Project management** is a way to help achieve this improvement (Georgy et al., 2005). The purpose of project management is to produce a complete project that meets the client's requirements by applying knowledge, skills, tools, and techniques to project activities (Guide, 2001). The management of a project has five phases: initiating, planning, executing, monitoring & controlling, and closing. Unlike project management that cares about the entire life cycle of a product, **production management** pays particular attention to managing production operations and resources throughout the production system. Production management deals converting raw materials into finished goods or products, which applies management principles to production (Kumar & Suresh, 2006). **Quality engineering** is the discipline concerned with the principles and practice of product and service quality assurance and control (Juran & Godfrey, 1999). It covers all activities related to product design, development and manufacturing process analysis, with the purpose of improving product quality and the quality of the production process, while identifying and reducing various forms of waste. Another popular research area of IE is **innovation management**. According to Hansen & Birkinshaw (2007), it is the active and conscious organization, control and execution of activities that lead to innovation. It refers to product, business process, marketing and organizational innovation. Innovation management allows the organization to respond to external or internal opportunities, and use its creativity to develop new ideas, processes or products.

Table 6.3: Examples of the issues of IE disciplines

Discipline	Issue addressed
Eco-design	How to reduce the negative environmental impacts throughout the studied system life cycle?
Eco-innovation	How to innovate, while taking particular attention on environmental impacts and social impacts?
Project management	How to manage a project to meet its objectives?
Production management	How to manage production operations and resources?
Quality engineering	How to state, evaluate and control the quality of a product or a service?
Innovation management	How to manage an innovation process?

Finally, we define IE methodology as follows.

IE methodology: An IE methodology is a study of the principles, practices, and procedures that promote a specific activity, which relates to the design, improvement, and installation of integrated systems of people, materials, information, equipment, and energy (Derived from [Institute of Industrial and Systems Engineers, n.d.]).

We can notice certain confusion in the literature where authors sometimes use "IE techniques/methods/tools/systems" to represent IE methodologies (Khatun, 2013; Raut et al., 2014; Rao, 2016). But distinguishing between these terms is beyond the scope of this dissertation.

Table 6.4 lists the 12 IE methodologies we chose to try to decompose into our 7-piece of language model, providing we made sure to have 2 methodologies per discipline.

Table 6.4: Examples of IE methodologies

IE discipline	IE methodology	Main reference
Eco-design	Life Cycle Assessment (LCA)	[ISO 14040; ISO 14044]
	Material Flow Analysis (MFA)	[Brunner & Rechberger., 2016]
Eco-innovation	Eco-ideation Stimulation Mechanisms (ESMs) explorer	[Tyl et al., 2016]
	Eco-innovation methodology for complex industrial systems	[Cluzel et al., 2012]
Project management	Program Evaluation Review Technique (PERT)	[Cook, 1971]
	Agile Management (SCRUM)	[Schwaber & Sutherland, 2017]
Production management	Kanban	[Krajewski et al., 1987]
	Material Requirements Planning (MRP)	[Krajewski et al., 1987]
Quality engineering	Lean Six Sigma	[Arnheiter & Maleyeff, 2005]
	Total Quality Management (TQM)	[Talha, 2004]
Innovation management	Radical Innovation Design (RID)	[Yannou, 2015]
	Design Thinking (DT)	[Brown, 2008]

6.4 Creation of the descriptive language for IE methodologies

The first version of the descriptive language was created based on our empirical knowledge of designing the RID textbook (Appendix B). We found that all the relevant objects of RID can be categorized into five types: *process description*, *performance*, *innovation competencies*, *principle*, and *methods & tools*. The RID process has eleven different representations, which describe RID from four perspectives: a) tasks and deliverables, b) usage-centered & activity-centered, c) data perspective, and d) comparison of the RID process with other processes. The innovation competencies refer to all competencies that can be acquired when executing the RID process. There are nine critical competencies (Moubdi et al., 2018): the ability to tackle

ill-structured problems, system thinking skills, analytical skills, knowledge management skills, problem-solution pairing, creativity, experimenting & prototyping skills, synthesizing skills, and collective intelligence. Principles are the internal rules of RID that guide the innovation process. "Activity theory" is a vital principle, which means that the RID process considers all design issues within the activity-centered design framework. RID contains five methods and tools. Each of them is beneficial for performing design tasks. This descriptive language has been validated by Prof. Yannou, who is at the initiative of the RID methodology. It offers a template (Table 6.1), which serves well to describe and structure RID objects.

6.5 Refinement of the descriptive language for IE methodologies

The results about applying the descriptive language on LCA and ESMs explorer are presented in this section. Two experts (Experts A and B) filled out templates and proposed two new object categories, namely "Concepts" and "Objective of the methodology." After the test, a refined descriptive language was generated, as shown in Table 6.5. It has seven kinds of descriptive objects; each of them is defined. During the meeting, we explained to experts that these definitions are just fields of inspiration. For example, all performance-related information should be recorded in the corresponding place, whatever the performance indicators provided by the methodology or the methodology's performance itself.

Table 6.5: Descriptive language for IE methodologies

Descriptive object	Definition
Objective of the methodology	The main problem solved by the targeted IE methodology.
Process description	A set of information that specifies the characteristics of a process related to the targeted IE methodology. It defines a series of interrelated tasks to design, improve, and install integrated systems of people, materials, information, equipment, and energy. These tasks may be carried out by people, nature or machines using various resources (Wikipedia[8]). Several processes can be provided for a given IE methodology.
Performance	The performance field may cover two different aspects: • The criteria or indicators adopted by the targeted IE methodology for ensuring that a set of activities and outputs meets an organization's goals in an effective and efficient manner (Wikipedia[9]). • An IE methodology's merit, worth and significance compared

[8] https://en.wikipedia.org/wiki/Process_(engineering)

[9] https://en.wikipedia.org/wiki/Performance_management

	with other methodologies used for the same research topics.
Competencies	The skills, personal characteristics, and behaviors developed or needed when performing tasks that design, improve, and install integrated systems of people, materials, information, equipment, and energy (Sanchez, 2000).
Principle	An idea or rule that explains on what the IE methodology stands (inspired by Cambridge Dictionary[10]).
Concepts	Abstract ideas or general notions. They are understood to be the fundamental building blocks of targeted IE methodology (Wikipedia[11]).
Methods & Tools	Methods mean prescribed processes for completing tasks embedded in the targeted IE methodology (Wikipedia[12]). Tools are objects used to extend the ability of an individual to perform the tasks.

[10] https://dictionary.cambridge.org/dictionary/english/principle

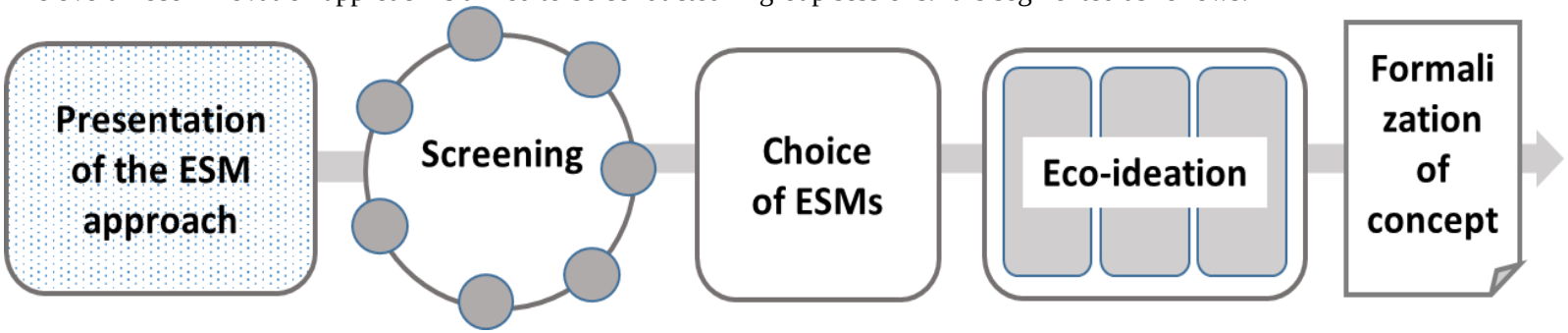
[11] https://en.wikipedia.org/wiki/Concept

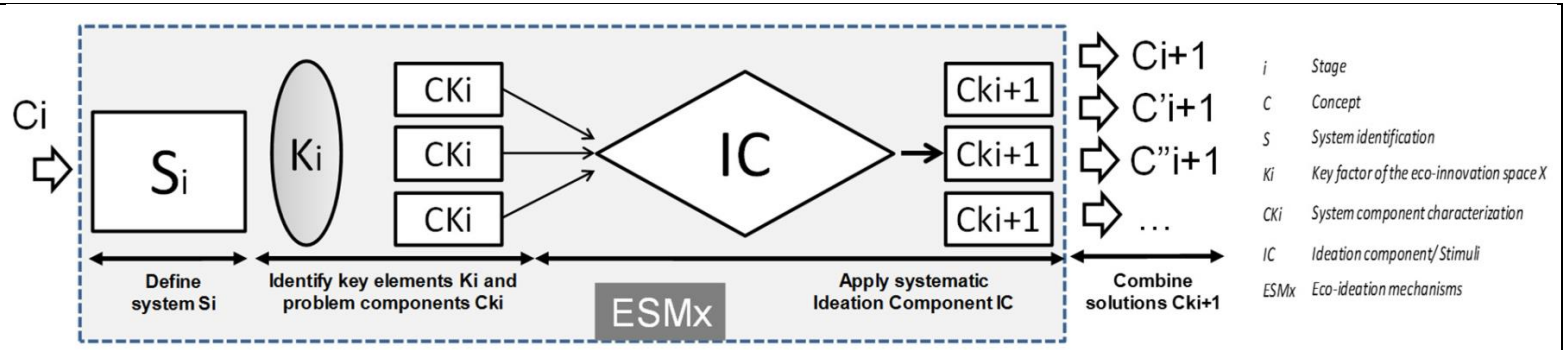
[12] https://en.wikipedia.org/wiki/Method

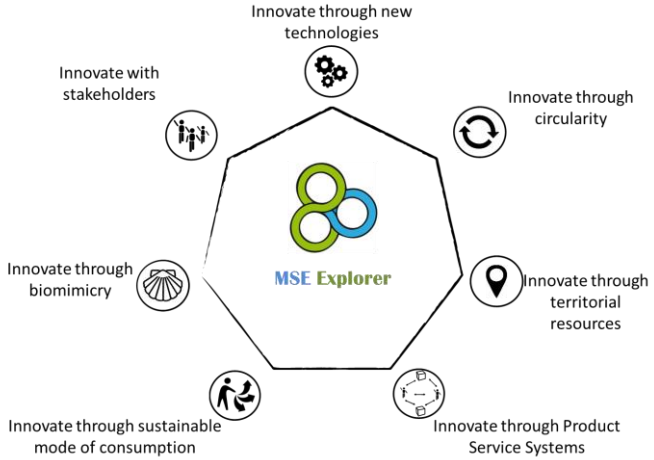
6.5.1 Results about ESMs explorer

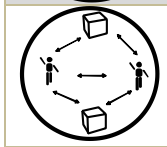
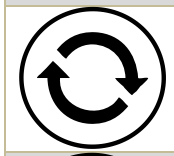
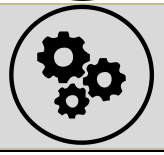
The ESMs explorer expert successfully used the language to provide a concise and comprehensive description of the methodology. The relevant results are shown in Table 6.6.

Table 6.6: Description of ESMs explorer (By Expert A)

Object category	Detailed object
Objective of the methodology	Foster the generation of eco-innovative ideas in SMEs.
Process description	The overall eco-innovation approach is aimed to be conducted in group sessions. It is segmented as follows:  Each Eco-ideation Stimulation Mechanism (ESM) is structured as a small creative process based on three common steps: • Define the initial state of the system, • Identification of key parameters, which are dimensions specific to the mechanisms, • Generation of ideas (through application of ideation components): the initial system is modified, submitted to distortions in time and space to come up with new concepts Cki+1.

	
Performances	• **Sustainable performances of outcomes**: at this early stage of the eco-innovation process, quantitative performances are difficult to establish (based on a simplified LCA for instance). We propose to qualitatively characterize the sustainable performances of the concept at different scales: user, value chain, society. Directs impacts are considered: potential environmental impacts and value created. Indirect impacts and rebound effects are also examined. • **Collective creativity performance**, for instance by measuring a "Width of exploration of design space".
Competencies	The competencies that are expected to be developed thanks to the approach, based on our expertise (since eco-innovation is not a standardized or normalized approach). • Systemic thinking (see principles) • Ability to tackle ill-defined problems • Creative thinking

<table>
<tr>
<td>Principles</td>
<td>Core principles:
• Life cycle thinking: Just as in LCA, life cycle thinking is a mandatory framing for eco-innovative concepts
• Systems thinking: Exploring and expanding the system under study
Seven ESMs help covering meaningful dimensions of sustainability for innovation, see right figure. The 7 ESMs are complementary and may be used one after the other, or in parallel by several groups.</td>
<td> 
</td>
</tr>
<tr>
<td>Concepts</td>
<td colspan="2">Eco-ideation stimulation mechanism (ESM): a transformation process that makes a system evolves according to sustainability principles.
A set of key parameters associated with each mechanism, see below.
<table>
<tr><th></th><th>Title (key parameters)</th><th>Explanation</th></tr>
<tr><td>  </td><td>Innovate with stakeholders
Stakeholders network
Relationship between stakeholders
Captured value, destroyed value</td><td>This ESM raises the question of the stakeholder network, through the value creation for the users, the environment, society, and all other relevant actors value creation for all stakeholders.</td></tr>
<tr><td>  </td><td>Innovate through biomimicry
Physical flows
Informational flows</td><td>This ESM question the similarities between man-made industrials practices and natural strategies of development at several system levels (organ, organism, and ecosystem).</td></tr>
</table></td>
</tr>
</table>

		**Innovate through sustainable mode of consumption** Usage drift Just need	This ESM raises the question of the unsustainable use of products/services and how the system can fit the system to end users and territorial specificities (skills, resources, etc.)
		**Innovate through Product Service Systems** Use cycle and product lifecycle Supply and demand	This ESM raises the question of optimizing the functionality of the materials and energy consumed by the system (use intensity, dematerialization) and of dissociating the product property and the consumption.
		**Innovate through territorial resources** Distribution of territories Territorial capitals: natural resources, industrial ecosystem, social capital, infrastructures	This ESM question the integration of territorial capitals in design strategy: natural capitals, industrial ecosystems, social capitals and infrastructures.
		**Innovate through circularity** Physical flows System architecture	This ESM question the different ways to design a product in closed loop (of material, energy, information). It also questions the question of recycle, repair, and upgradability.
		**Innovate through new technologies** Production process Organisation Materials	This ESM raises the question the possibility to integrate new technologies, new process and organization, new material, in the design of the system.
Methods & Tools	The set of ESMs is associated with a supportive tool for generating eco-innovative ideas. The first version of the tool (spreadsheets) is given in Tyl et al. (2018). The final set of 7 ESMs can be used in group session and are provided in an eco-ideation toolbox with boards and cards.		

Regarding the three qualitative questions asked to the expert, the answers are reported as follows.

- Answer to Q1: Expert A thinks it is **easy** to apply the language for describing the methodology. The only difficulty she reported was “it was less easy about competencies as, as a co-author of this methodology, she did not take the time to explicitly formulate these needed competencies.

However, see though it would have been necessary to do so and, consequently, the descriptive language was inspiring from this point of view.

- Answer to Q2: Expert A feels **confident** that most knowledge can be embedded thanks to the language. She thinks a missing aspect that seems important is the way(s) to impart the methodology's elements to learners. What she concerns is actually the teaching methods of the methodology. However, we believe that the teaching approach is not an invariant element of IE methodologies but a way of transferring knowledge. Each methodology may have multiple effective teaching methods. For example, our university adopts three ways for teaching RID: lecture courses, project-based learning, and serious gaming. This is a valuable topic in IE education: "what could be effective methods of teaching IE methodologies," which is beyond our research scope.
- Answer to Q3: Taking advantage of this practice, Expert A **identified the need** to define the relevant competencies of ESMs Explorer to complement the methodology. She **believes** the template based on descriptive language can be used as a tool for the initial introduction to ESMs Explorer for students.

6.5.2 Results about LCA

Expert B considers that "the descriptive language **very well depicts** the main elements that make a methodology in IE." After adding two missing categories (Concepts and Objective of the methodology), he feels **comfortable** and **at ease** using it to illustrate LCA. Regarding the third validation question, Expert B **agrees** that the identity card he created for LCA is useful for teaching the methodology. However, more explanations need to be provided to the students to understand the card's content fully. He did not report that whether the practice brought him some additional value. The following table shows the results. Most of the contents are extracted from *ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework* and *ISO 14044:2006 - Environmental management - Life cycle assessment – Requirements and guidelines*.

Table 6.7: Description of LCA (By Expert B)

Object category	Detailed object
Objective of the methodology	Assessing environmental impacts associated with all the stages of the life-cycle of a commercial product, process, or service.
Process description	There are four phases in an LCA study. These phases are detailed in the standards, including sub-processes, requirements and guidelines. a) the goal and scope definition phase,

	b) the inventory analysis phase, c) the impact assessment phase, and d) the interpretation phase.
Performances	LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave). The environmental performance of a product system is generally assessed on several indicators associated with several impact categories. Different sets of indicators can be used (mid-point, end-point, single score). An uncertainty analysis is recommended to make the results more robust.
Competencies	Examples of competencies acquired after a LCA training (https://pre-sustainability.com/solutions/training/simapro-and-lca-in-depth/): • Goal and scope definition: you will learn to define the objectives and scope of your study and understand the implications of your methodological choices. • Inventory analysis: you will understand the difference between process and input-output data, learn about various data sources and get tips on how to effectively collect data. • Impact assessment: you will get insight into the four different steps of impact assessment, what each step allows you to do in terms of decision-making and learn how to select the most appropriate method. • Interpretation: you will learn how to check if your conclusions are valid and robust by applying a number of recommended interpretation steps.
Principles	**Principles of LCA** **1) General** These principles are fundamental and should be used as guidance for decisions relating to both the planning and the conducting of an LCA. **2) Life cycle perspective** LCA considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal. Through such a systematic overview and perspective, the shifting of a potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided. **3) Environmental focus**

	LCA addresses the environmental aspects and impacts of a product system. Economic and social aspects and impacts are, typically, outside the scope of the LCA. Other tools may be combined with LCA for more extensive assessments. **4) Relative approach and functional unit** LCA is a relative approach, which is structured around a functional unit. This functional unit defines what is being studied. All subsequent analyses are then relative to that functional unit, as all inputs and outputs in the LCI and consequently the LCIA profile are related to the functional unit. **5) Iterative approach** LCA is an iterative technique. The individual phases of an LCA use results of the other phases. The iterative approach within and between the phases contributes to the comprehensiveness and consistency of the study and the reported results. **6) Transparency** Due to the inherent complexity in LCA, transparency is an important guiding principle in executing LCAs, in order to ensure a proper interpretation of the results. **7) Comprehensiveness** LCA considers all attributes or aspects of natural environment, human health and resources. By considering all attributes and aspects within one study in a cross-media perspective, potential trade-offs can be identified and assessed. **8) Priority of scientific approach** Decisions within an LCA are preferably based on natural science. If this is not possible, other scientific approaches (e.g. from social and economic sciences) may be used or international conventions may be referred to. If neither a scientific basis exists nor a justification based on other scientific approaches or international conventions is possible, then, as appropriate, decisions may be based on value choices.
Concepts	See **section 3 – Terms and definitions** of ISO 14040 standard. Some concepts: life cycle, co-product, process, elementary flow, allocation, functional unit, intermediate flow, input, output, product system, reference flow, system boundary, unit process, characterization factor, impact category, critical review…
Methods & Tools	**Methods:** See *ISO 14044:2006 - Environmental management - Life cycle assessment – Requirements and guidelines*, which detail the different phases, stages of these phases and provide methods for implementing them. See also the ILCD Handbook from the European Commission that provides detailed guidance and methods: https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf Lots of papers propose methods putting into practice LCA in different contexts, for different purposes, for robustifying some parts of the methodology, and so on. See for example the International Journal of Life Cycle Assessment : https://www.springer.com/journal/11367

	Tools: LCA software: OpenLCA, Gabi, Simapro, Bilan Produit, etc. Databases: Ecoinvent, etc. Impact Assessment methods: Recipe, CML, and Eco-Indicator.

6.6 Validation

Finally, in a third stage, we invited five relevant IE experts to test the proposed language by describing the nine methodologies during the validation stage. Each expert may be responsible for one or more methodologies (Table 6.8).

Table 6.8: Responsible experts for the IE methodologies

IE discipline	IE methodology	Expert
Eco-design	Material Flow Analysis (MFA)	C
Eco-innovation	Eco-innovation methodology for complex industrial systems	D
Project management	Program Evaluation Review Technique (PERT)	E
	Agile Management (SCRUM)	E
Production management	Kanban	F
	Material Requirements Planning (MRP)	F
Quality engineering	Lean Six Sigma	D
	Total Quality Management (TQM)	F
Innovation management	Design Thinking (DT)	G

Each methodology in Table 6.8 has been comprehensively described by experts using our descriptive language. The detailed methodologies' descriptions are presented in Appendix C. Below, we introduce and discuss the answers given by experts to validation questions (Table 6.9).

About the first validation question, the five experts involved in our experiments all feel that the proposed descriptive language for IE methodologies is clear, and it is easy to apply it for describing their designated methodologies. They believe each category in the language is necessary. The experts reported that they encountered a common problem, i.e., spending much time reviewing the methodologies to ensure that sufficient information can be filled in the template. Of course, this is not the problem of the language itself.

Most of the experts feel confident that they have listed the core of the methodologies. Three experts expressed the importance of the practical applications of IE methodologies. We agree it is necessary to provide such examples in the template (*Process*) so that learners understand the theoretical knowledge and apprehend how to apply it.

Regarding the last question, experts think the description they gave could serve as introductory tools of learning IE methodologies for students. However, it is necessary to provide more detailed teaching content to meet the needs of students. Experts consider that this practice has brought them three aspects of value:

- Allow them to recall and better organize their knowledge about IE methodologies;
- Improve their abilities for imparting IE methodologies to others;
- Get a logical template for organizing teaching materials.

To sum up, the language we proposed has been successfully applied to describe nine IE methodologies. Experts consider it easy to use and effective.

Table 6.9: Answers of validation questions

Expert	Q1	Q2	Q3
C	• Each objects of the descriptive language is **clear** enough to start filling the template; • It is **easy** to provide and organize sufficient information about MFA by using the template.	• The **most important knowledge and competencies** about MFA has been listed based on the descriptive language.	• The identity card of MFA can introduce the methodology to learners briefly; • In order for learners to better understand the methodology, some examples of MFA applications should be provided; • The exercise allows him to review and better sort out the knowledge of MFA.
D	• The template is **easy** to understand thanks to the definitions of descriptive objects; • He **did not encounter any difficulties** in describing the eco-innovation methodology for complex industrial systems and Lean Six Sigma but spent some time reviewing them.	• He feels **confident** that the core of these methodologies has been listed.	• When doing this practice, he feels like a student summing up what he know about the two methodologies; • The templates he filled in provide a simple introduction to the two methodologies, useful for learners.
E	• It is **convenient** to use the template for describing PERT and SCRUM; • Categories like *Process description*, *Concepts*, *Principles* are **more comfortable** to fill comparing with others; • It is a little bit complicated to list all the useful *Tools* because of the bad memory; • He encountered difficulties filling the category *Competencies* for PERT because he was unsure whether to mention some apparent abilities, like mathematical calculation;	• Many software can be used as the *Tools* for supporting SCRUM and PERT, so he only listed some commonly used tools; • For other categories, he feels **confident** to provide most of the knowledge; • He suggested defining the sequence for fill out the seven categories, which may improve the user experience for applying the template.	• This practice allows him to review these methodologies with the template, developing his capacity to introduce them to others; • These identity cards are beneficial for new learners. However, they still require a teacher to provide more details and answer their questions.

	• He believes that the category *Objective of the methodology* is **very important** because often, people are too used to apply a methodology directly and ignore why they use it.		
F	• She feels **at ease** describing Kanban, MRP, and TQM with descriptive language; • She spent more time defining the purpose and appropriate context of each methodology as accurately as possible; • For her, Kanban itself is a practical method to achieve just-in-time manufacturing (JIT);	• She **believes** that the most important information for each methodology has been listed; • She suggested that when describing the *methodology's objective*, examples should be given to illustrate the application of the methodology.	• Through this practice, she conducted a systematic review of the three methodologies; • The templates she filled in can provide the initial introduction to the three methodologies to learners; • She believes that the template she filled out can provide **sufficient guidance** for students when applying these methodologies.
G	• It is **easy** for him to describe DT based on the template; • He found that certain knowledge may be related to multiple categories, so he needed to think about how to arrange it reasonably, e.g., the se of indicators "Desirability/Viability/Feasibility" is relevant to categories *Performances* and *Concepts*.	• He **believes** that most of the knowledge of DT has been put in the template; • He feels it is important to introduce the best books and history of DT in the template; • He emphasized the importance to present how things happen or are put into practice in the *Process* slot.	• This template is **easy** and **logical** to fill; • It asks good questions to pedagogically present materials; • He believes the DT identity card is a **very good memento** for students to start learning the methodology.

6.7 Conclusion

This chapter addresses the question that “How to describe and structure all relevant objects for a given industrial engineering (IE) methodology?” We put forward a descriptive language that decomposes a given IE methodology based on seven invariant objects. Experts successfully practiced the language on nine IE methodologies. According to validation results, it is a useful tool for describing any IE methodologies briefly but sufficiently.

This descriptive language is essential to continue our research. In the next chapter, we introduce it into the generic V-model for constructing an adapted V-model for SGs in the field of IE. We employ the language to define explicit design purposes for the game and inspire the design of the different SG elements identified in Chapter 4.

We insist that the proposed language can be easily extended to other contexts. For example, as an instrument to formulate teaching objectives for all types of IE courses and training. Teachers can also use it as an assessment tool to understand how well students have mastered a particular IE methodology and then give useful feedback.

Chapter 7. Proposition of an adapted V-model for serious games on industrial engineering methodologies

In the previous chapters, we have proposed: 1) a generic V-model for designing serious games (SGs), which defines the tasks, expected outcomes, participants of each design stage; 2) a descriptive language for industrial engineering (IE) methodologies. As we noticed that teachers in the IE domain encounter some difficulties designing SGs due to lack of expertise, we now develop a customized V-model for SGs on IE methodologies by combining the two contributions mentioned earlier. More specifically, for each invariant element of a given IE methodology, we explain how it can inspire SGs objects' design at a particular stage. This chapter aims to answer the fourth research question, "How to design effective serious games that balance fun and learning to teach industrial engineering methodologies?"

7.1 An adapted V-model for IE serious games

This section constructs an adapted V-model based design framework for IE serious games (SGs) through two steps. First, we make a mapping between SG design objects and IE methodology descriptive elements, i.e., to explain how each invariant element of IE contributes to the design of SGs objects. Then we introduce their relationship into the V-model to illustrate at which stage these descriptive elements are beneficial to the design of SGs.

7.1.1 Mapping SG design objects with IE methodology descriptive elements

In total, we have identified eight generic SG design objects (*Design purposes, Design constraints, Story, Gameplay, Game props, Evaluation, Aesthetics, and Information*) and seven invariant elements (*Objective of the methodology, Process description, Performances, Competencies, Principles, Concepts, and Methods & Tools*) for describing IE methodology. Figure 7.1 associates these objects and illustrates their internal connection.

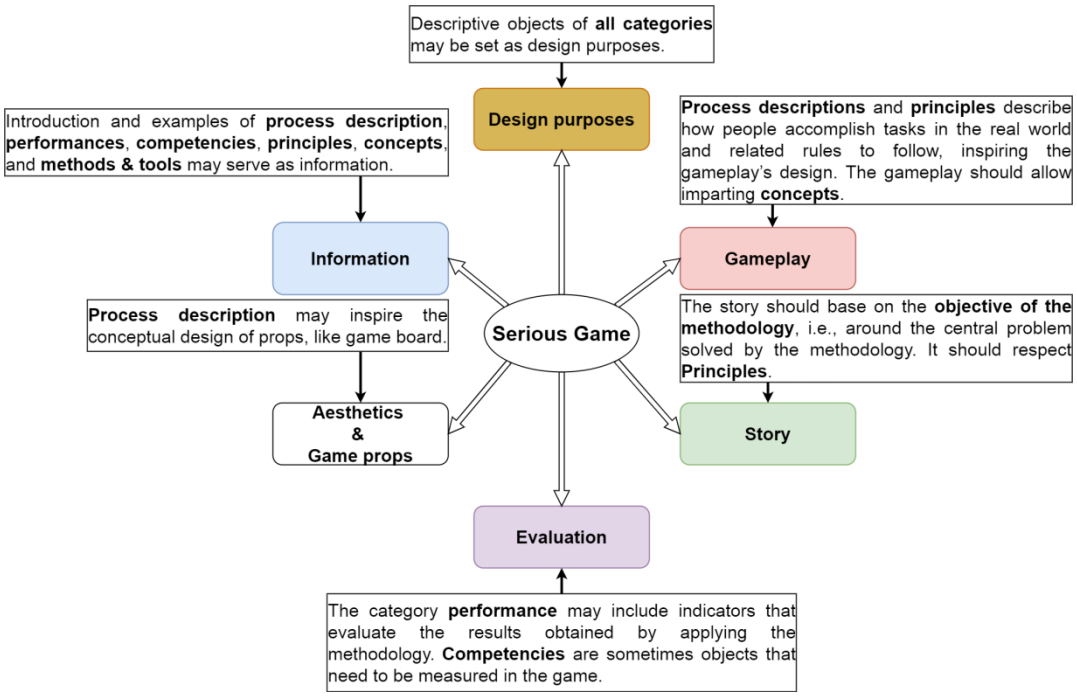


Figure 7.1: Mapping SG design objects with IE methodology descriptive elements

Design purposes

The most important purpose if that playing the SG must be a living and convincing user experience that results in proving the usefulness of the IE methodology and the circumstances on which it can be applied. Further, the design objectives can relate to any of the seven invariant elements of the descriptive language or subsets of these elements. SG designers are recommended first to utilize the language to describe the targeted IE methodology and then choose and prioritize the knowledge they want to let users learn/experiment/understand. The selected knowledge is the learning objective of the SG.

Information

The design purposes of SG formulated by applying the descriptive language can help deduce the information that should appear in the game.

- Suppose we are designing an SG for teaching LCA. One of the design goals is to make players understand a list of concepts, like "life cycle, co-product, process, elementary flow, allocation, etc." Then in the game, we must provide players with definitions and examples of these concepts.

Story

SGs offer unique and engaging environments to support situated learning (Taisch & Fradinho, 2013). Students acquire and practice the knowledge when immersing in the game scenarios that imitate reality. To ensure the authenticity of the SG environment, the story's design should not conflict and be in accordance with the principles of the IE methodology in reality.

- For instance, one of the essential principles of LCA is the environmental focus. LCA addresses the environmental aspects and impacts of a product system. Economic and social aspects and impacts are, typically, outside the scope of the LCA. Therefore, the story of an LCA game needs to respect this principle. It is unreasonable to create a plot like "players are working in a company that arbitrarily destroys the environment for economic benefit."

A story conceived based on the "objective of the methodology" is the foundation for creating this active learning experience for players.

- For example, LCA's objective is "assessing environmental impacts associated with all the stages of the life-cycle of a commercial product, process, or service (Ilgin & Gupta, 2010)." To provide players with the opportunity to practice LCA, we can design a story on the basis of a product development project. Players, who act as eco-designers in the game, are responsible for estimating the product's environmental impacts throughout its life by adopting LCA.

Evaluation

IE methodologies usually contain some performance indicators to evaluate the results obtained. These indicators are also useful for measuring players' performance in the SG. "Competencies" are the skills developed or required when performing the tasks supported by IE methodologies. These competencies are usually the design purposes of the game. Designers need to think about how to measure changes in these competencies of players when playing.

- For example, one indicator applied in LCA is "climate change." In an LCA game, we can ask players to compute the potential greenhouse gas emissions caused by a given product and compare their results with the convincible answer offer by LCA experts. In this way, we incent players to interrogate their actions in terms of the IE methodology performances.
- One competence required for the impact assessment phase of LCA is to select the most appropriate method. Therefore, in an LCA game, we can measure players' performance by observing whether they can choose a reasonable method according to their needs.

Aesthetics & Game props

Here, we strongly believe that, for an IE methodology, the graphical representations of the process for this methodology may inspire game props' design, especially the game board. These representations vividly and succinctly describe the process of applying the methodology to carry out related activities. The game board of an IE game should depict the player's entire game journey of practicing the methodology.

- For example, the process embedded in LCA has four stages (Figure 7.2; ISO 14040): goal and scope definition, inventory analysis, impact assessment, and interpretation. These stages must be reflected on the game board, of course, in an attractive way.

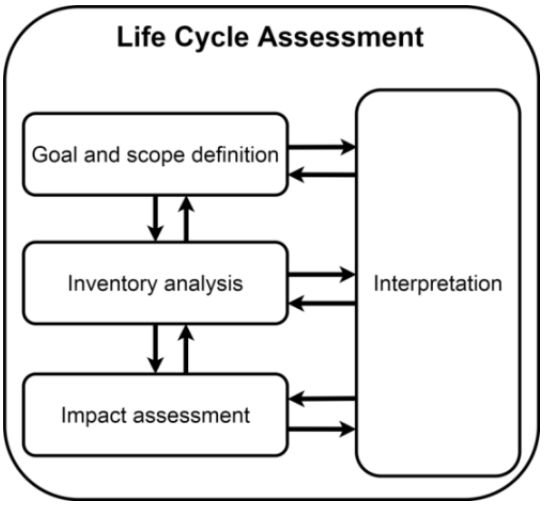


Figure 7.2: Stages of a Life Cycle Assessment (adapted from ISO 14040)

Gameplay

The gameplay of an IE game defines what the player needs to do and how to do it while experiencing the game. It can be extracted and then refined based on "process descriptions" and "principles," which detail how people complete relevant tasks in the real world and the rules that must be followed. In addition, "concepts" deeply influence the design of the gameplay. Each IE methodology contains specialized vocabulary. Designers need to design the game rules to allow players to receive and utilize these concepts in a natural and interesting way.

- For example, the second stage of LCA includes data collection and the compilation of the data in a Life Cycle Inventory (LCI) table (Guinée & Heijungs, 2017). One way of data collection is to use the available databases. As an SG, it is boring to provide this data directly to the player. Instead, we need to imagine a challenging and exciting means to accomplish this task.
- One principle of LCA is iteration. The individual phases of LCA use the results of the other phases. Thus, an LCA game's gameplay should allow players to review and apply the results gained at a previous game level to solve the next game level's problems.
- ISO 14040 standard defines 46 terms adopted in LCA, e.g., life cycle, life cycle impact assessment, inputs, and outputs. In order to convey these concepts, we can imagine basic gameplay that "players need to apply LCA to conduct the compilation and evaluation of the inputs, outputs, and potential environmental impacts of a given product system throughout its life cycle."

The descriptive element "process description" is beneficial in designing several SG design objects and defining the system layout & interfaces.

- An LCA game may have four game levels corresponding to the four stages of the methodology. The expected outcomes of each stage defined by LCA can be used to describe what kind of results the player needs to achieve at each level to enter the next level, i.e., the interfaces between levels.

7.1.2 Building an adapted V-model for IE games

In the previous subsection, we explain how each invariant descriptive element of a given IE methodology can stimulate the design of different SG objects. Their relationships are now integrated into the generic V-model, resulting in an adapted V-model for IE games.

Figure 7.3 shows the adapted V-model. To keep it concise, we simplify the description of pre-validation and pre-verification activities and use abbreviations to indicate different descriptive elements (Table 7.1).

Table 7.1: Abbreviations of IE methodology descriptive elements

Name	Abbreviation
Objective of the methodology	OM
Process description	PD
Performance	Per
Competencies	Com
Principle	Pri
Concepts	Con
Methods & Tools	M&T

The descriptive elements of an IE methodology offer inspiration on the conceptual design of the system layer's objects so as to influence the related design objects in the other two layers. The work packages, expected deliverables, and participants of each stage in the adapted V-model are the same as those of the generic V-model. Therefore, we will not repeat them here.

There are two prerequisites for novice designers to use this adapted V-model. First, the description of the targeted IE methodology must be delivered. Second, they should understand the generic V-model so as to be familiar with the SG design objects. Finally, they will be able to use this customized V-model for linking relevant objects of an SG and the methodology.

According to the analysis of the previous studies on SGs, there is no research focusing on the design of IE games, making it difficult for teachers in our domain to sufficiently transfer their expertise (knowledge of IE methodologies) into the game. The adapted V-model provides them with expertise in SGs design and guides them through the transfer process.

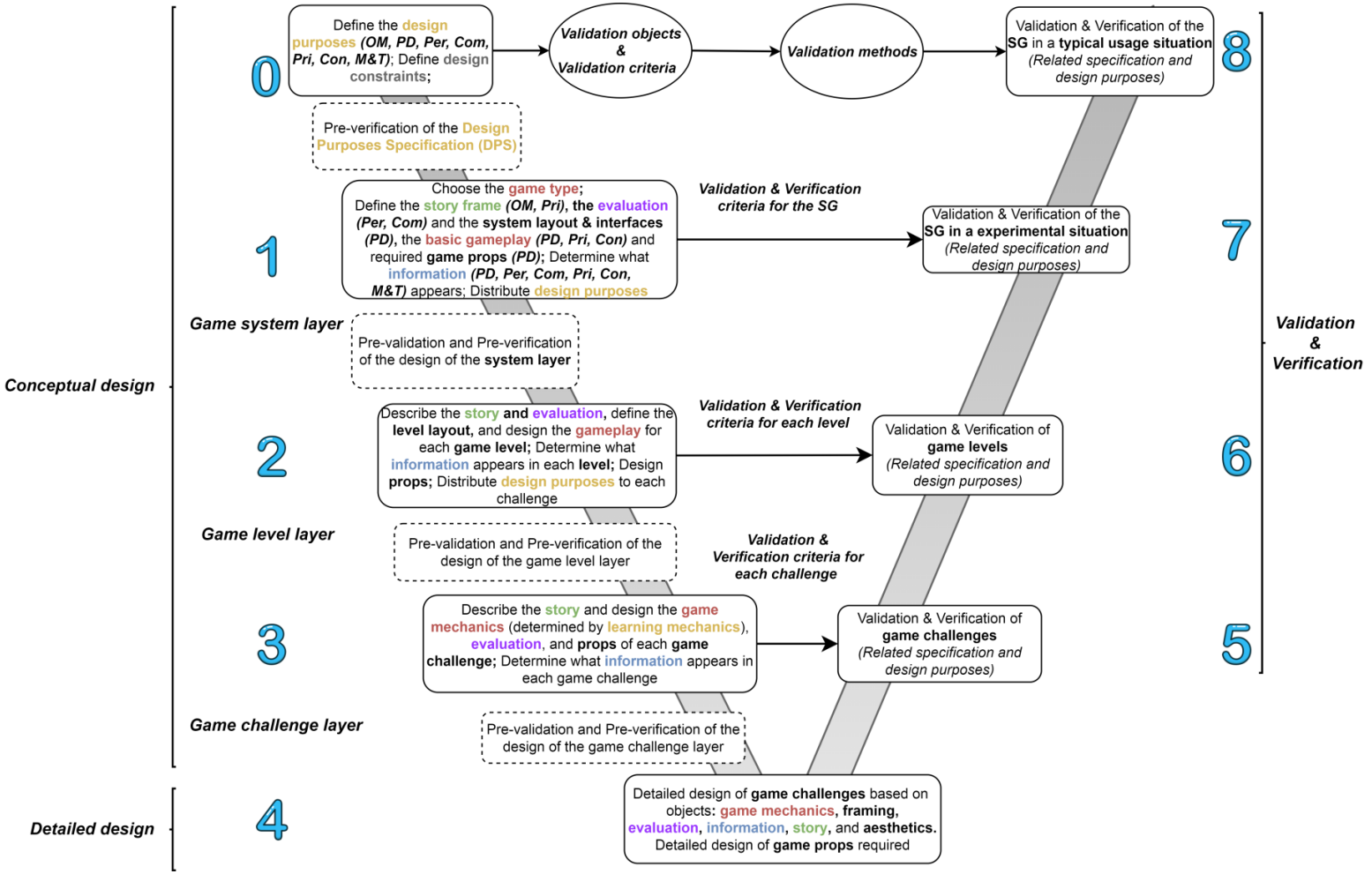


Figure 7.3: Adapted V-model for IE serious games

7.2 Conclusion

In this chapter, based on IE methodology's descriptive language and the generic V-model for SGs, we put forward an adapted V-model for SGs of teaching IE methodologies. We show how the seven descriptive elements of the IE methodology inspire the creation of different SG design objects. This model creates the possibility of designing IE games for people who have no experience. First, it presents a complete design process of SGs. Then it proposes a way to describe and structure the knowledge related to IE methodologies. Finally, it intuitively points out how to design SG elements based on methodological objects. To validate and exemplify the adapted V-model, we apply it to design an SG on innovation management.

Chapter 8. Design of an innovation game: application to Radical Innovation Design methodology

This chapter introduces our fifth contribution, a serious game (SG) on Radical Innovation Design (RID) methodology designed based on the adapted V-model. We present the results of the conceptual and detailed design phases. More specifically, we first introduce the RID game's design purposes and then provide the specification of the game system layer. Due to time constraints, we only further designed the third level of the game. The different design objects of this game level are described. Finally, the prototype is displayed. The game is experimented and validated in Chapter 9.

8.1 Introduction

In the following sections, we illustrate the process and outcomes of designing the Radical Innovation Design (RID) serious game (the left part of the adapted V-model). Figure 8.1 shows how these contents are arranged in the chapter. The design purposes of the RID game are stated in section 8.2. Then section 8.3 presents the specification of the system layer of the RID game. The description of the game level and game challenge layers is given in section 8.4. Finally, we show the prototype in section 8.5.

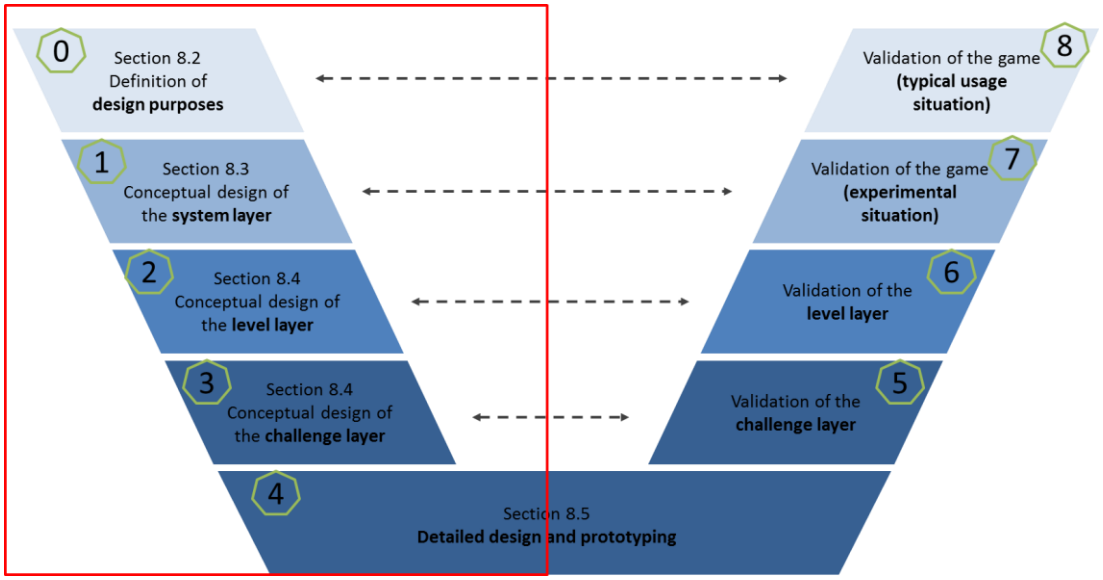


Figure 8.1: Organization of Chapter 9

8.2 Design purposes specification of the RID game

The first stage of the adapted V-model is to define the *design purposes*. This section presents the design purposes specification (DPS) for a serious game (SG) on the RID methodology (Yannou, 2015). RID is a novel, complete and well-structured innovative design methodology that prioritizes the improvement of the user experience within a field of activity. The game aims at disseminating the most structuring and original aspects of the RID methodology, like cognitive concepts, process description (tasks & deliverables), performances, tools, methods, principles, and paradigms.

RID game will be employed as an innovative teaching tool for delivering a Novice-RIDer label (Appendix D) to participants (called users further) after a one-day training session (it defines our expected Minimum Viable Product). If possible, we would like the SG to be tunable to adapt to a particular user type. This is why we will consider personas to feature these particular expected audiences.

The following subsections first describe the process for defining the RID game's design purposes and then present all of them.

8.2.1 Process for defining the design purposes

To specify what should be learned and experienced by players when playing the game, we followed the process shown in Figure 8.2. The process consists of five steps, which are detailed in subsections 8.2.1.1~8.2.1.5

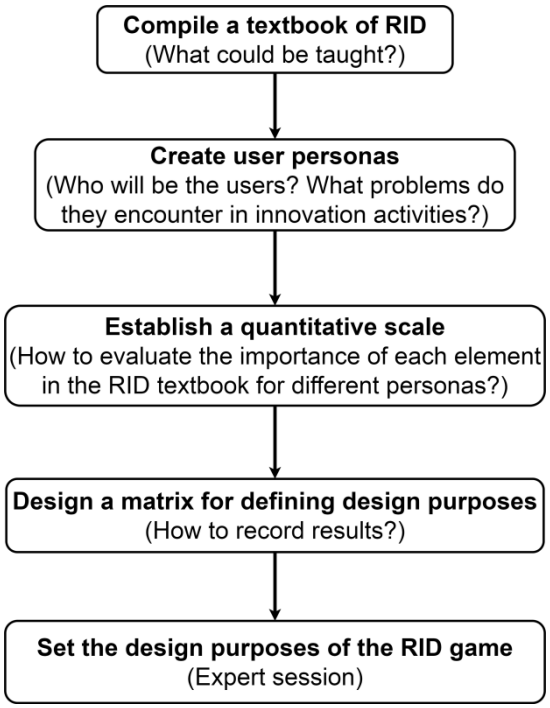


Figure 8.2: The process for defining the design purposes of the RID game

8.2.1.1 Compile a textbook of RID

For the first step, we compiled a RID textbook to establish a problem domain boundary. A problem domain boundary identifies which elements will be included and which elements will be excluded. It is a typical step in serious game design to identify and define the education problem (Aslan, 2016). The objective is to collect RID's salient points - how we can describe it, what can be taught - to result in a descriptive language of RID. We did it from the RID Guidebook v13.0 by Yannou (2020), which has been produced in that spirit to embrace all aspects to know apart the necessary competencies. This is why we completed it with the competency framework for "radical innovation in need seeker strategy" proposed by Moubdi (Moubdi et al., 2018). Then, Prof. Yannou validated that this textbook was representative of the typical RID corpus. Finally, we summarized it as an ontology to highlight and mention the different objects that compose the RID methodology. Doing so, it has been the descriptive language to define the teaching objectives of any kinds of RID training. The RID ontology is finally constituted by six main classes: innovation competencies, process description, structuring concepts, performances, methods & tools, and principles & paradigms. Each of them corresponds to several elements (or instances) in the textbook (Table 8.1). RID ontology inspires us to generate the descriptive language of IE methodologies introduced in Chapter 6.

Table 8.1: RID textbook elements

Category of the element	Name of the element
Process description (Description of tasks and deliverables)	The general breakdown
	The detailed representation
	The actigram representation
	Navigation dashboard of the RID CSCW system
Process description (Usage and activity perspectives)	The usage-driven representation
	The activity-centered representation
	The representation as a transformation of activity
Process description (Data perspectives)	The data streaming representation
Process description (Comparison of the RID process with other processes)	The Usage-Driven Innovation Process (UDIP) model
	The representation as a production process
	The problem and solution duality
Performances (Comparison of RID with known design methodologies)	Comparison of innovation methodologies along design stages: Design Thinking (DT) and RID
	Unique Selling Propositions (USP) of RID
Performances (Innovativeness Indicators)	Innovativeness indicators are introduced in the section "Principles and paradigms"
Innovation competencies	General innovation competencies and relevant specific innovation competencies
Principles and paradigms	Reframing by the problems/needs
	Reframing by the activity
	The innovativeness indicators UNPC
	Nature of an idea
	Intensity of an idea
	RID philosophy of innovation

	Activity field and three rules of classicism
	Thinking inside the box
	Disruption
	The four dimensions of a value bucket
Methods and tools (Methods)	Computation of the value buckets (DSM-VB algorithm)
	Determination of the ambition perimeter
	The BMC-RID
Methods and tools (Tools)	RID creativity tool
	UNPC monitor tool

8.2.1.2 Create user personas

Personas are "fictitious, specific, concrete representations of target users (Pruitt & Adlin, 2006)," which are a commonly used tool in product and service design. The benefits of personas have been widely described in the literature (Cooper, 1999; Grudin & Pruitt, 2002; Ma & LeRouge, 2007; Miaskiewicz & Kozar, 2011), such as "empathy creation," "audience focus," "problem scope definition" and "challenge assumption". We employed this tool in the RID serious game design process to understand and characterize SG users' archetypes. In doing so, we could better identify users' needs to define the scope of the problem, that is, the RID game's design purposes. We had the intention to design a minimum viable product (MVP; Moogk, 2012) with minimal features to satisfy all users and, in a second stage, we wanted to keep the possibility to propose configurable serious games (Omelina, 2012) adapted to the specific expectations of a given persona. Our ambition is that the game will be used for higher education, executive education and professional training. We created three user personas for students (see more details in Appendix E): an engineering student, a design student, and a business student since they are the primary groups of students participating in the RID training. We also proposed three professional personas: a user experience designer, a business consultant, and a startup founder. They seem appropriate as they may potentially be attracted by RID because of the obvious utility in their professional context and missions. For example, startupers can plan the maturation of their technology by using RID several times so as to find value buckets in the markets potentially linked to the technology (Bekhradi, 2018).

8.2.1.3 Establish a quantitative scale

After clarifying potential users, we needed to develop one or several measurement scales to distinguish the importance of different elements in the RID textbook according to the persona's needs. The standard should also provide a language for describing design purposes. We adopted the Numerical Rating Scale (NRS) to develop this scale, which is a commonly used tool in survey research for quantifying qualitative data such as pain, feelings, and product satisfaction (Treiblmaier & Filzmoser, 2011). We employed it to quantify the relevance of each element to the design purposes. More and more educators utilize Bloom's taxonomy (Krathwohl and Anderson, 2009) to specify the assessable learning goals of the curriculum (Starr, 2008), which is conducive to the design of teaching content and the

evaluation of the course quality. To predefine the game element "content" (all the data that the player can access when playing the game) and plan game testing in advance, we decided to describe the learning outcomes of the RID game based on Bloom's taxonomy. Teaching and learning centers have compiled lists of measurable verbs aligned with the six categories that comprise Bloom's taxonomy to support the process (Figure 8.3; Stanny, 2016).

Knowledge	*f*	Understand	*f*	Apply	*f*	Analyze	*f*	Evaluate	*f*	Create	*f*
cite	17	classify	18	act	19	analyze	24	appraise	22	arrange	22
define	21	compare	11	apply	22	appraise	11	argue	12	assemble	14
describe	14	convert	13	calculate	10	categorize	19	assess	17	combine	14
identify	20	defend	12	choose	11	classify	10	choose	10	compose	19
label	21	describe	22	compute	10	compare	24	compare	18	construct	29
list	27	discuss	21	construct	13	contrast	19	conclude	13	create	19
locate	10	distinguish	12	demonstrate	20	criticize	11	criticize	11	design	24
match	14	estimate	11	dramatize	16	diagram	12	critique	14	develop	18
memorize	10	explain	28	employ	16	differentiate	20	defend	15	devise	13
name	22	express	17	illustrate	18	discriminate	11	estimate	15	formulate	18
outline	11	extend	11	interpret	15	distinguish	21	evaluate	16	generate	11
recall	24	generalize	11	manipulate	10	divide	12	judge	25	invent	10
recite	12	identify	14	modify	12	examine	18	manage	15	modify	10
recognize	14	infer	15	operate	17	infer	14	prepare	12	organize	21
record	13	interpret	17	practice	15	outline	10	rearrange	19	plan	21
relate	11	locate	10	prepare	11	point out	12	reconcile	12	prepare	12
repeat	20	paraphrase	22	produce	13	question	12	set up	15	produce	13
reproduce	11	predict	12	relate	12	relate	17	synthesize	16	rate	21
select	16	recognize	11	schedule	11	select	12			revise	12
state	23	report	10	show	13	separate	10			write	17
		restate	15	sketch	17	subdivide	10				
		review	15	solve	19	test	14				
		rewrite	12	use	25						
		summarize	20								
		translate	21								

Figure 8.3: Measurable verbs identified for a level of Bloom's taxonomy for describing student learning outcomes (Stanny, 2016)

The quantitative scale is established based on a broad context: all training for industrial engineering (IE) methodologies using SGs (Chapter 6). It should help designers of these SGs define design purposes and write the design purposes specification (DPS) document. The quantitative scale (Table 8.2) has seven levels. Level 0 means that the element will not be used in serious game design, and there is no design purpose related to it. Levels 1 to 6 correspond to the six layers (From "Remember" to "Create") of learning from the revised version of Bloom's taxonomy (Krathwohl and Anderson, 2009). Each level is defined based on measurable verbs identified for a level of Bloom's taxonomy. The definition of each level consists in two parts: 1) learning experiences related to the element (how players interact with it?); 2) learning outcomes related to the element (What should players acquire after playing?). When applying the scale to the RID game design, two examples are offered to help RID experts understand each level.

Table 8.2: The quantitative scale for defining the design purposes based on Bloom's taxonomy (Krathwohl and Anderson, 2009)

Level	Level definition (for any IE methodology)		Example 1 on RID SG DSM-VB method & Principle of four segmentations		Example 2 on RID SG Four innovativeness indicators & Principle of the UNPC tool	
	During the game	**After the game**	**During the game**	**After the game**	**During the game**	**After the game**
0	The element is not useful to be included in the game.	There is no design purpose related to this element.	The "DSM-VB method" will not be included in the game. There is no evocation of it at all.	There is no design purpose related to the "DSM-VB method."	The four innovativeness indicators are not useful for designing the game.	There is no design purpose related to the "four innovativeness indicators".
1	**The element should be mentioned** in the game but not precisely explained or exemplified.	A player should have the **ability to memorize** related information to gain the interest to deepen by oneself without the necessity to fully *understand*.	The "DSM-VB method" is briefly mentioned in the game as a way of crossing the four dimensions: user profiles, usage situations, problems, existing solutions, but the algorithm for computing the end value buckets is not provided.	A player should be able to recall the definition of the value bucket and the four segmentations.	The four innovativeness indicators should be briefly explained in the game.	A player should be able to recall the related information of the four indicators.
2	**The element should be sufficiently explained or exemplified in the game but will not be practiced by players**.	A player should have the **ability to explain** its definition, principle and interest in his or her own words.	The "DSM-VB method" is well described, especially the nature of entry matrices and the questions asked to fill them, and also the meaning of the end value buckets. But the	A player should be able to explain the principles for filling entry metrics and the meaning of the end value buckets.	The four innovativeness indicators (definition, examples, and value) should be precisely introduced in the game. They can also be used as indicators	A player should be able to explain the motivations to use UNPC indicators for selecting a subset of promising innovative ideas. However, s/he is not able to apply them.

			details of the computational logics as well as the process of interpretation and validation of the end value buckets are not presented. At most, the notion of quantified value bucket expressed as a 4-tuple on the four dimensions could be used in the SG.		for reflecting game progress.	
3	**The element is precisely explained or exemplified, and players must practice it at least in a simplified manner**.	A player should have the **ability to apply it in a simplified manner** in a similar real situation or, at least, to consider differently the real situation.	A simplified version of filling the entry matrices of the "DSM-VB method" and the approximated computation of the end value buckets is simulated in the SG.	A player should be a prescriber for using the "DSM-VB method" on a real innovation project.	The four innovativeness indicators are precisely explained. Players can apply them for evaluating an innovative idea based on the given arguments.	A player should be able to roughly rate UNPC indicators (with green-orange-red lights for instance), according to the description of an innovative idea or project. And consequently, to decide if the idea/project merits to be pursued or abandoned.
4	**The element is precisely explained or exemplified in the game and players must practice it in**	A player should have the **ability to analyze** the related real situation in order to categorize, contrast the possible solutions	A full use of "DSM-VB method" must be practiced in the game from the filling of entry matrices, to the computation of the	A player should have the ability to analyze the context of innovation to fill the four entry matrices and then generate	The four innovativeness indicators are precisely explained and players can contrast two given	A player should have the ability to gather a sufficient number of relevant evidence under each U/N/P/C categories for an

	a non-trivial manner. When playing, players must **take initiatives to analyze** the game situation in order to *categorize*, *contrast* the possible solutions, and make informed decision.	and make a decision.	end value buckets. In addition, the players should "play" with the method in improving the entry data (modifying the categories of the 4 dimensions or the matrix data) until the end value buckets are totally validated.	end value buckets.	innovative ideas based on the relevant evidence under each U/N/P/C.	innovative idea/project, to assess their impact and corresponding certainty. This is the basic mechanism of the UNPC monitor tool.
5	**The element is practiced in a non-trivial manner. The player is able to evaluate the benefit of the element in the game situation.**	The value generated when applying the element in real situation must be **appraised**. The player must be able to apply differently the element, to *compare* the two results, to *argue* while choosing the best, and to *synthesize* the whole action.	The "DSM-VB method" is fully applied (see above). Players are asked to justify their end value buckets.	A player should have the ability assess the quality of the entry categorizations and the potential of value creation of the whole set of value buckets. For instance, the player should be able to assess for which user profile, which usage situation and which problem are priorities to innovate.	The four innovativeness indicators are precisely explained. Players are asked to gather evidence for evaluating a set of innovative ideas and choose the best idea for convincing reasons.	In addition to the above, a player must be able to concurrently apply the UNPC monitor tool to several competing innovative ideas. Moreover, to pursue the evidence gathering on the appropriate idea(s) until the idea evaluations are sufficiently mature to choose the most promising idea with motivating reasons.
6	**The element is practiced in a non-trivial manner. The**	The element is fully mastered by the player, i.e. not only he is able to apply it in a	The "DSM-VB method" should be not only fully applied but also used in	A player should have the ability to apply the method in creative manners (see	The player is considered creative when he/she can sometimes decide to	A player should have the ability to apply the method in creative manners (see

	player is able to create around the element in the game situation.	non-trivial manner and evaluated its benefits, but he is able to **be creative** with it. It means that the player can decide when to apply the element, *invent* a new way to apply it as to *combine* it with another, proposing useful *modifications* or *arrangements*. In addition, he is able to *plan* its application and to clearly *formulate* its expected results.	creative manners. For instance, one could start applying it with broad grain-size categories for the four dimensions. Then, for the most important value buckets, a second finer and focused application of the method could allow for zooming on selected sub-categories. This practice is reserved for highly experimented practitioners.	the left) in a real situation.	skip the use of the UNPC monitor tool or, conversely, to discover during its use on a subset of innovative ideas, that a given idea can be split into different idea variants, then adapting the UNPC monitor process.	the left) in a real situation.

8.2.1.4 Design a matrix for defining design purposes

After creating the quantitative scale, we designed a matrix to record all design purposes (Figure 8.4). Each column in the matrix corresponds to an element in the RID textbook, and each row corresponds to a user persona. The row "comments" was created to record some key arguments to support decisions. The column "unique design purposes" was created for recording the design purposes set specifically for each persona. The row "common design purposes" was created for recording the design purposes set for all personas (features of the minimum viable product). When filling the matrix, the executors (three RID experts) used the quantitative scale to indicate how relevant each element is to the design purposes.

	Process description										**Methods and tools**				
	Description of tasks and deliverables				**Usage and activity perspectives**			**Data**	**Comparison with other processes**			**Methods**			**Tools**	
Persona	General breakdown	Detailed rep.	Actigram	RID platform	Usage-driven rep.	Activity centered rep.	Transformation of activity	Data streaming	UDIP	Production process	Prob. and Sol. duality	DSM-VB method	Ambition perimeter	BMC-RID	RID creativity	UNPC monitor
Engineering student																
Business student																
Design student																
UX designer																
Innovation consultant																
Startup founder																
Common design purposes																
Comments																

(a)

Principles and paradigms										Performances		
										Comparison with known methodologies		Innovativeness indicators
Reframing by problems	Reframing by activity	Innovativeness indicators UNPC	Nature of an idea	Intensity of an idea	Philosophy of innovation	Activity field and 3 rules of classicism	Thinking inside the box	Disruption	Four dimensions of value bucket	Unique Selling Propositions	Comparison along design stages	UNPC

(b)

Innovation competencies									Unique design purposes
Ability to tackle ill-structured problem	Systems thinking skills	Analytical skills	Knowledge management skills	Problem-solution pairing	Creativity	Experimenting and prototyping skills	Synthesizing skills	Collective intelligence	

(c)

Figure 8.4: Matrix for defining the design purposes of the RID game

8.2.1.5 Set the design purposes of the RID game

There were two steps to define the design purposes of the RID game. Prof. Yannou executed the first step as the main inventor of RID, who has a deep understanding of the methodology. He filled out the matrix introduced above and wrote down all the reasons for supporting his decisions. For the second step, we adopted the co-design approach, which has been used to develop a wide range of effective curriculum materials in school science (Reiser et al., 2000). For example, Barbera et al. (2017) brought teachers, domain experts, and students together to define the learning experience of a sustainable development online course. For the same intention, we involved two other RID experts (Dr. Cluzel and Dr. Vallet), who have years of relevant teaching experiences, and organized a session for discussing the preliminarily defined design purposes. During the session, Prof. Yannou explained his understanding of the quantitative scale to ensure the other two RID experts establishing a unified quantitative standard. Then, he presented each design purpose in turn, and the other two put forward opinions. At the end of the discussion, three experts reached a consensus on each design purpose.

8.2.2 Design purposes specification

Table 8.3 presents the results of the design purposes of the minimum viable RID serious game. The first edition game is dedicated to providing players with a basic understanding of RID in one-day training. To avoid sitting too ambitious design goals, we only applied the first six levels (0 to 5) from the quantitative scale. The last level will be used when designing configurable RID games for a specific persona audience.

Table 8.3: Design purposes of the RID game

Level	Category of the element	Name of the element
5	*Process description* (Description of tasks and deliverables)	General breakdown
	Principles and paradigms	Four dimensions of value bucket
	Performances (Comparison of RID with known design methodologies)	Comparison of innovation methodologies along design stages: Design Thinking (DT) and RID
	Innovation competencies	Ability to tackle ill-structured problem
		Analytical skills
4	*Process description* (Comparison of the RID process with other processes)	The representation as a production process
	Principles and paradigms	The innovativeness indicators UNPC
		Intensity of an idea

		Disruption
	Innovation competencies	System thinking skills
		Knowledge management skills
		Synthesizing skills
		Collective intelligence
3	*Process description* (Usage and activity perspectives)	The activity-centered representation
		The representation as a transformation of activity
	Methods and tools (Methods)	Computation of the value buckets (DSM-VB algorithm)
		Determination of the ambition perimeter
		The BMC-RID
	Methods and tools (Tools)	RID creativity tool
		UNPC monitor tool
	Innovation competencies	Problem-solution pairing
		Creativity
2	*Process description* (Description of tasks and deliverables)	Actigram
	Process description (Comparison of the RID process with other processes)	The Usage-Driven Innovation Process (UDIP) mode
		The problem and solution duality
	Principles and paradigms	Philosophy of innovation
	Performances (Comparison of RID with known design methodologies)	Unique Selling Propositions
1	*Process description* (Description of tasks and deliverables)	Detailed representation
	Process description (Data perspectives)	The data streaming representation
	Principles and paradigms	Reframing by problems
		Reframing by activity
		Nature of an idea
		Thinking inside the box
0	*Process description* (Description of tasks and deliverables)	Navigation dashboard of the RID CSCW system
	Process description (Usage and activity perspectives)	The usage-driven representation
	Principles and paradigms	Activity field and 3 rules of classicism
	Innovation competencies	Experimenting and prototyping skills

The content presented in section 8.2 is actually a *design purposes specification* document, which had been sent to the RID experts who were involved in this stage. They checked (pre-verification) that this specification and confirmed that it records all the design purposes accurately. Each design purpose should be validated later with the users of the RID game.

8.3 Design of the system layer for the RID serious game

Based on the previously defined design purposes of the RID game, we completed the *game system layer*'s conceptual design (stage 1 in the V-model) while respecting *design constraints*. This section presents the research process and results.

8.3.1 Objectives

The system layer's design objectives are mainly divided into two parts: 1) the common elements at the system level, i.e., *game type & basic gameplay*, *story frame*, *information*, *evaluation*, *game props*, and *aesthetics*; 2) the *system layout* (game levels that constitute the game), and the *interfaces* between the *game levels*. All the outcomes will serve as inputs for designing the *game level layer*.

8.3.2 Design process of the RID game

To reach the objectives, we followed a process, which consists of three steps. The first step is about planning the design of the game system layer. In this step, we scheduled workshops and specified the participants (Table 8.4) and all expected deliverables. All the participants understand the RID methodology but with various expertise levels (Appendix D).

Table 8.4: Participants of the workshops

Name	RID certification level	Role
A	MASTER RIDER	• Design of the RID serious game based on their mastery of RID and years of teaching experience.
B	MASTER RIDER	
C	EXPERT RIDER	
D	EASY RIDER	• Design of the RID game based on the mastery of RID; • Preside over workshops and document results.

The second step refers to the organization of three workshops (two hours per workshop), during which participants produced the relevant results of the design objects that belong to the system layer. Table 8.5 links each workshop with targeted design objects.

Table 8.5: Design objects of workshops

Workshop	Design object
#1	game type, story frame
#2	evaluation, game props, aesthetics
#3	basic gameplay, system layout & interface, information

Each workshop (Figure 8.5) starts with a brief introduction to help participants recall the previous design results; understand the expected outcomes and the flow to generate them. Then participants reviewed the RID game's design constraints (see section 8.2) and design purposes (Table 8.3). These purposes describe the importance of each element in the RID textbook to the RID game. There are six levels after the Bloom taxonomy of apprenticeship, from 0 to 5. To simplify the design of the system, three RID experts (⩾EXPERT RIDER) imagined a heuristic that "*consider the elements of levels 4 and 5 as the most crucial points to teach in the game, which should be used first to influence the game system layer. The less important elements can be covered when describing the game level layer and the game challenge layer*." This method remains to be validated through checking if the resulting RID game achieves all the design purposes.

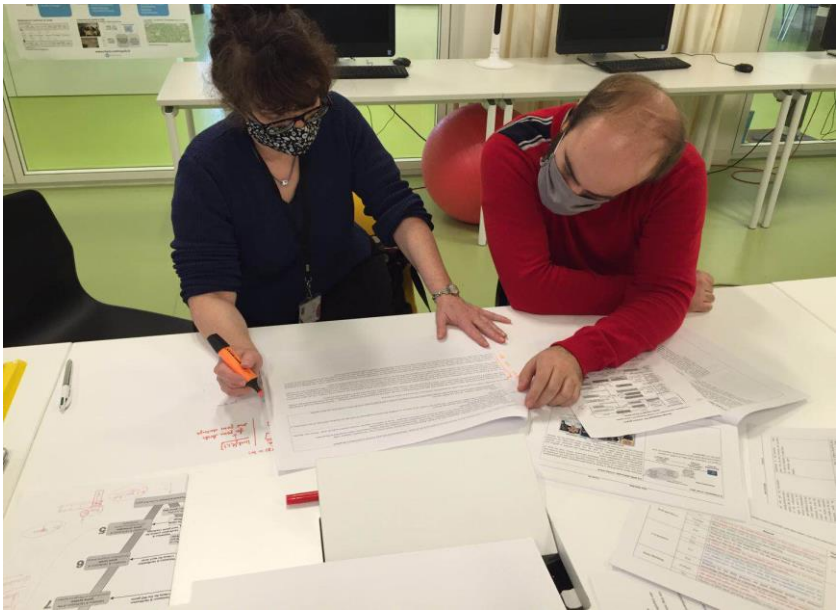


Figure 8.5: RID serious game workshop

Based on the method, the participants gradually designed each object by brainstorming (both individual and collective). For example, when conceiving the story frame, each participant first imagined stories under three criteria:

- The authenticity of the story: whether this story can happen in real life?
- The attractiveness of the story: is the story interesting and novel?
- The story's consistency with the design purposes and design constraints of the game: whether the story is conducive to achieving design purposes and meets design constraints?

These stories should offer opportunities to learn and practice the RID methodology. Each of the participants first generated one or two stories and then shared individual outcomes with others. In total, there were seven stories created (Appendix F). For example, one story is about an "*Innovation competition within the company: players are employees who sign up for the contest need to constitute different innovation teams and complete the challenge by using the RID methodology. The team with the best results will be the winner.*" Finally, they made a synthesis to analyze their stories' similarities and differences, which served as a basis to inspire a story frame in a theme of urban mobility.

The theme was chosen for two reasons. First, moving around cities is a fundamental requirement for the development of most human activities; this is an activity – starting point of a RID study – that everyone has some knowledge about it. It is meaningful to apply RID to solve the problems people encounter when using transportation. Second, RID experts have completed some related innovation projects, and the data in these projects can be applied to game design.

When defining the system layout and their interfaces, the four participants individually imagined the game levels and the relationship between them based on the different process descriptions in the RID methodology. Then they shared and summarized the results, as shown in Figure 8.6.

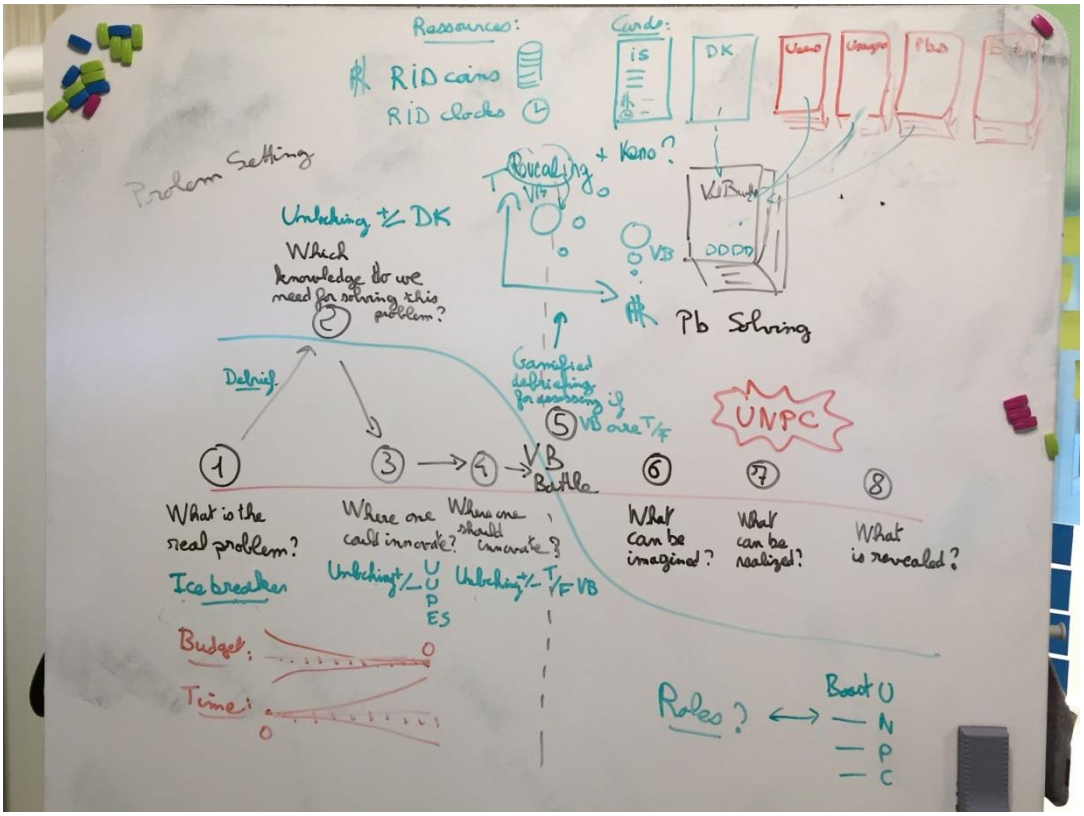


Figure 8.6: Discussion results about system layout & interfaces

The last step intends to *pre-validate* and *pre-verify* obtained outcomes. The workshops'

results were provided to the participants for two objectives:

- Check whether all design purposes of levels 4 and 5 have been considered (pre-validation).
- Check whether the descriptions of the design objects are accurate and complete (pre-verification).

Figure 8.7 is a graphical representation of the aforementioned design process.

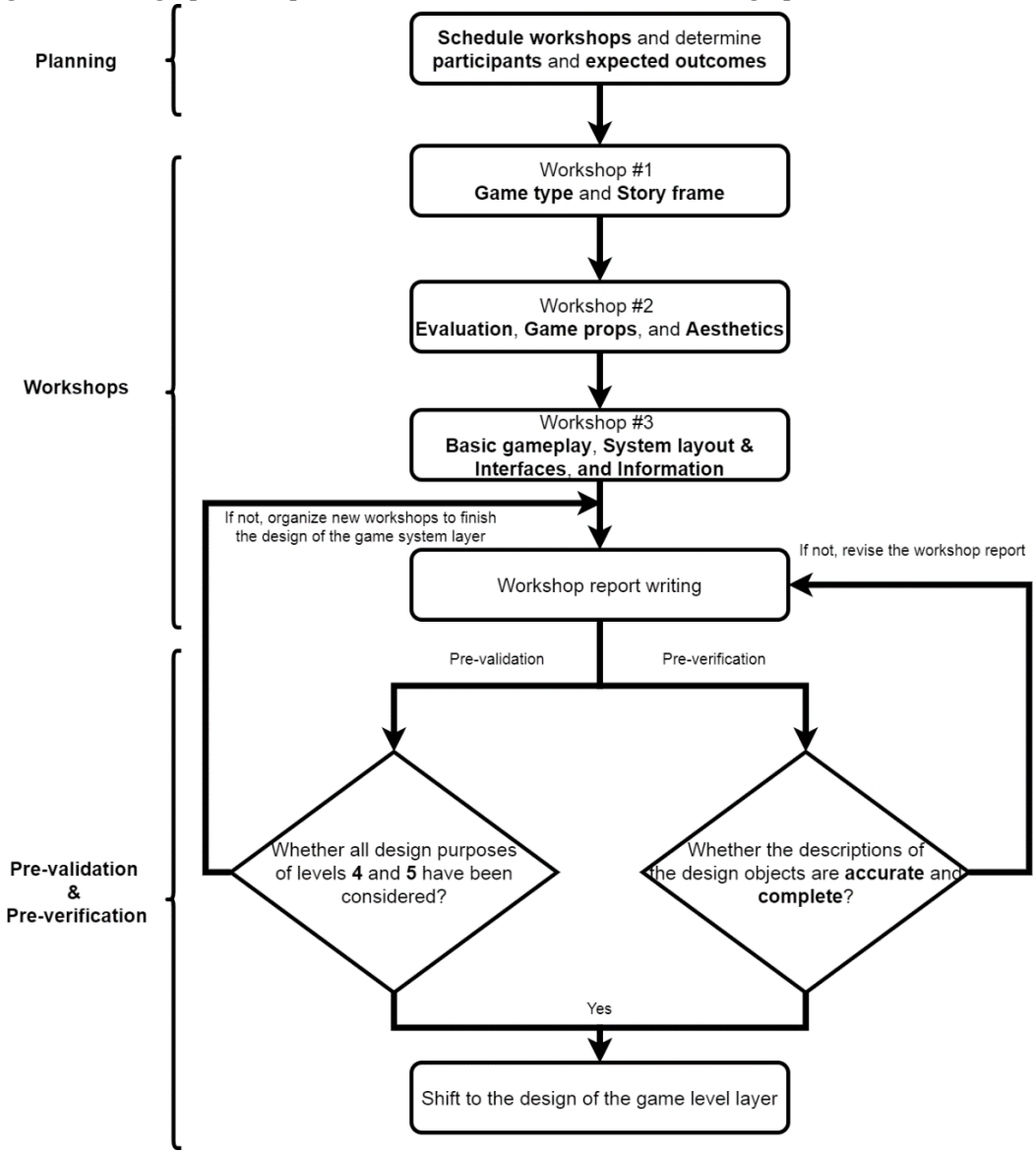


Figure 8.7: Design process of the system layer design

8.3.3 Results of the system layer design

This subsection illustrates the results of the system layer design. It introduces the two most essential design objects, the system layout and the basic gameplay. The former enhances the

game system's internal cohesiveness and coherence, while the latter shapes users' playful learning experiences. Then the descriptions of the remaining design objects are provided.

System layout & Interface

Figure 8.8 shows the structure of the RID game (redraw from Figure 8.6), which is based on the general breakdown (scale level 5 element) of the RID process.

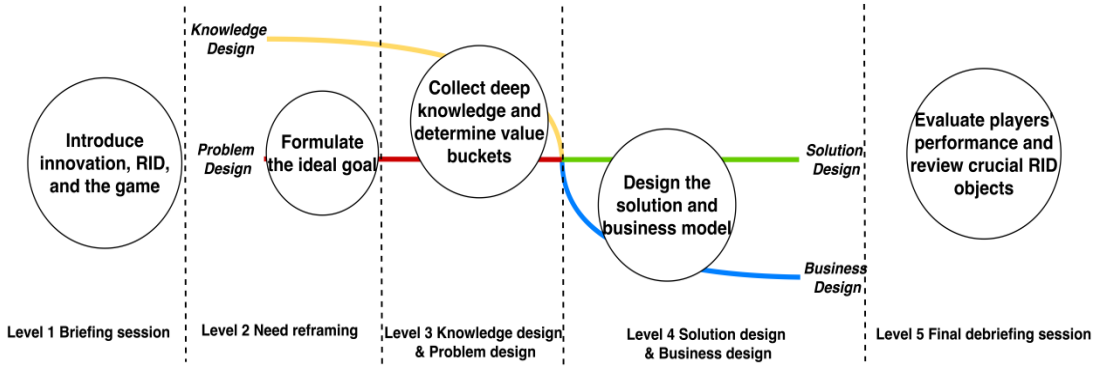


Figure 8.8: System layout of the RID game

There are five sequential game levels, and each of them may further consist of several game challenges, which will be defined when designing the game level layer:

1) The first game level is the **"Briefing session."** During the session, players will get an initial understanding of innovation and critical RID objects. The general game rules and the game story will be introduced. After the introduction, players can start the next game level.

2) The second game level corresponds to the RID elementary tasks of **defining activity field and reframing goal**. The players will first establish teams; do the icebreaker and a "warm-up" before starting the real game. Each team plays the role of a company defined by some characteristics. Then they will put effort into answering the question, "what is the real problem?" At the end of this level, the trainer will provide feedback to players to ensure each team starts the next level with the same *ideal goal*: the interface between levels 2 and 3.

3) The third game level covers the **"knowledge design" and the "problem design" sub-processes**. Players will gather investigation strategies and deep knowledge, contribute to segment *user profiles*, *usage situations*, *problems*, and *existing solutions*, and finally *identify value buckets*. At the end of this game level, the trainer will evaluate the value buckets of each team. Each team will start work on different value buckets from the next level.

4) The fourth game level covers the **"solution design" and the "business design" sub-processes**. Each team will generate several alternatives of solutions covering a set of value buckets and design the business model based on the solutions. Players will apply the UNPC monitor tool to increase the maturity of their solutions.

5) The last game level is the **"Final debriefing session."** Each team will present its main

results, like value buckets, ambition perimeter, solutions, and business model, and there will be a general discussion. The trainer can probably discuss each team's performance using graphical tools. The important RID objects and the Unique Selling Propositions (USP) will be emphasized. The USP of RID describe its advantages compared with other innovation methodologies.

Basic gameplay

There are five game levels. Players need to complete all the tasks in the previous level to start the next level. They are assembled in one or several teams and need to work on an innovation project about urban mobility. The rules adopted for the system design are:

- At *level 1*, each team plays the role of a **company** addressing the innovation project. Each company is defined by its **pre-existing knowledge** and its **technological domain**.
- At *level 2*, each team should analyze the **initial idea** offered by the project initiator to understand the **real problem**. The **problem** should be expressed relative to the **activity field** of particular users.
- At the *end of level 2*, there is a RID expert intervention, which aims to evaluate the **problems** defined by each team and place all teams at the same starting point, i.e., the same **ideal goal**.
- At *level 3*, the team must acquire some relevant **complementary knowledge** with limited resources of money and time. For that, they must choose appropriate **investigation strategies** that cost time and money. Probably an investigation strategy allows addressing several **deep knowledge pieces** with different success partially. These knowledge pieces must be relevant to (a) the innovation project, (b) the markets that the company used to propose new offers. This knowledge acquired must favor discovering relevant categories of **User Profiles**, **Problems**, **Usage Situations**, and **Existing Solutions**.
- The players must also experiment with the crossing between categories and propose relevant **value buckets (VBs)** from the identified 4-dimension categories. Of course, not all value buckets exist, and not all of them are of high importance. Then, one can probably assess the relevance of their proposed **VBs**, providing the Urban Mobility example has been modeled and computed.
- Next, they have now to choose a subset of their discovered VBs to compose the ambition perimeter. One should assess their choice by (a) the **relevance** of the selected VBs for augmenting the activity (**usefulness**), (b) the **adequacy** of their company profile (**opportunity**).
- At the *end of level 3*, there is a second RID expert intervention, which aims to evaluate the **ambition perimeter** defined by each team. After the evaluation, each team is expected to work for different value buckets with high-value creation potential.
- At *level 4*, the team needs to come up with at least one **product-service concept** and related **business model** for the defined ambition perimeter. At the *end of level 4*, each team should create at least one concept and be able to justify it with the **UNPC monitor tool**.

- At *level 5*, the team needs to introduce its process to generate solutions. There is a third RID expert intervention, which aims to evaluate the overall performance of each team. After the evaluation, players will follow the expert to review some essential RID objects and the **USP of RID**.

Game type

The selected game types are "roll and move," "cooperative," "deck-building," "role-play," and "resource management."

The RID serious game is a collaborative physical board game. The game can be played by one team (cooperation) or more (competition between teams, collaboration inside teams) teams of players simultaneously. Each team plays a different role (a different company). Each role has a personal mission that needs to be completed before the end of the game. Different teams have the same resources of budget and time but different preliminary decks of cards (e.g., investigation strategy cards or deep knowledge cards). When a team of players completes a game level, their performances are evaluated to determine whether they should advance or retreat on the game board.

Story frame

The story of the RID serious game is based on the innovation project "Urban mobility", with the concern to ensure authenticity of the game. The following paragraph is rephrased based on the outcome of workshops (Figure 8.9).

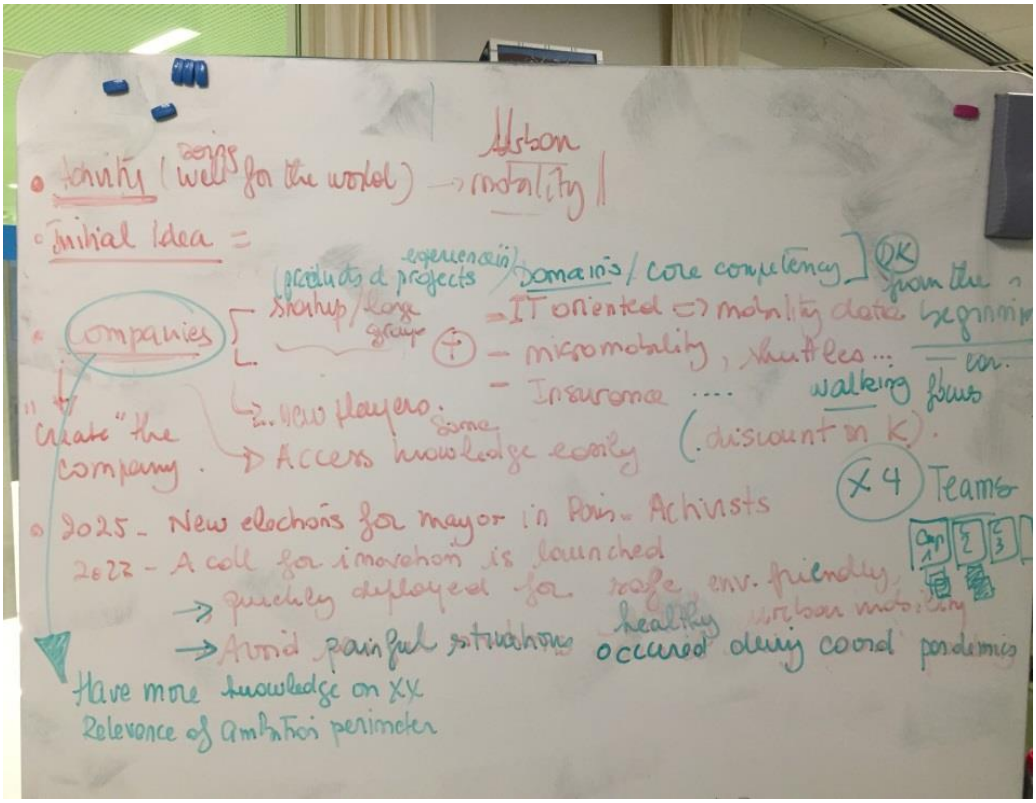


Figure 8.9: Discussion results of the story frame

The mayor of Paris has begun laying the city's strategy for the next Olympic Games in 4 years. A call for innovation is launched, which aims to promote the deployment of sustainable urban mobility and avoid painful situations that occurred during the COVID-19 pandemic. The city is particularly attached to promoting safe, healthy and environmentally friendly mobility solutions to all its citizens, in an inclusive and equal manner. You are all companies belonging to the urban mobility ecosystem. Each of you has a part of the knowledge required for the project. You will follow the Radical Innovation Design® methodology, gather information, and generate solutions to convince the mayor! Each of you will represent different companies of the same business size. Each team must complete the project within a limited time and with a limited budget. Please note that you are not the only company that has responded to this call; your competitors are all around you.

There will be several types of company representative for mobility ecosystems, for example:

- One IT-oriented company (dealing with mobility data),
- One micro-mobility or cycling company (free floating e-scooters or bikes),
- One insurance company
- One car sharing company
- One autonomous shuttle operator.

Evaluation

To evaluate each team's performance in the game, we decided to build a scoring system, especially for game levels 3~5. At level 3, the trainer scores the team based on its selected value buckets. At level 4, the trainer uses the UNPC monitor tool to score the solutions generated by the team from four perspectives: **usefulness**, **newness**, **profitability**, and **proof of concept**. The last three indicators will be further merged into a sole one **"opportunity"** (the opportunity to success in the market) to simplify the game. At level 5, the trainer makes a comprehensive evaluation based on the team's scores at level 3 and level 4.

Game props and aesthetics

There are three kinds of game props identified so far:

- Game cards: *role card* (describe the company represented by each team), *investigation strategy car*d (describe the way to collect some kinds of deep knowledge), *deep knowledge card* (carry some knowledge required to solve the problem), problem card (describe the issue experienced by users), usage situation card (describe the task related to the activity field), user profile card (describe the user concerned by the activity field), and *existing solution card* (describe the existing product-service-systems solution linked to a given activity field).
- Game board: The game board (Figure 1.1 in Chapter 1) presents the entire RID process in an "X-shape." The game cards can be placed somewhere on the game board. The UNPC tool appears on the game board to assess the players' conceptual solutions' maturity at level 4. Indicators like budget (named as *RID coin*) and time (named as *RID clock*) also appear on the game board to remind them of the

remaining resources.

- Resources: There are two kinds of resources: RID coins and RID clocks, which are used to purchase investigation strategy cards.

The specification of each prop will be enriched when designing the relevant game levels/challenges.

Information

There are two kinds of information, the first is RID-related information, and the second is project-related information. At this stage, we only determine what information is needed. Based on the design purposes listed in Table 8.3, we deduced the following RID vocabulary (Table 8.6) that should be embedded as much as possible – and with respect with prioritization - in the game.

Table 8.6: RID vocabulary to appear in the game

Level	Name of the element	RID vocabulary
5	General breakdown	Knowledge design, Problem design, Solution design, and Business design; Problem setting and Problem solving.
	Four dimensions of value bucket	User profiles, Usage situations, Problems, and Existing solutions; Value bucket, Activity field
	Comparison of innovation methodologies along design stages: Design Thinking (DT) and RID	Structured problem setting, Activity-centered, User-centered, Targeted value buckets, Business model, and Decision traceability.
	Ability to tackle ill-structured problem	Reframing, Activity field, Ideal goal and Initial idea
	Analytical skills	-
4	The representation as a production process	Innovation cockpit, Problem setting and Problem solving
	The innovativeness indicators UNPC	Usefulness, Newness, Profitability, and (*proof of*) Concept.
	Intensity of an idea	Radical innovation and User experience.
	Disruption	Disruption and Need-seeker innovation strategy
	System thinking skills	-
	Knowledge management skills	Deep knowledge, Investigation strategies, and Books of knowledge; Observation protocol and Observation techniques.
	Synthesizing skills	DSM-VB (or Value Bucket algorithm), BMC-RID, and Innovation dossier.
	Collective intelligence	-
3	The activity-centered representation	Users and Activity field
	The representation as a transformation of activity	RID existing usage scenario and RID dreamt usage scenario

	Computation of the value buckets (DSM-VB algorithm)	User profiles, Usage situations, Problems, Causality of problems, Existing solutions, and Value bucket.
	Determination of the ambition perimeter	(Macro) Value bucket, Kano feature, Blue ocean, Voice of the company, and Ambition perimeter. Macro Value Bucket, justification (of an MVB)
	The BMC-RID	Usefulness, Newness, Profitability, and Concept; Business model, Strategic partners, Key activities, Key resources, Value proposition, Customer relationship, Customer segment, Distribution channel, Cost structure, and Revenue streams; Conceptual solution, Ambition perimeter, and Dreamt usage scenario.
	RID creativity tool	(Macro) Value bucket, Attributes of an MVB, Existing situation, Dreamt usage scenario, Prototyping, and Conceptual solution; Revealed and Targeted value buckets.
	UNPC monitor tool	Usefulness, Newness, Profitability, and Concept.
	Problem-solution pairing	Value bucket and Existing solution.
	Creativity	-
2	Actigram	*Related vocabulary has been covered*
	The Usage-Driven Innovation Process (UDIP) mode	The 10 design issues: Idea, Activity, Usage, Problems, Value buckets, Expected or targeted value buckets, Structure, Expected Behavior, Structure behavior, and Value buckets derived from structure. The 6 fundamental and 15 elementary design processes: Formulation, Synthesis, Analysis, Evaluation, Documentation, Reformulation.
	The problem and solution duality	Knowledge design, Problem design, Solution design, and Business design; Problem setting and Problem solving.
	Philosophy of innovation	Jobs to be done and Sustainability.
	Unique Selling Propositions	-
1	Detailed representation	Transfer function approach, Transformation service approach;
	The data streaming representation	
	Reframing by problems	
	Reframing by activity	
	Nature of an idea	
	Thinking inside the box	Thinking inside/outside the box.

To create a virtual innovation project on urban mobility for players to practice the knowledge about RID, we should prepare the information on game cards:

- Role card: the name and the mission of the company; the initial deep knowledge,

RID coins, and RID clocks owned by the company.

- Investigation strategy card: the name and the description of the way for collecting deep knowledge about urban mobility; the required amount of RID coins and clocks; the relevant deep knowledge items.
- Deep knowledge card: detailed description of one deep knowledge item.
- User profile card: the name and the description of one category of the users.
- Usage situation card: the name and the description of one task that related to the activity field.
- Problem card: the name and the description of one issue encountered by the user.
- Existing solution card: the name and the description of a solution to solve the problem.

8.3.4 Pre-validation and Pre-verification of the system layer design

The design team of the RID game was composed of four RID experts in Table 8.4. For health and safety considerations, we did not invite other co-designers. The RID game designers have a high level of teaching expertise; they can ensure the gameplay's effectiveness. In this case, there is no need to invite other experts to conduct such pre-validation. The high-level specification of the RID game presented in this section was sent to the potential users (pre-validation), and they were attracted by the SG objects we have defined. Each RID game designer had read the specification carefully to ensure it records all the results accurately and completely (pre-verification).

8.4 Game level "Knowledge design & Problem design"

Due to time constraints, we only designed the third game level, "Knowledge design & Problem design," based on the game system's specification. The process to conceptual design this game level is similar to what was introduced in subsection 8.3.2. At this stage, we organized four workshops, three of which aimed to specify the design elements of level 3, and the fourth intended to pre-validate the results. It is worth mentioning that we applied the adapted V-model flexibly when designing this level. Level 3 and its six different game challenges were designed simultaneously because we almost fully described the level when we defined the game system. The introduction of this game level is given below.

8.4.1 Layout of game level "Knowledge design & Problem design"

Thanks to a brainstorming session (Figure 8.10), the four designers of the RID game imagined the layout of level 3 and reached a consensus. Game level 3 constitutes six successive game challenges, which require players to complete different tasks to solve a virtual project on *urban mobility*:

- **Initiation**: Players need first to random pick or select one *company card* and then discover the company profile (mission, resources, and knowledge & skills);
- **Investigation**: Players need to buy a relevant set of *investigation strategies (IS) cards* that are not exceeding their available resources (*RID coins and RID clocks*);
- **Acquisition of knowledge**: Players pick up the *deep knowledge (DK) cards* unlocked by *IS cards* and then count the points of user profiles (Up), usage situations (Us), and problems (P);
- **Exploration of Usage situations, User profiles, and Problems**: Players need to select *Up, Us, and P cards* allowed by *DK cards* and then unlock them by answering the trainer's questions.
- **Proposition of value buckets**: Players need to discover the *book of existing solutions (Es)* and their *efficiency profiles*. They are then asked to propose five *value buckets (VBs)* to maximum **usefulness** and create relevant **opportunities** for their company. They need to record VBs on the template and provide the list of VBs to the trainer;
- **Evaluation of selected value buckets**: Players need to make a debriefing to the trainer about the results gained when playing. Finally, they will get comments from the trainer and discuss their overall performance.

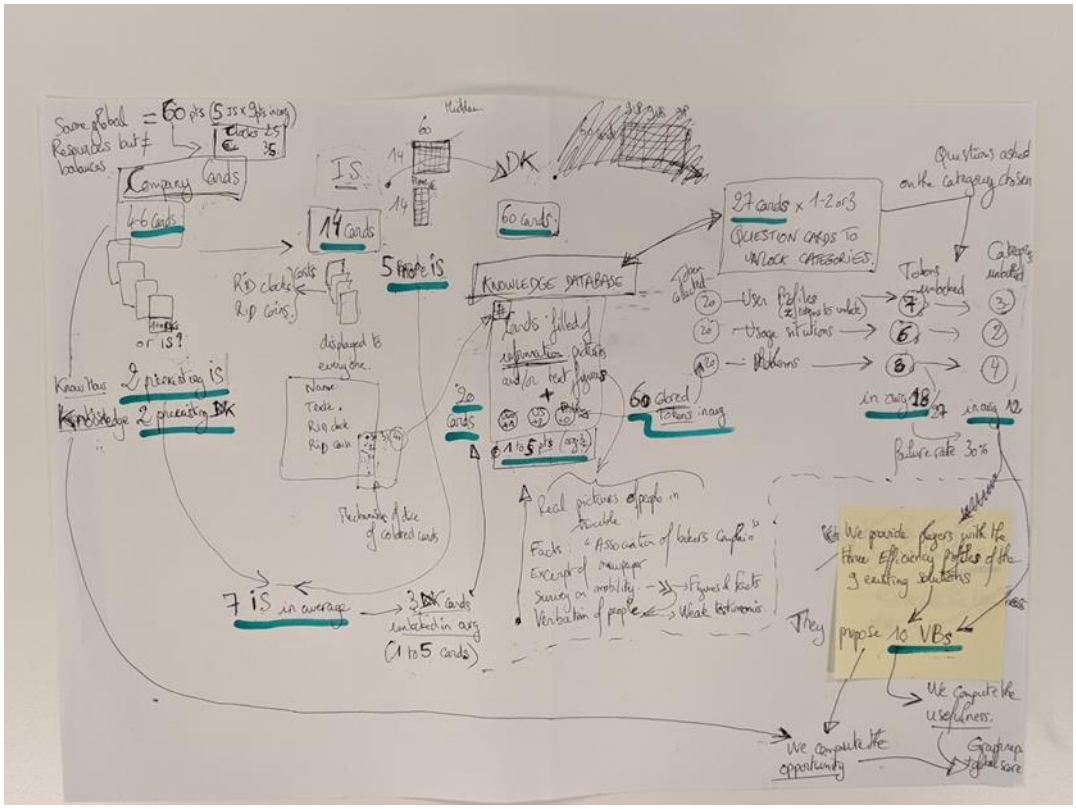


Figure 8.10: Game process of level 3

8.4.2 Gameplay of level "Knowledge design & Problem design"

Based on the discussion results shown in Figure 8.10, we also determined the gameplay of level 3 and the detailed game mechanics employed in the six game challenges. More specifically, how the cards are interlaced and the average number of each card each team should gain were all specified. All these results are elaborated as follows.

At the beginning of level 3 (*initiation*), each team needs to select a role. These roles are four companies that may be involved in an "urban mobility" innovation project. The companies are required to complete the project with the similar amount of limited resources (around 50 *RID clocks* and 50 *RID coins*). These companies are different in two perspectives:

- Each company has its own ambition. For example, one company is committed to providing services or products for a specific user profile.
- Different companies have different knowledge bases. Their previous knowledge allows them to have two pre-existing *DK cards* and two pre-existing *IS cards* before starting the third game level. The pre-existing cards should be consistent with a company's ambition. These cards have two advantages, help the team better understand: a) its mission to make reasonable choices later; b) what DK and IS are. One *DK card* contains part of the deep knowledge of a specific category. According to different sources and forms of knowledge, we have defined six kinds of DK cards: testimony, scientific data-graph, scientific data-table, scientific data-quotation, observation, and media.

For example, MOBICOMPANION (Figure 8.11) is an IT company that offers services related to GPS navigation. This company put their customers in the first place but also concerns about environmental issues.

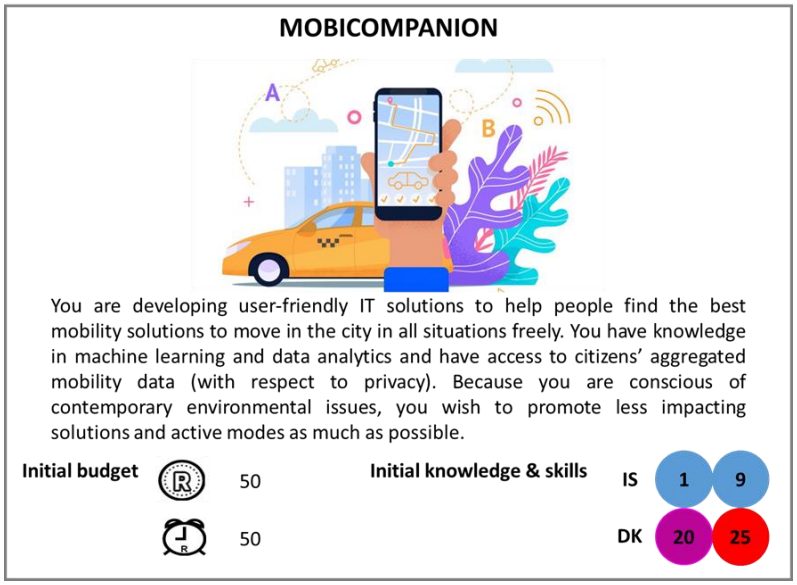
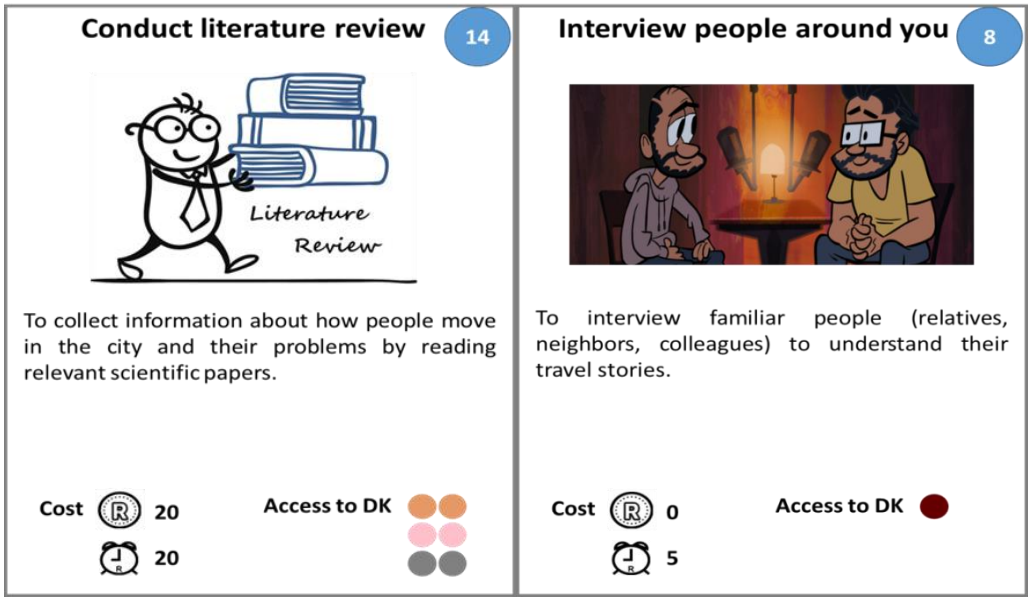


Figure 8.11: Company card: MOBICOMPANION

The second game challenge (*investigation*) of level 3 is to buy *IS cards* (Figure 8.12a). There are 14 *IS cards* in total. Each *IS card* links with one or more *DK cards* categories and allows the team to gain a certain number (1~5, on average 3) of *DK cards*. Players in one team are expected to purchase five more *IS cards*; thus, they will have on average 7. Each *IS card* costs a specific number of *RID coins* and *RID clocks*. The cost of each *IS card* should be based on reality. For example, conducting an in-depth literature review can cost more time and money than other strategies, so the related *IS card* costs more *RID clocks* and RID coins in the game. Of course, this valuable *IS* will bring more *DK cards* to the team.



(a) IS card: Conduct literature review (b) IS card: Interview people around you

Figure 8.12: Examples of IS cards

As mentioned before, there are six categories of *DK cards*. We use different colors on IS cards to indicate the types of these *DK cards*. Players need to apply their budget to buy as many different types of *DK cards* as possible based on this information to avoid acquiring too much knowledge of the same type. One thing to note is that the "quality" of knowledge on *DK cards* gained through these *IS cards* is different. For example, if players choose the *IS card* "Conduct literature review," they can get scientific results shown on *DK cards*. If they buy the *IS card* "Interview with the people around you," (Figure 8.12b) they only receive testimonies from a few people, which may be less reliable. In short, players need to make the most of their budget to buy reliable and comprehensive *IS cards*. As shown in Figure 8.13, players are expected to make all these strategic choices when playing the RID game.

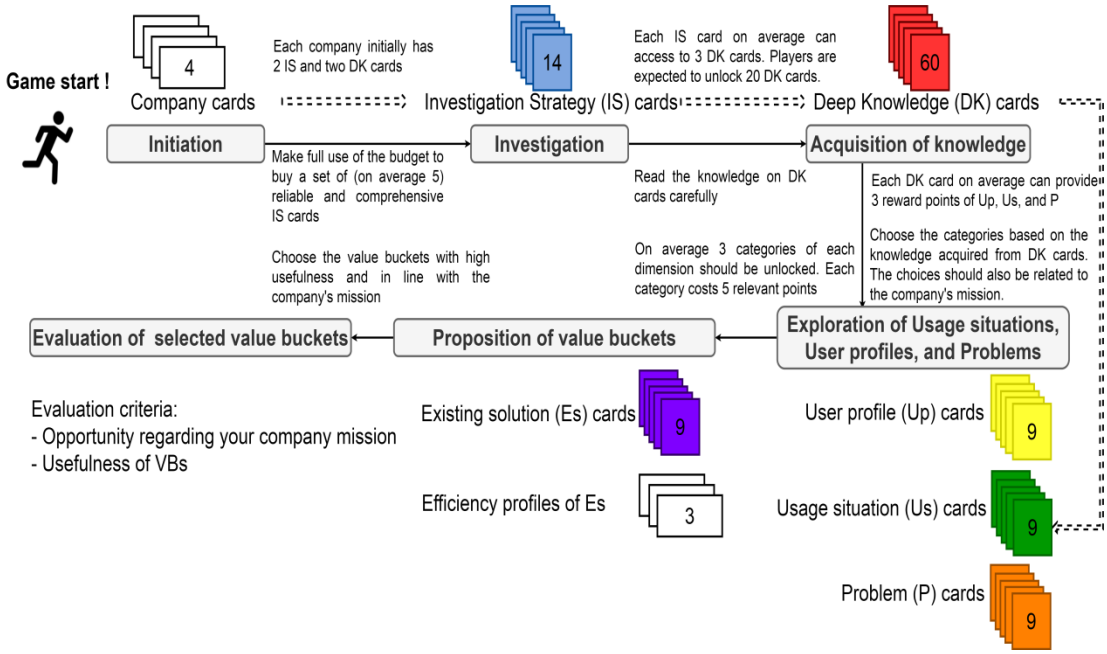


Figure 8.13: Strategic choices in the RID serious game

The third game challenge (*acquisition of knowledge*) is to unlock *DK cards* taking advantage of the owned *IS cards*. There are 60 *DK cards* with a serial number. But for the prototype, only 30 of them were designed. Each team is required to unlock on average 20 *DK cards* (contain two pre-existing cards). The team can randomly pick the *DK cards* allowed by the *IS cards*.

The *DK card* is filled with text and figures and also three quantitative indicators to measure its contribution (called "*reward points*" in the game) to the understanding of Up, Us, and P. For example, the *DK card* shown in Figure 8.14 is designed based on a scientific paper. This card summarizes all the travel experience aspects that could influence the overall satisfaction when using public transport. Based on it, we can deduce the problems encountered by the public transport users, like lack of comfort, noise, lack of safety, etc. It really contributes to the understanding of travel problems, so it provides three points of P. Players need to carefully read the contents of each card they have in order to answer the trainer's questions in the fourth challenge.

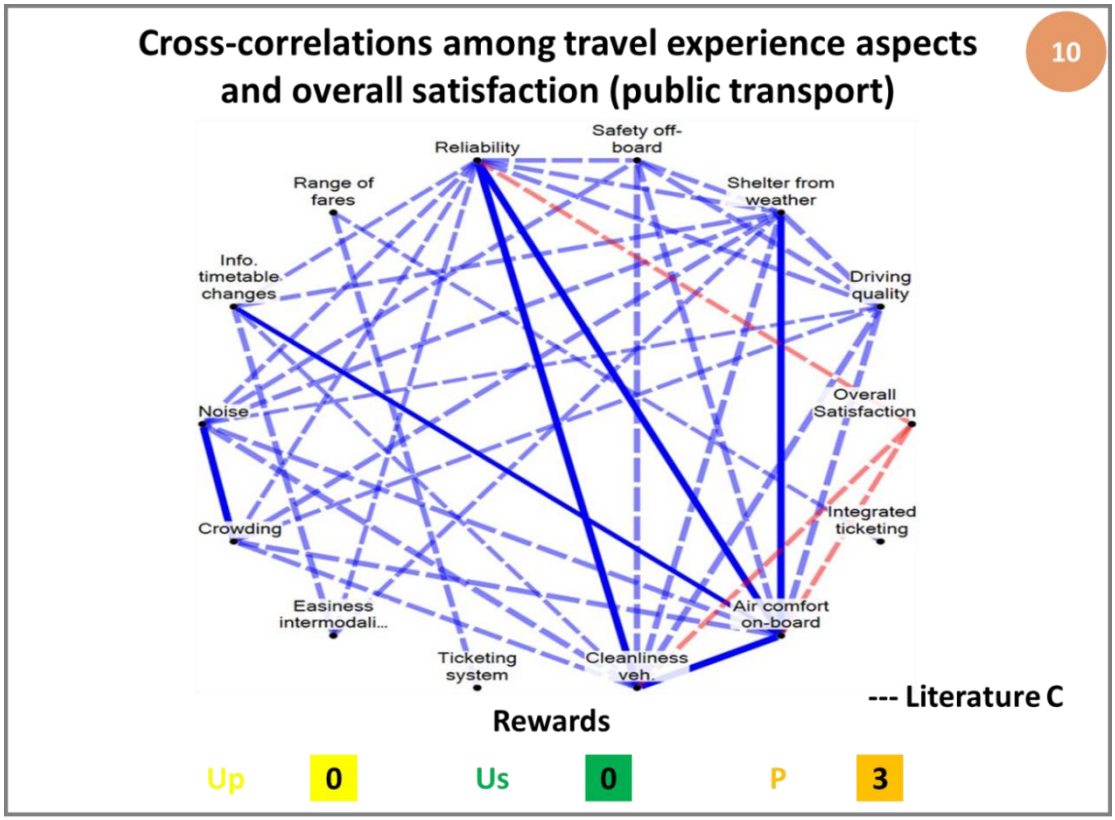
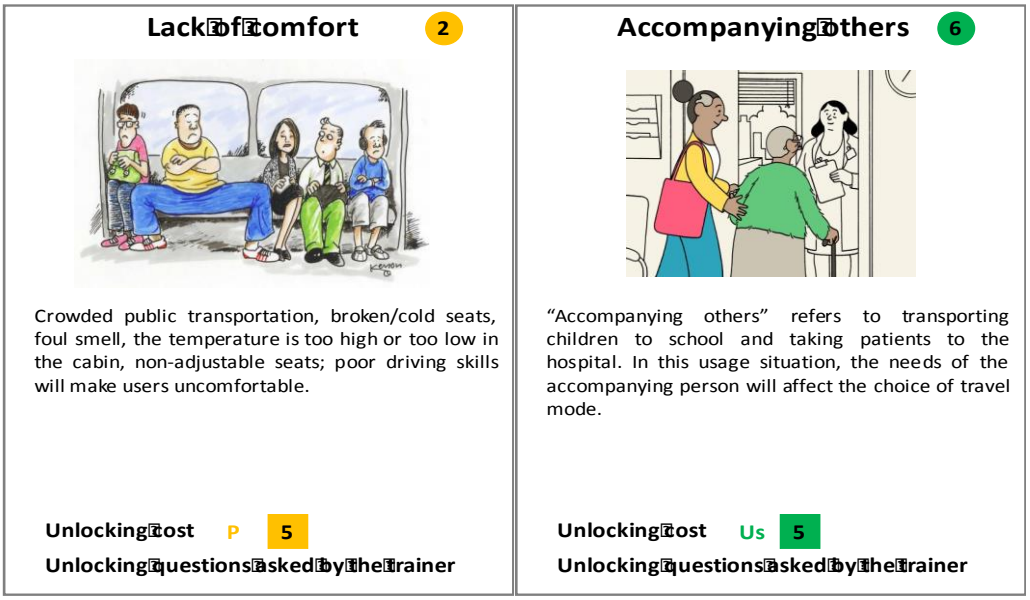


Figure 8.14: DK card: Cross-correlations among travel experience aspects and overall satisfaction (public transport)

The overall contribution (the sum of the three indicators) of a *DK card* can be from one to five, thus three points on average of all *DK cards*. At the end of this challenge, the team is expected to obtain *DK cards* with total points of 45 on average, and each indicator is 15 on average. But a "weak team" could reach an unbalanced understanding (points) on the three dimensions. The total points represent the amount of knowledge gained by the team.

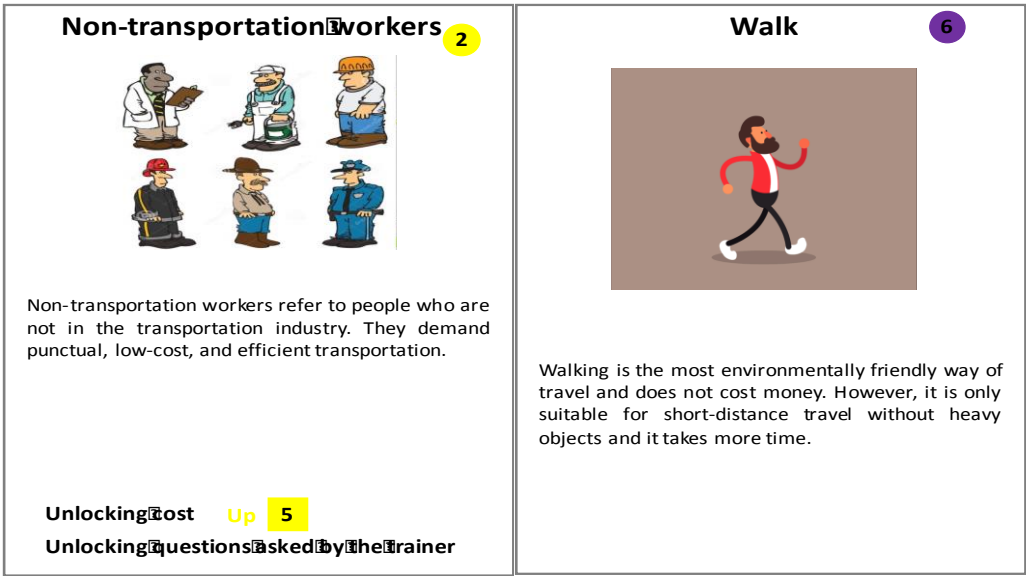
The next game challenge (*exploration of Up, Us, and P*) is to unlock *Up*, *Us*, and *P cards*. There are nine cards of each type, which will be displayed to everyone. Each card requires the team to spend five points of a particular type gained before. To unlock a card, the team also needs to answer the questions asked by the trainer. These questions are designed based on the *DK cards* which represent the nature and content of the knowledge. For example, to unlock the P card "lack of comfort," (Figure 8.15a) the team needs first to spend 5 P points and then answers the question, "what can be the causes of this problem?" Players can find part of the right answers like "crowded, bad smell, and dirty" from Figure 8.14. Each team is expected to unlock three Us, Up, and P cards in average. The team needs to read and analyze *DK cards*, which helps players answer their interested *Us, Up, and P cards' questions*. The team should report their answers to the trainer, and once they pass the verification, they can get the relevant cards. If the team fails to provide the right answer, they will lose their *Up, Us, or P points* and also not get the card. We managed at this point to be able to unlock between 3 to 5 cards of one type out of 9.



(a) P card: Lack of comfort (b) Us card: Accompanying others

Figure 8.15: Examples of P and Us cards

In the fifth game challenge (*proposition of value buckets*), each team must generate and select about five value buckets (VBs) based on their identified *Us* (Figure 8.15b), *Up* (Figure 8.16a), *and P*. The official definition (Yannou, 2020) of the value bucket is "a major *problem* (i.e., with serious consequences) for a *user profile* that arises during a frequent *usage situation* within an activity field **and for which existing solutions provide too little or no relief**." To ease the understanding, we interpret this concept based on the story as "a major issue (P) encountered by a category of traveler (Up) that arises when moving in the city (Us), and existing transportation modes (Es) provide too little relief."



(a) Up card: Non-transportation workers (b) Es card: Walk

Figure 8.16: Examples of Up and Es cards

To allow players to transform a potential value bucket to a real value bucket, they need to assess if "existing solutions provide too little or no relief." This is why we provide them with nine *Es cards (Figure 8.16b)* representing 9 transportation modes and the three *efficiency profiles of these existing solutions*. Efficiency profiles display the percentage of VB relief for a given Existing Solution under a given User Profile, Usage Situation or Problem – this is why there are three efficiency profiles -. For example, Figure 8.17 describes the relative efficiencies of Existing Solutions for Problems. All the data is generated based on the real data processed by the RID methodology.

Players first need to understand all available value buckets by combining the *Up*, *Us*, and *P* cards they have unlocked. Then, they must select five value buckets of value according to two criteria:

- Usefulness. Players need to consider each existing solution's efficiencies for each *Up*, *Us*, and *P* comprehensively. If a *P* encountered by an *Us* in an *Up* has been well solved by the *Es*, then the usefulness of the corresponding value bucket is very low.
- The possibility of success that a value bucket could bring in the company's target market. Players are expected to select the value buckets which cover the *Up*, *Us*, and *P* that their company should concern about according to the company's mission.

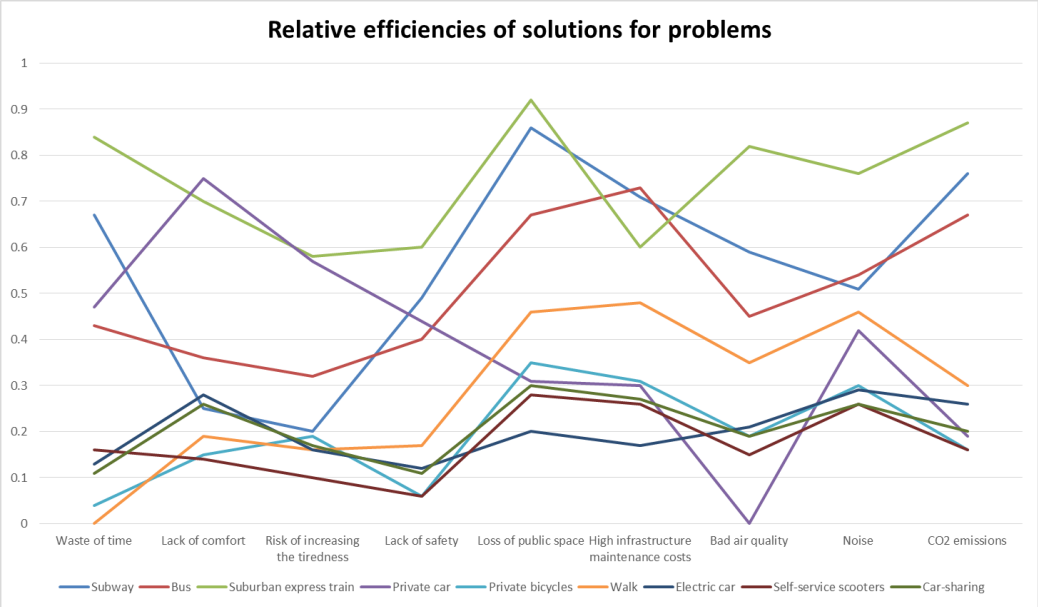


Figure 8.17: Relative efficiencies of solutions for problems

In the next step, players need to record their proposed value buckets in the *template for value buckets* (Figure 8.18) and provide it to the trainer.

Company:

Team members:

Filled out by players (write down number + name)				Filled out by the trainer	
Value bucket	**Up**	**Us**	**P**	**Opportunity**	**Usefulness**
#1					
#2					
#3					
#4					
#5					
			Total		

Figure 8.18: Template for value buckets

Figure 8.19 summarizes all the game mechanics applied in the fifth game challenge. Players first need to combine their *Up*, *Us*, and *P cards* to understand all the potential value buckets. Then they should make reasonable choices that are consistent with the company mission (**opportunity**) and have not been satisfactorily alleviated (**usefulness**) by existing solutions.

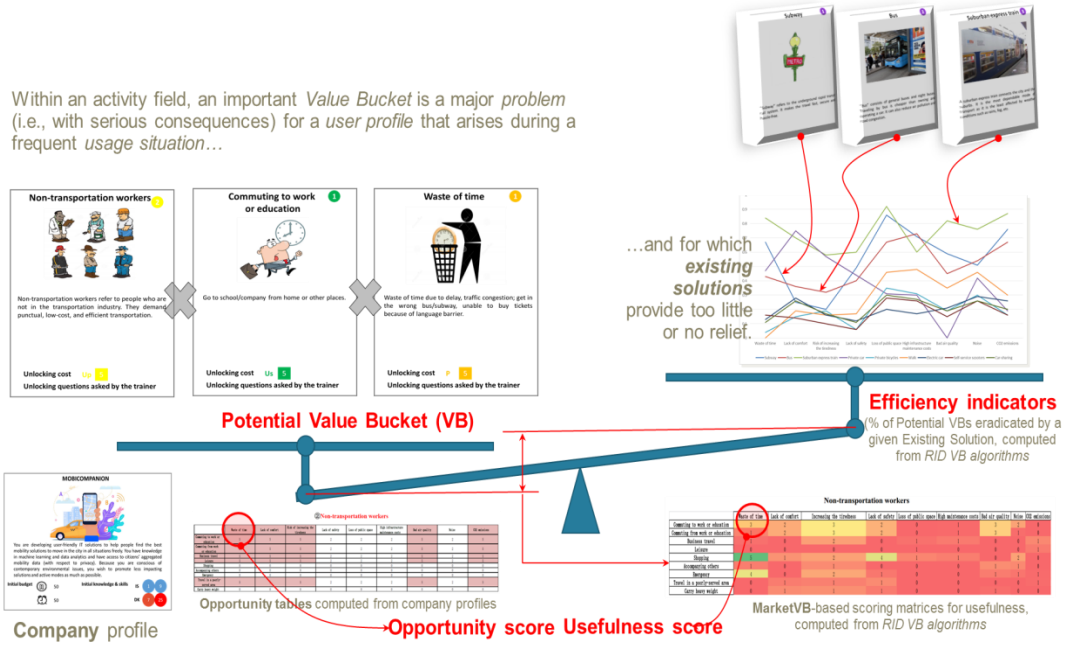


Figure 8.19: Game mechanics of hidden data and scoring

In the last challenge (*evaluation of the selected value buckets*), each team will show its results. The trainer will apply a two-dimensional graphical representation (Figure 8.20) to evaluate the team's performance based on the same criteria that the players used when choosing VBs:
1) Opportunity. Whether the selected VBs line with company missions?
2) Usefulness. Whether the selected VBs reflect users' critical needs in frequent usage situations that have not been alleviated by existing solutions?

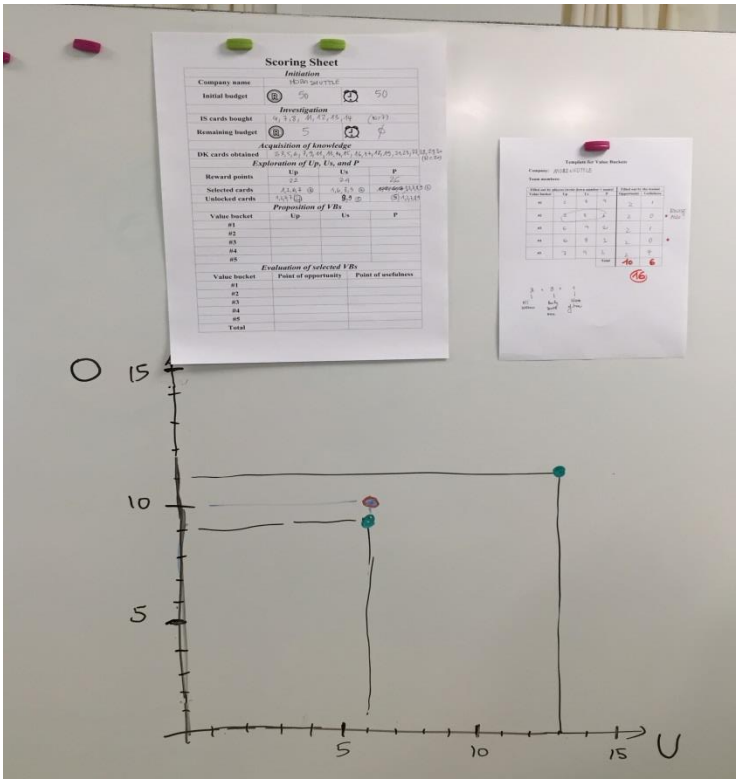


Figure 8.20: Evaluation of player's performance

The evaluation of players' performance is based on the hidden data (*grading standards*) introduced in subsection 8.4.4. Each of the value buckets can get a score for the opportunity and also a score for the usefulness. The former is deduced from company missions, and the latter is computed from VB algorithms based on the real data (Figure 8.19). The total two-part score of the five value buckets is plot on a 2D graph foe each team (Figure 8.20). If one team has a higher opportunity score (ordinate) than other teams, their value buckets are more aligned with the company mission. If one team has a higher usefulness score (abscissa) than other teams, their value buckets are more meet with the user needs.

When two or more teams play at the same time, we establish a partial ordering ranking of these teams. It means that all teams may be declared as winners if they all have a plot on the Pareto frontier, i.e. no team Pareto-dominates another[13]. Elsewhere, some teams are said to be

[13] https://en.wikipedia.org/wiki/Pareto_efficiency

more deserving than others. We plan, for given subsets of unlock *Up*, *Us*, and *P cards* and *Company card*, to provide and comment to players several examples of five-best-VBs with important *(U, O)* coordinates; a program to develop can compute them. Then, each team needs to optimize its choices of VBs and set the ambition perimeter based on the trainer's recommendation to start the following levels.

We conducted reverse reasoning to define the combinations and likelihood of unlocking different kinds of game cards (i.e., the average number of each type of card to be unlocked). First, we expect the team to unlock 3 *Up* out of 9, 3 *Us* out of 9, and 3 *P cards* out of 9 to create value buckets. Each of these cards costs five *reward points* of a particular type. Thus, the team needs to gain at least 45 points. However, considering the possibility of their failure for answering unlocking questions (assumed to be 25%), it is better to get 60 points. On average, one *DK card* can provide 3 points, which means the team should unlock around 20 *DK cards*. On average, one *IS card* can access 3 *DK cards*. Thus, to unlock 20 *DK cards*, the team should have around 7 *IS cards*. Because the team already has two *IS cards* at the beginning of the game, they only need to buy five more.

8.4.3 Game props required by level 3

When playing the game, players will manipulate different game props introduced before. The following table specifies each of them from six aspects: quantity, size, color, content, function, and relationship with other props.

Table 8.7: Specifications of game props

Category	Quantity	Size	Color (RGB)	Content	Function	Relationship with other props
Game board	1	A0	Print in color	• Name • Diagram of game flow • Indicators for RID coins and RID clocks • Indicators for the points of Up, Us, and P • Space for placing game cards	• Receive game cards • Indicate the game progress • Indicate the remaining budget of the company • Indicate the points of Up, Us, P gained	• Provide the space for placing other props
Company card	4	A5	Print in color	• Name • Picture • Description of company ambition and mission • Initial budget • Initial knowledge and skills	• Provide the information about the company	• At beginning of the game, each company has 2 DK cards and 2 IS cards
IS card	14	1/6 A4	**Blue** (91, 155, 213)	• Name • Serial number with color • Picture • Definition (one sentence) • Cost • DK cards obtainable (number and type)	• Introduce the IS strategy • Each IS card allows to unlock different kinds and different amount of DK cards	• Unlock DK cards
DK #1 (Testimony) card	6	A5	**Blood red** (102, 0, 0)	• Name • Serial number with color • Description of knowledge • Reward points of Up, Us, and P	• Provide the knowledge about urban mobility • Provide the points of Up, Us, and P	• The content of DK cards are useful to unlock Up, Us, and P cards
DK #2 card (Scientific data-	5	A5	**Apricot** (230, 153,	*Same as DK #1*	*Same as DK #1*	*Same as DK #1*

graph)			102)			
DK # 3 card (Scientific data-table)	4	A5	**Pink** (255, 192, 203)	Same as DK #1	*Same as DK #1*	*Same as DK #1*
DK # 4 card (Scientific data-quotation)	4	A5	**Gray** (128, 128, 128)	Same as DK #1	*Same as DK #1*	*Same as DK #1*
DK # 5 card (Media)	5	A5	**Fuchsia** (255, 0, 255)	Same as DK #1	*Same as DK #1*	*Same as DK #1*
DK #6 card (Observation)	6	A5	**Red** (255,0,0)	Same as DK #1	*Same as DK #1*	*Same as DK #1*
Up card	9	1/6 A4	**Yellow** (255, 255, 0)	• Name • Serial number with color • Picture • Description • Unlock cost (5 points of Up)	• Introduce relevant user profile • Help players to generate VBs	• Combine with Us and P cards to create a VB
Us card	9	1/6 A4	**Green** (0, 176, 80)	• Name • Serial number with color • Picture • Description • Unlock cost (5 points of Us)	• Introduce relevant usage situation • Help players to generate VBs	• Combine with Up and P cards to create a VB
P card	9	1/6 A4	**Orange** (255, 192, 0)	• Name • Serial number with color • Picture • Description • Unlock cost (5 points of P)	• Introduce relevant problem • Help players to generate VBs	• Combine with Up and Us cards to create a VB
Es card	9	1/6 A4	**Purple** (112, 48, 160)	Similar as Up card but without cost	• Introduce relevant usage situation • Help players to generate VBs	-

Efficiency profiles	3	A4	Print in color	• Name • Colored high-resolution line chart	• Introduce the relative efficiencies of solutions • Help players to generate VBs	-
Scoring sheet	1	A4	White and black	• Name • Table for recording all the results	• Let players record their outcomes	-
Template for value buckets	1	A4	White and black	• Name • Table for recording value buckets	• Record value buckets	-

8.4.4 Hidden data required by the gameplay

Hidden data refers to information that is not displayed or partially displayed to players, which is essential for the game design. There are five kinds of hidden data (Appendix G) embedded in the third game level. To generate all the hidden data, we organized two dedicated workshops.

1) The correspondence between *company cards* and pre-existing *DK and IS cards*. When the team selects a *company card*, it will receive the relevant two *DK cards*, and two *IS cards*. Their relationship needs to be defined. We designate cards related to their company profiles for each company and ensure that the total value of all initial cards of each company is similar. The initial cards we provide to players are determined based on the consideration of the knowledge and skills their company should have in reality. For example, as an IT company, MOBICOMPANION (Figure 8.11) should be good at mining useful information from the web. Thus the initial IS cards they have are "visit blogs" and "benchmark competing products and services." This company offers navigation services for different travelers, like non-transportation workers (Figure 8.16a) and tourists. Thus they probably have relevant knowledge about these two user profiles. Their first DK card is with news of a surge in tourists. The second one is a picture taken at the central subway station at the peak hour, which shows the workers crowded together.

2) The correspondence between *IS cards* and the *resources* spent. We need to define how much *RID clocks* and *RID coins* cost by each *IS card*. This data is developed by estimating and comparing the time and money cost by these strategies in reality. For example, "interview with people around you" is free and just takes a little time, so it costs 0 *RID coin* and only *5 RID clocks*. Compared with this strategy, "conduct in-depth interviews with users" should take more time and money. Therefore it costs *5 RID coins* and *10 RID clocks*.

3) The correspondence between *IS cards* and *DK cards*. This data links each *IS card* with one or more categories of *DK cards*. It also defines the number of *DK cards* that can be obtained through this *IS card*. The *IS cards* determine the six categories of *DK cards*. Each *IS card* only allows players to gain the knowledge that may be obtained by implementing the strategy in reality. The number of *DK cards* that each *IS card* allows to obtain is positively related to the resources (*RID coins* and *RID clocks*) it consumes. For example, the *IS card* "literature review" costs 20 RID clocks and 20 RID coins, so it allows players to get 6 *DK cards* of the categories of "quotation from the literature," "tables from the literature," and "figures from the literature" (2 cards per category). Players cannot gain access to the testimony from interviewees through this *IS card*.

4) The correspondence between *DK cards* and their *points of Up, Us, and P*. This data refers to defines how many *reward points* can be obtained from each *DK card*, which is entirely based on the card's specific content. The following DK card (Figure 8.21) contains the

testimony of a suburban resident. According to the card, we know that the story's protagonist is a non-transportation worker (*Up*). He commutes (*Us*) with suburban trains every day, but it takes him much time (*P*) to walk to the railway station. Thus this *DK card* provides one reward point of each type.

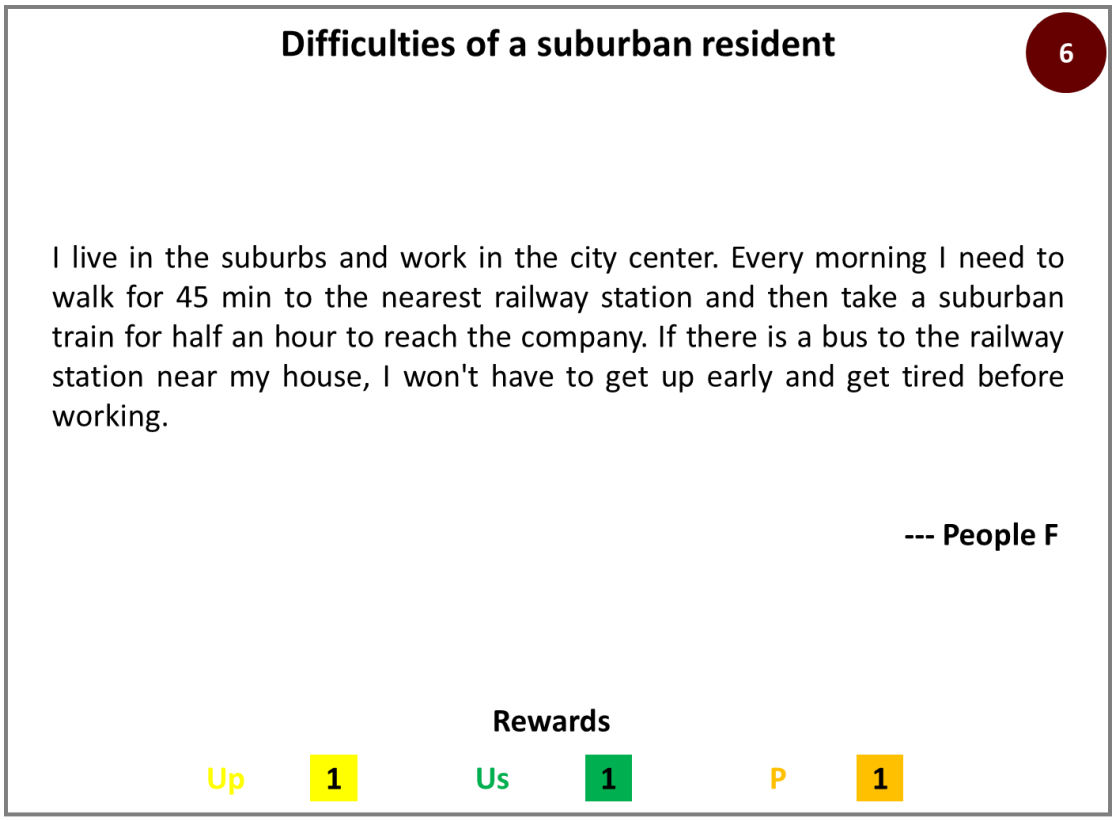


Figure 8.21: DK card: Difficulties of a suburban resident

5) Grading standards. The trainer will use this data to evaluate the VBs selected by players based on two criteria, *opportunity* and *usefulness*. For "opportunity," we need to define the preferable VBs for each company and their scores. To achieve this purpose, we discussed "in reality, the four companies in the game should focus on which Up, Us, and P" and then established a relevant scoring mechanism (Table 8.8) based on the discussion results.

Table 8.8: Scoring mechanism of the "opportunity"

Score	Explanation
0	If the Up, Us, P associated with the value bucket are all not concerned by the company, this value bucket gets no score.
1	If only one category of the Up, Us, and P associated with the value bucket is of concern to the company, then the value bucket gets one point.
2	If two categories of the Up, Us, and P associated with the value bucket are of concern to the company, then the value bucket gets two points.
5	If all the Up, Us, and P associated with the value bucket are of concern to the company, then the value bucket gets five points (Bonus!).

For example, we consider the company MOBICOMPANION (Figure 8.11) should focus on the categories shown in Table 8.9. If one team plays this role in the game and proposes a value bucket that "the tiredness (*P*) suffered by students (*Up*) when commuting to education (*Us*)," then the team can get five points.

Table 8.9: Up, Us, and P concerned by MOBICOMPANION

Dimension	Category
Up	Non-transportation workers, Students, Elderly travelers, Disabled travelers, Tourists, Short-term visitors, and Passing travelers
Us	Commuting to work or education, Commuting from work or education, Business travel, Leisure, and Travel in poorly-served area
P	Waste of time, Lack of comfort, Increasing the tiredness, Bad air quality, and CO2 emissions

The evaluation for "usefulness" is based on MarketVBs (Figure 8.22), which is computed by the DSM-Value-Bucket algorithm (Yannou, 2020) included in the RID methodology. We realistically drove the algorithm to identify the problems in urban mobility until generating MarketVB that reflects each value bucket's relative importance (usefulness) for each kind of users. The input data (matrices "WW," "UpEs," "Esp," and "UsEs") comes from two parts: scientific results in the relevant literature and one designer's urban mobility domain expertise. The output data, i.e., MarketVB, is automatically calculated by the Python code of the algorithm.

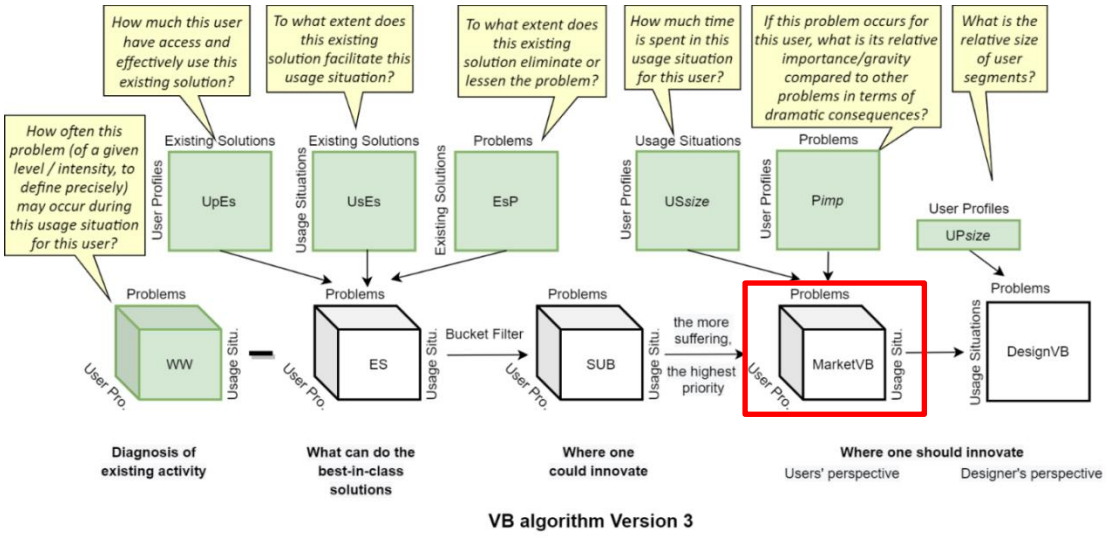


Figure 8.22: VB algorithm Version 3

We generated nine MarketVB matrices (one per user profile) to support the evaluation of value buckets from usefulness. For example, Figure 8.23 is the MarketVB matrix of transportation workers. Numbers in colored zones intuitively display each value bucket's (cell in the matrix) usefulness for this user profile. The higher the score, the stronger the usefulness of the value bucket.

Problem / Usage situation	Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
Commuting to work or education	0.375294446	1.96772924	2.096059408	1.725327812	0	0.22985359	0.900022244	1.0140935	0
Commuting from work or education	0.375294446	1.96772924	2.096059408	1.725327812	0	0.22985359	0.900022244	1.0140935	0
Business travel	0.642449338	1.225125336	1.32778947	1.145275454	0.33491322	0.563055741	0.55484261	0.6004711	0.515602097
Leisure	0	0	0	0.019106936	0.040267155	0.033879164	0.040381226	0.0460848	0.085439374
Shopping	0	0	0	0	0	0	0	0	0
Accompanying others	0	0	0	0	0	0	0	0	0
Emergency	0.398108699	0	0.376149981	0.100382709	0	0.01266191	0.132778947	0.1042611	0.035590233
Travel in a poorly-served area	0.519708662	0.59830376	0.681005424	0.69241255	0	0	0.011863411	0	0.152399204
Carry heavy weight	0.700853823	1.26619099	1.394521157	1.458686241	0	0	0.316205534	0	0

Figure 8.23: MarketVB matrix of transportation worker

A simplified matrix (Figure 8.24) is generated based on the previous one to facilitate the trainer to score the players' value buckets. This matrix transforms the original matrix numbers to the integers from zero to five. More specifically, the value bucket in the green area (Figure 8.24) has a score of 4 or 5 points (according to the original data), the value bucket in the yellow area has a score of 2 or 3 points, and the value bucket in the red area has a score of 1 or 0 points. With this simplified matrix's help, the trainer can quickly score each player's value buckets.

Problem / Usage situation	Waste of time	Lack of comfort	Increasing the tiredness	Lack of safety	Loss of public space	High maintenance costs	Bad air quality	Noise	CO2 emissions
Commuting to work or education	0	5	5	4	0	0	2	2	0
Commuting from work or education	0	5	5	4	0	0	2	2	0
Business travel	1	3	3	2	0	1	1	1	1
Leisure	0	0	0	0	0	0	0	0	0
Shopping	0	0	0	0	0	0	0	0	0
Accompanying others	0	0	0	0	0	0	0	0	0
Emergency	0	0	0	0	0	0	0	0	0
Travel in a poorly-served area	1	1	1	1	0	0	0	0	0
Carry heavy weight	1	3	3	3	0	0	0	0	0

Figure 8.24: Simplified MarketVB matrix of transportation worker

8.4.5 Pre-validation of the specification for game level 3

To pre-validate the specification of game level 3, we adopted two strategies. The first strategy is to evaluate the authenticity of the game through mapping expected game actions with real behaviors. If the gameplay is consistent with the process of using RID in reality, then the player is likely to be able to apply the knowledge learned in the game to practice. Table 8.10 matches the expected player's actions with the behaviors to complete a RID project in reality. Taking advantage of this analysis, we found that the third game level simulates the entire knowledge design and problem design sub-processes, but in a simplified and playful manner.

Table 8.10: Player's actions vs Real behaviors

Action in the game	Behavior in reality
Choose a company card	Participants in innovation projects are often organizations with different missions.
Purchase IS cards to unlock DK cards under consideration of resources	The innovation team needs to select efficient IS and then perform investigation activities to collect deep knowledge.
Throw dice or randomly pick to unlock DK cards	Deep knowledge is the outcome of conducting research.
Read and analyze DK cards	Design the books of knowledge and identify the Us, Up, P, and Es required by the DSM-VB algorithm.
Unlock Up, Us, and P cards by Q&A	The innovation team needs to collect and analyze all the deep knowledge required for the project. Based on this analysis, the team can model the four dimensions related to the concerned activity field.
Read three efficiency profiles of Es and propose VBs to the trainer	The innovation team should fully apply the DSM-VB algorithm to identify MarketVB, and then choose subset of VBs according to the voice of its company.

The second strategy is to analyze the design purposes that the current gameplay covers. Table 8.11 illustrates all the design purposes that this level has

covered. Based on such analysis, we found that as long as we follow the specification to design the third game level, the prototype will definitely achieve some critical design goals.

Table 8.11: Design goals covered by game level 3

Importance Level	Name of the element	Explanation
5	General breakdown	The game level 3 focuses on the knowledge design and problem design
	Four dimensions of value bucket	Players need to extract the Up, Us, and P from deep knowledge, and the Es are directly provided to help them generate VBs
	Analytical skills	Players need to analyze deep knowledge to identify Up, Us, and P; Players need to analyze VBs and define macro VBs considering Es and the company's mission
4	The representation as a production process	Players can experience the innovation cockpit and problem setting when playing this level; This representation will be shown on the game board
	Disruption	The gameplay of this level reflects a radical user-centered innovation
	System thinking skills	Players need to gather sufficient data to clearly understand the system through its different dimensions, not to miss something.
	Knowledge management skills	Players select IS cards, unlock DK cards, and then use the deep knowledge collected to model the three

		dimensions
	Synthesizing skills	A simplified practice of the DSM-VB algorithm
	Collective intelligence	The team requires all members to participate when making decisions
3	Computation of the value buckets (DSM-VB algorithm)	A simplified practice of the DSM-VB algorithm
	Determination of the ambition perimeter	The team needs to define macro VBs
	Problem-solution pairing	Players could have a reflection when reading the efficiency profiles of Es to develop this skill
1	Nature of an idea	The practice of the DSM-VB algorithm has partially covered this principle
	Thinking inside the box	Players start the game level 3 from an ideal goal defined by the user activity's clear boundaries.

8.5 Detailed design and prototyping

At this stage, we organized three workshop sessions. In the first session, we sketched each game prop (especially for different game cards; Figure 8.25) on the whiteboard according to their specifications (Table 8.7).

Figure 8.25: Sketch of game props

In the second session, we used drawing software to create templates for each prop based on the sketches to prepare for the prototyping. Figure 8.26 shows the front and back of the *Es card*' template. We also defined the content that should be shown on each game card. In the last session, we add the predefined images and text to each card and then printed out and cropped the cards. At this point, we had a first but complete game prototype ready to use for verification and validation.

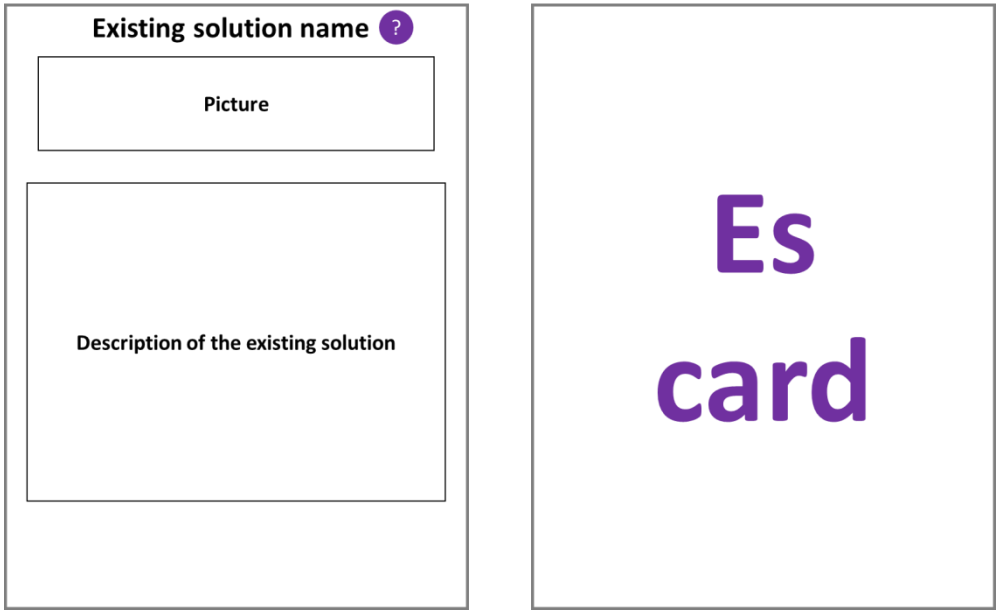


Figure 8.26: Template of Es cards

All the physical prototypes for different game props are included in Appendix H. Here we only offer three game instruction cards not mentioned before. Figure 8.27 is the *game process card*, a self-efficient prop for illustrating the overall gameplay. It is designed for players to understand what they will do and what they will manipulate during the game quickly. There are six challenges in the game. When players receive different game props, they can complete each challenge according to the guidance of this card.

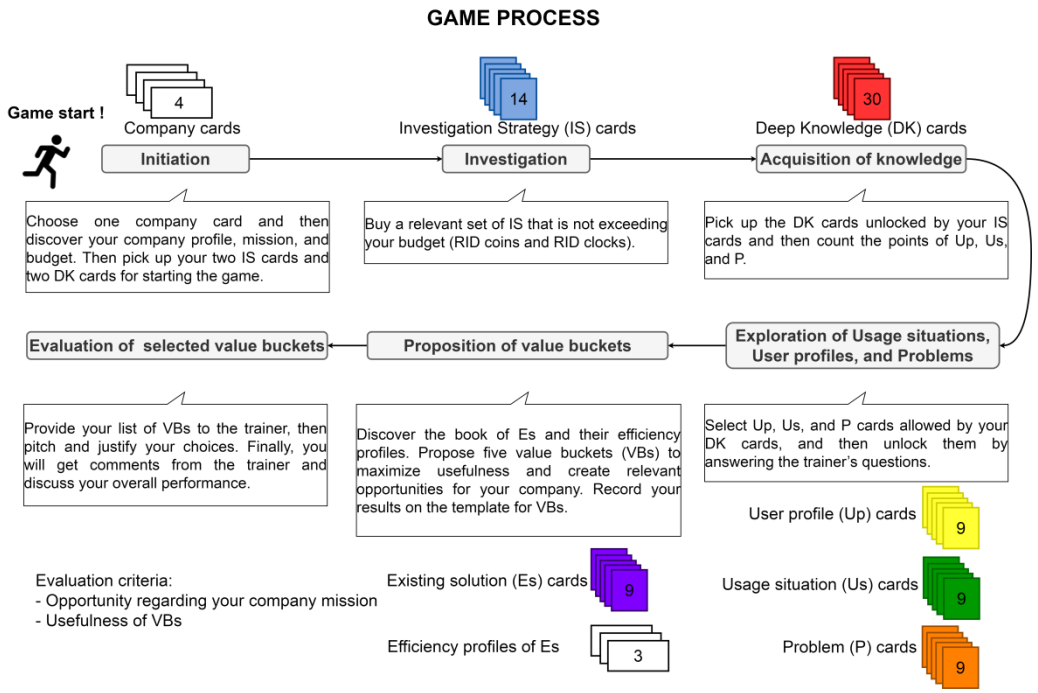


Figure 8.27: Game process card

The second card (Figure 8.28) is a supplement to the *game process card*. It focuses on describing some concepts related to RID and appearing in the game. All concepts are explained based on the game's story, i.e., a virtual innovation project on urban mobility.

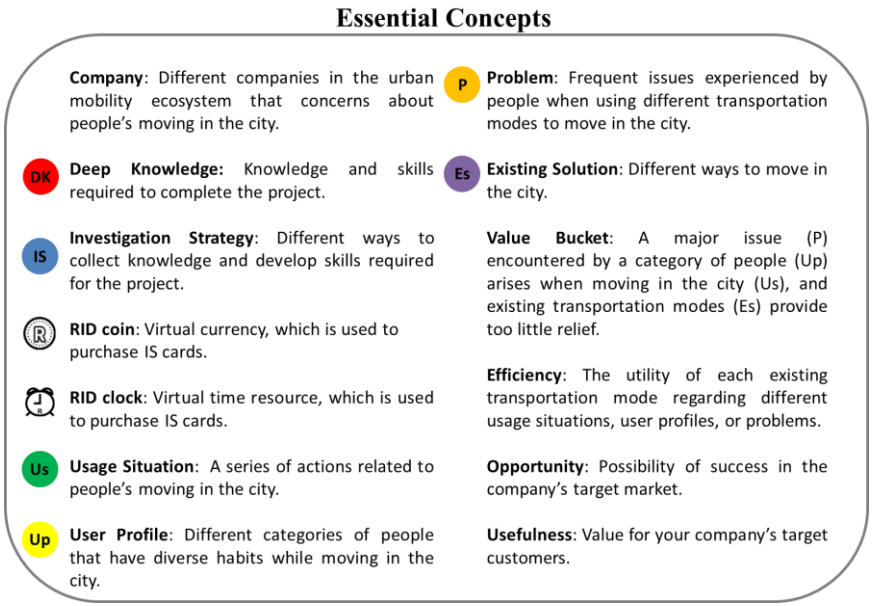


Figure 8.28: Essential concepts card

The last card named as *game props card* (Figure 8.29). It provides a detailed description of each game prop that appeared in the game process card.

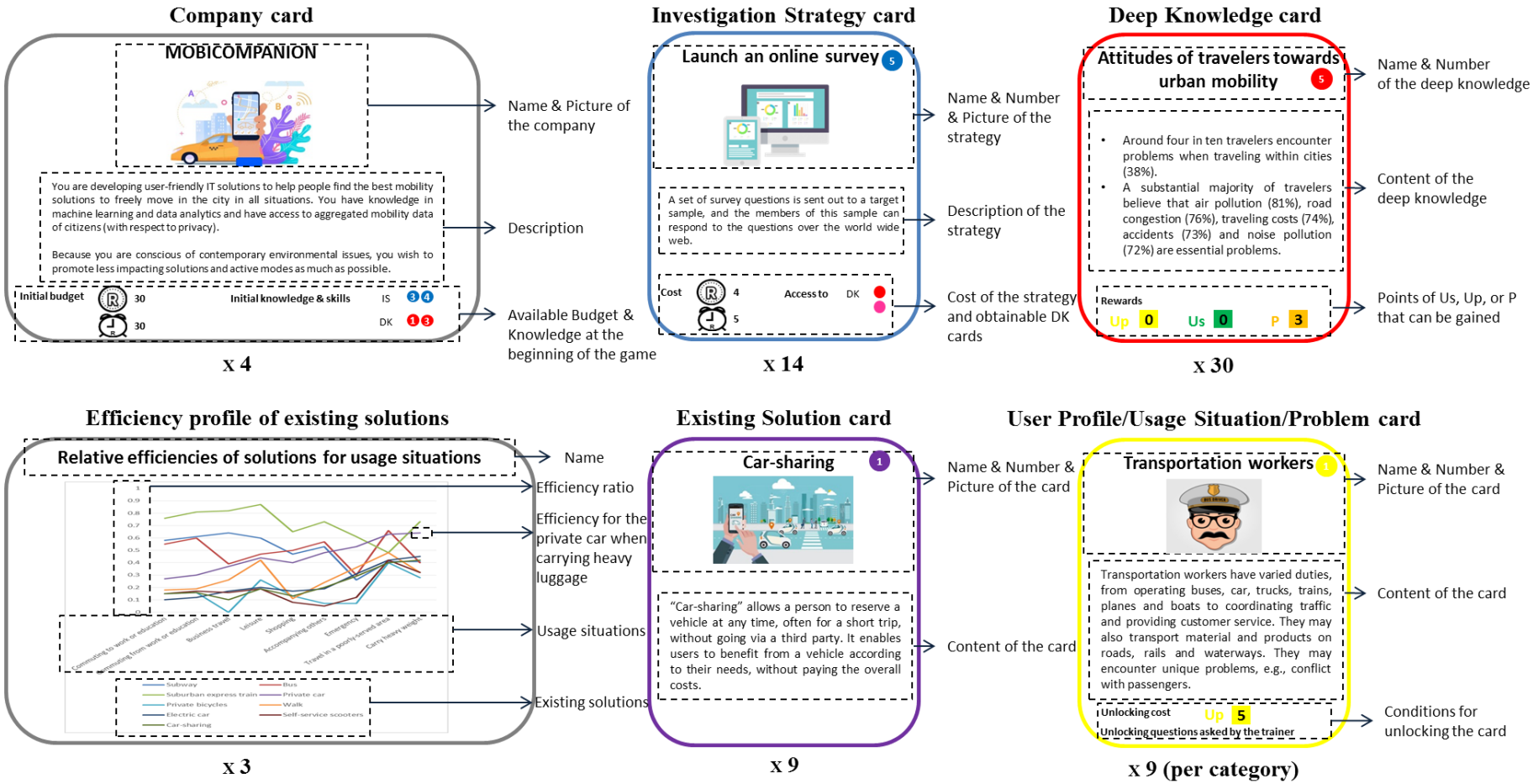


Figure 8.29: Game props card

8.6 Conclusion

This chapter details the conceptual and detailed design phases of a practical application (RID game) we designed based on the adapted V-model. Its gameplay is about expressing and eradicating value buckets on urban mobility. The game comprises six challenges, a game board inspired by the RID process, seven card decks (in total 84), sophisticated game mechanics, and a simple two-dimensional scoring for fighting simultaneously for developing usefulness for mobility users and business opportunity for its own mobility company. More importantly, with the help of this game, we offer a quantitative scale for defining the design purposes of the SGs on IE methodologies, which is adapted from Bloom's taxonomy. We also explain how to organize workshops to design the different SG elements and write specifications, offering novice designers sufficient guidance for creating their own games. The next chapter reveals how we validated the prototype with potential users.

Chapter 9. Validation of the innovation serious game

This chapter aims to illustrate how we verify and validate a first prototype of the serious game (SG) on Radical Innovation Design (RID) methodology following the adapted V-model. We detail the processes for planning and organizing one verification session and two validation sessions. The related results are also reported. The prototype for the RID game meets all the specifications generated at the conceptual design phase. According to users' positive feedback, the game achieves its designated design purposes, delivering a playful and effective learning experience.

9.1 Verification of the RID serious game

The verification activities refer to the tasks to check whether the functional prototype generated at the detailed design phase is consistent with the specifications of three systematic layers proposed in the V-model (game challenge layer, game level layer, and game system layer). The designers should first evaluate the playability of serious games (SGs) by themselves before inviting real users to do the validation.

We, the four designers of the Radical Innovation Design (RID) game, organized a dedicated session to complete the game's verification. The session started by reviewing the specification made for the whole RID game. Even though we only designed the game level 3 (*Knowledge design & Problem design*), there is a need to ensure the interfaces between this game level and other levels are fully developed. We must provide users with the results they should obtain (according to the specification) in the previous level when they start the third level. After their playing, users should also get the outcomes needed to start the fourth level. Then, we recalled the specifications of level 3 as well as its related six game challenges (*Initiation, Investigation; Acquisition of knowledge; Exploration of user profiles (Up), usage situations (Us), and problems (P); Proposition of value buckets; Evaluation of proposed value buckets*). With all the necessary information in mind, we began to verify the game. All the design elements that belong to level 3 should be verified at this stage.

Table 9.1: Verification objects of the RID game

Verification object	Description
Interface between levels 2 & 3	• Whether the "ideal goal" has been clearly stated and can be conveyed to players at the beginning of level 3.
Interface between	• At the end of level 3, whether players understand reasonable

levels 3 & 4	choices of value buckets and be able to create the ambition perimeter.
Game props	• The size, color, function, quantity, and content of each game props should respect its specification. • The predefined relationships between game props should be realized.
Gameplay	• The prototype needs to implement the predefined gameplay in a smooth way, which means that the interfaces between the six game challenges should be verified.
Evaluation	• Whether the trainer can quickly evaluate the player's performance, i.e., scoring the value buckets proposed by the player based on the opportunity and the usefulness and giving feedback. • The pedagogical evaluation of players' performance so as to propose valuable feedback concerning their learning of innovation engineering
Information	• The content on different props should be the same as designed.
Aesthetics	• The clarity of the picture on each game card. • The consistency of the appearance of the same kind of cards (the position of the serial number, the size of the illustration, etc.). • The color of game cards (prevent the colors of different types of cards from being similar).
Design constraints	• The game's duration should not exceed two hours to be embedded in a half-day RID training.

At the beginning of the game, the "ideal goal" (interface between levels 2 and 3) that "proposing solutions to solve or elevate the problems encountered by travelers in situations of moving in big cities" has been clearly stated. We decided to directly tell it to users during the two upcoming validation sessions. We imagined ourselves as players who do not know of the game, then experienced the entire game. We first read the three *game instruction cards* (*game process card*, *game props card*, and *essential concepts card*) and imagined which kind of minimal information players should get before to understand these cards. Thanks to these cards, we understood the game process and had an initial impression of all types of game props. We followed the instruction provided by the *game process card* to simulate level 3, started by selecting one *company card* until evaluating value buckets. Based on the hidden data "grading standards," we knew the reasonable choices of value buckets, which met the prerequisite of starting the next game level. Thus, the interface between levels 3 and 4 had been reasonably designed. We confirmed that the current game could achieve the expected gameplay through this simulation, and the prototypes of all game components are in full compliance with the related specifications. However, through this verification, we found three aspects that need to be improved urgently. Some pictures on *deep knowledge (DK) cards* were not clear enough. Second, the colors of the two categories of *DK cards*' were two similar. The third problem was that we directly applied the abbreviations of some vocabulary (Up, Us, P, Es, and VBs) in the RID methodology to game props without giving the full names, which

would make it difficult for players to understand. We solved these problems and re-prepared the prototype. Besides, it took about an hour to simulate the entire game process (including exchanging ideas for improvement). However, as designers, we are very familiar with the gameplay, so whether players can complete the game in two hours remains to be verified.

More importantly, we improved the validation experiments' plan with the help of this verification session.

- To give players an effective training experience, we refine the content of introductory speech (introduction to RID and to the RID game) to trainees.
- The timing and instructions for each game challenge was modified.
- We envisioned the questions they could have and came up with answers.
- We also better prepared the pedagogical feedbacks, providing a part they could have played.
- Beyond the verification of the use of RID in the training session, we prepared a welcome ceremony of the experience subjects.
- We checked if all the participants answered the pre-questionnaire and prepared the post questionnaire to ensure that it could be sent to them just after the session.

At this point, we completed the verification of the RID game. The next step was to invite players to test the game in a ***typical training situation*** and gather their feedback. The design constraints define the game's typical training situation as "it will be used for a one-day RID training, and the training also includes all the necessary teaching content for a full training session." Thus, playing level 3 requires half-day. The validation requires advanced planning. We made a precise and practical validation plan, which is introduced in the next section.

9.2 Validation plan of the RID serious game

This section presents a detailed plan for organizing the two validation sessions of the RID game. It first clarifies the validation sessions' objectives and, based on which we determined the relevant list of participants. Then the structure of the two sessions is stated. Finally, the method "pre- and post-test" and related questionnaires to validate the game are introduced.

9.2.1 The objectives of the two validation sessions and the participants

We planned to hold two validation sessions, one for beginners (students or professionals who are not familiar with RID) and the other for experienced people (professionals who are familiar with RID). We realized that experienced people are more likely to give us suggestions to improve the RID game's learning experience. Therefore, we decided to let experienced people experience the game first. Based on their feedback, we could adapt the game to provide a better experience for beginners. Thanks to these two complementary

sessions, we were able to collect data for validating different aspects of the RID game. The objectives of these sessions are summarized in Table 9.2.

Table 9.2: Objectives of the two validation sessions

Objectives	Session for experienced people	Session for beginners
Unique	• Test whether a half-day training using the RID game is more efficient than a lecture course	• Test whether a half-day training using the RID game can allow players to retain knowledge • Test whether a half-day training using the RID game can stimulate their motivation to further learning
Common	• Test whether the RID game provides an exciting gaming experience • Collect participants' feedback to improve the RID game	

Regardless of the participants, they must be selected to be able to play the role of future potential users of the RID game in one of the two following situations:

- They could be asked to play the role of professionals exerting some missions in a company linked to innovation management, with an intrinsic motivation to learn more about it;
- They could be asked to play the role of students who choose it in their curriculum to initiate learning innovation management with a vague or firm intention to consolidate their knowledge.

We defined the candidates (Table 9.3) for the two validation sessions based on these criteria. Hence, the participants must already have (a) the appropriate educational background and (b) the motivation corresponding to play the role corresponding to one of the two evoked apprenticeship situations of innovation management.

Table 9.3: Candidates for the two validation sessions

Experienced people	Beginner
Team #1 • Participant A • Participant B	**Team #3** • Participant E • Participant F • Participant G
Team #2 • Participant C • Participant D	

In addition to validating the RID game, we also wanted to take advantage of this chance to explore two aspects that are important to the future development and deployment of the game:

- The appropriate number of players in each team;
- Whether putting the pressure on the importance of scoring and the limited time at each episode could augment the player's gaming experience.

Based on the above two intentions, we deliberately asked the four participants in the first

session to freely constitute two teams and represent different companies when playing the game. It allowed us to observe in two contexts which kind of requests for further explanations they could have and how much time they needed to complete each episode. In the second session, three participants played together in the same team so as to augment the playability and with more time pressure.

9.2.2 Validation sessions planning

After determining the two validation sessions' objectives, we planned the two sessions and completed all the preparations. The planning mainly covers the following aspects:

- Activity: A series of consecutive steps of the validation session;
- Time & Duration: The start and end time of each activity;
- Objective: The significance and expectation of each activity;
- People & Role: The person who should complete the activity and his responsibilities;
- Required material: The documents, slides, or equipment that are needed for completing the activity.

Each session lasts three hours and has three parts. The first part aims to introduce the validation session's schedule and objectives. We expected each participant to play **two distinct roles** during the session (Figure 9.1).

- The role of a ***future trainee***, who begins in innovation management (in RID at least), and wants to acquire the basics of RID in a one-day funny session, to know if he deepens or not for the benefit of his new company mission.
- The role of an ***experimental subject***. Participants should act themselves like in reality and provide the feedback required to validate the game.

Figure 9.1: The two distinct roles of participants

Then, they must play the game while forgetting the validation experiment in which they are involved. They should behave like a ***trainee***. During this period, participants are expected first to understand the game, play the game and get feedback from the trainer about their performance, a typical layout for an SG (e.g., Consortio game; Jeu IØ, 2016). Finally, there is a debriefing session for participants as the ***experimental subjects*** to report comments about the game validation.

Prof. Yannou is the founder of the RID methodology, has decades of RID teaching experience, served as the trainer for the session, and other organizers will act as facilitators. The planning of the two validation sessions is basically the same. There is only one difference regarding the slides presentation provided by the trainer. The intensity of the presentation of the innovation management as well as the RID methodology will be higher during the validation session for the experienced person, which matches their receptivity.

9.2.3 Questionnaires

We adopted a pre- and post-test approach in the two validation sessions. The questions used in the pre-questionnaire and the post-questionnaire should respect the objectives set in Table 9.1. The pre-questionnaire (it takes 10~15 minutes to complete) was sent to participants before the validation session, and we made sure that replies from all participants were received before the session starts. We sent the post-questionnaire (it takes 15~20 minutes to complete) to participants after the validation session and reminded them to fill it in. These questionnaires mainly contain two types of questions, multiple-choice questions and short answer questions. Each questionnaire is starting with a brief introduction to explain the goals of the questionnaire. The detailed questions are introduced below.

9.2.3.1 Pre-questionnaire for experienced people

First, for experienced people, the pre-questionnaire (Table 9.4) should allow making sure they fit the characteristics of potential future users of the RID game and assess what they know about innovation management (Q1 ~ Q4). Second, it is expected to help us understand participants' attitudes (efficiency and attractiveness of serious gaming) towards serious games before experiencing the RID game (Q5 ~ Q6). At the end of the questionnaire, there is a general open question (Q7) to collect respondents' opinions and questions on the questionnaire itself and the RID game.

Table 9.4: The pre-questionnaire for experienced people

Q1	*Could you please briefly describe your current work position or educational background?*
Q2	*How do you evaluate your expertise in the following methodologies (from 0 to 5)?* • Design Thinking • Creativity • Project Management

<table>
<tr><td></td><td>
• C-K theory
• TRIZ
• Blue Ocean Strategy
• Lean Startup
• Radical Innovation Design
<table>
<tr><th>Rate</th><th>Category</th><th>Definition</th></tr>
<tr><td>0</td><td>N/A</td><td>You have not enough information about this methodology</td></tr>
<tr><td>1</td><td>Newbie</td><td>You begin to learn this methodology and still have some confusion about related basic concepts</td></tr>
<tr><td>2</td><td>Learner</td><td>You know basic concepts, but cannot apply of this methodology in practice</td></tr>
<tr><td>3</td><td>User</td><td>You can apply the methodology in a simplified manner</td></tr>
<tr><td>4</td><td>Professional</td><td>You can apply the methodology thoroughly to solve real-life problems</td></tr>
<tr><td>5</td><td>Expert</td><td>You can apply the methodology flexibly and even adapt it according to your needs</td></tr>
</table>
</td></tr>
<tr><td>Q3</td><td>When you think of RID, what are relevant words come to your mind? Please list them.</td></tr>
<tr><td>Q4</td><td>Have you participated in any innovation projects? If so, how many?</td></tr>
<tr><td>Q5</td><td>Imagine if you are a beginner at RID. What are your perceptions of the effectiveness of two approaches for learning RID: a serious game and a lecture course? Can you justify your answer?
- Serious game is far less effective than a lecture course
- Serious game is less effective than a lecture course
- Serious game is as effective as a lecture course
- Serious game is more effective than a lecture course
- Serious game is significantly more effective than a lecture course
- I do not know</td></tr>
<tr><td>Q6</td><td>Imagine if you are a beginner of RID, how do you evaluate your motivation to learn it by playing the RID serious game?
- I have no motivation
- I have a little motivation
- I have a moderate motivation
- I have a lot of motivation
- I have full motivation
- I do not know</td></tr>
<tr><td>Q7</td><td>Do you have any comments or questions?</td></tr>
</table>

9.2.3.2 Post-questionnaire for experienced people

Taking advantage of the post-questionnaire (Table 9.5) for experienced people, we first want to know the game can bring them something valuable (Q1). They should help us judge whether some RID concepts in the game are easily accessible to beginners (Q2 ~ Q3). Third, it is necessary to measure the participants' attitudes towards serious games after experiencing the RID game (Q4 ~ Q5). By comparing the answers to the questions regarding this same aspect in the pre-questionnaire and the post-questionnaire, we will be able to apprehend if the game is exciting and effective. To evaluate the different aspects of the gaming experience (immersion, flow, competence, positive and negative affect, tension, and challenge), we adopt the acknowledged Game Experience Questionnaire (GEQ) developed by Ijsselsteijn et al.

(2013). For each aspect, we select two items from the "Core Module of GEQ" and establish Q6. Finally, we also need to collect their feedback to improve the game (Q7 ~ Q9).

Table 9.5: The post-questionnaire for experienced people

<table>
<tr><td>Q1</td><td>Compared with your previous knowledge of RID, did you discover some new RID notions or gain some new insights during the game?</td></tr>
<tr><td>Q2</td><td>Do you think some RID notions (e.g., user profile, problem, usage situation, value bucket, etc.) in the game are difficult to understand for beginners?
- All notions are clear
- Some notions are unclear
- All notions are unclear
- I do not know</td></tr>
<tr><td>Q3</td><td>If you think some RID notions are unclear in the game, please list them and justify your answer.</td></tr>
<tr><td>Q4</td><td>Imagine if you are a beginner at RID. What are your perceptions of the effectiveness of two approaches for learning RID: a serious game and a lecture course? Can you justify your answer?
- Serious game is far less effective than a lecture course
- Serious game is less effective than a lecture course
- Serious game is as effective as a lecture course
- Serious game is more effective than a lecture course
- Serious game is significantly more effective than a lecture course
- I do not know</td></tr>
<tr><td>Q5</td><td>What is your motivation when playing the RID serious game?
- I have no motivation
- I have a little motivation
- I have a moderate motivation
- I have a lot of motivation
- I have full motivation
- I do not know</td></tr>
<tr><td>Q6</td><td>Please indicate how you felt while playing the game for each of the items, on the following scale:
<table><tr><td>Not at all</td><td>Slightly</td><td>Moderately</td><td>Fairly</td><td>Extremely</td></tr><tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td></tr></table>- I felt skillful
- I was interested in the game's story
- I thought it was fun
- I thought about other things
- I felt bored
- I enjoyed it
- I was fast at reaching the game's targets
- I felt annoyed
- I lost track of time
- I felt challenged
- I was deeply concentrated on the game
- I felt frustrated
- It felt like a rich experience
- I had to put a lot of effort into it</td></tr>
<tr><td>Q7</td><td>What did you like the least during the game?</td></tr>
</table>

Q8	*What did you like the most during the game?*
Q9	*Do you have any suggestions for improving the game?*

9.2.3.3 Pre-questionnaire for beginners

The pre-questionnaire for beginners is similar to that for experienced people (Table 9.4). The only difference is that the sixth and seventh questions are expressed differently. We asked experienced people to imagine themselves as beginners and then evaluate their motivation to learn RID through an SG and their perceptions of the game's effectiveness.

9.2.3.4 Post-questionnaire for beginners

For beginners, they are supposed to have no previous learning experience about RID. The post-questionnaire (Table 9.6) should first let us understand the game's effectiveness, i.e., if players have mastered some knowledge during the game (Q1). Second, we regard the RID game as a teaching tool that allows learners to understand and practice RID in a simplified manner, and it must be a motivating starting point for them to further learning RID. The evidence to prove this expectation should be gathered (Q2). This questionnaire also requires measuring the participants' attitudes (Q3 ~ Q4) towards serious gaming after playing, evaluates gaming experience (Q5), and collects their feedback (Q6 ~ Q8).

Table 9.6: The post-questionnaire for beginners

Q1	*After playing the game, what you have learned about RID? Please describe it in a few sentences.*
Q2	*Does the game stimulate your motivation to learn more about RID? Can you argue your answer?*
Q3	*How do you evaluate the effectiveness of serious gaming as an educational approach? Can you argue your answer?* - Not effective - Somewhat effective - Effective - Very effective - Extremely effective - I do not know
Q4	*How do you evaluate your motivation when playing the RID serious game?* - I have no motivation - I have a little motivation - I have a moderate motivation - I have a lot of motivation - I have full motivation - I do not know
Q5 to Q8	*[They are the same than Table 9.5's]*

9.3 Validation sessions of the RID game

This section replays the two validation sessions. The first one was held on 23.02.2021, and the second on 26.02.2021. Each session started at about 9:00 am and ended around 12:30 pm. Before starting each session, we welcomed the participants and let them have a short break so as to get ready for the validation session. Each session started with a clear introduction of the validation session's objectives and the two roles of participants (Figure 9.2). After participants adjusted their role as future trainees, a half-day training on RID began.

Figure 9.2: Validation session for experienced people

Then, the trainer introduced some essential concepts of RID in only 4 slides - about 10 minutes -, especially those participants can experience when playing the game, like user profile, usage situation, problem, existing solution, value bucket, etc. He also explained that the training only covers the knowledge design and problem design sub-processes of RID.

After this short introduction of RID, the game session was started. The trainer first vividly described the RID game's story to bring the participants into the game world. Then, he introduced the gameplay (Figure 9.3), game goals, and also the game process. Participants understood they were companies involved in the urban mobility ecosystem. At the end, they had to generate and select five value buckets based on the two important criteria, **usefulness** and **opportunity**, and some pedagogical debriefing was expected.

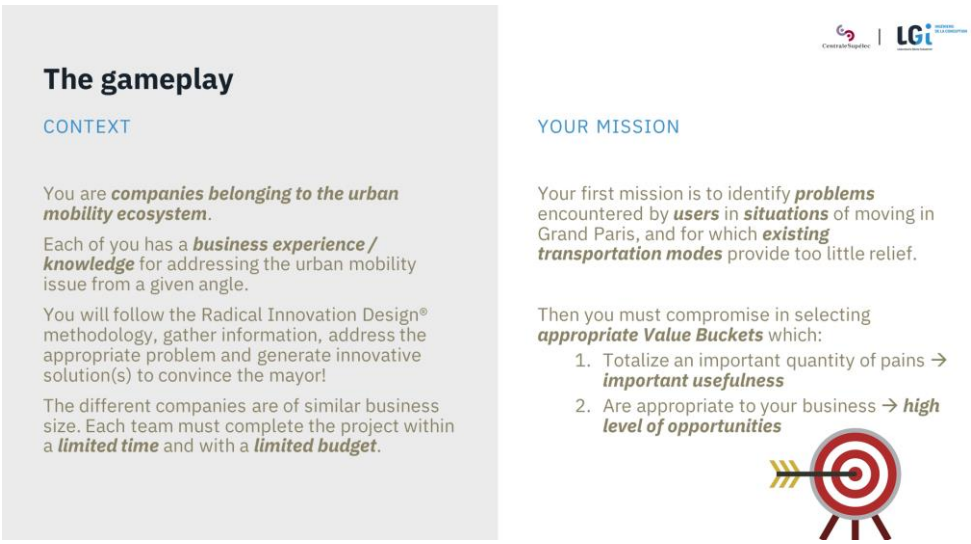


Figure 9.3: Gameplay of the RID game

Participants could read the three game instruction cards (*game process card, game props card, and essential concepts card*) while listening to the trainer (Figure 9.4). At this point, participants had a preliminary understanding of what challenges they need to complete and what props they need to use. They also knew that the results need to be recorded on the *scoring sheet* and the *template for value buckets*. Of course, when participants have any questions, they will be answered by the trainer or facilitators. When participants had no doubts about the game rules, the game officially began.

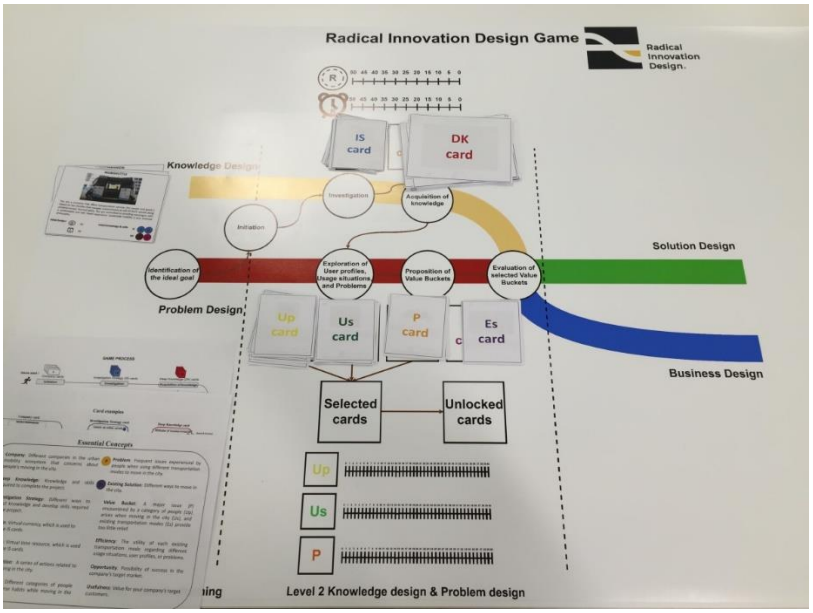


Figure 9.4: Game props of the RID game

Below we focus on describing the first validation session's experience and reporting all the differences between the first and the second session.

Game challenge 1: Initiation

Participants in the first validation session were asked to constitute two teams. Then they read the four company cards and make a decision (Figure 9.5). Team #1 chose MOBICOMPANION (offer GPS navigation service), and Team #2 chose MOB & PARK (offer parking rental service). The third team in the second session chose MOBISHUTTLE (offer transportation services). Each team then picked up its two initial *DK cards*, and two *IS cards* and indicated their initial budget (*RID clocks* and *RID coins*) on the game board (Figure 9.6). The trainer re-emphasized two indicators (*usefulness* and *opportunity*) that participants need to be aware of throughout the game.

Figure 9.5: Choose company card

Game challenge 2: Investigation

The trainer first introduced this game challenge and the relationship between *IS cards* and *DK cards*. Participants viewed all *IS cards* at this time and make the most of their budget to purchase some of them. Whenever a team purchased an IS card, they needed to adjust the two sliders on the game board to show their remaining budget (red area in Figure 9.6). When the participants had insufficient resources to purchase any additional *IS cards*, they ended this game challenge.

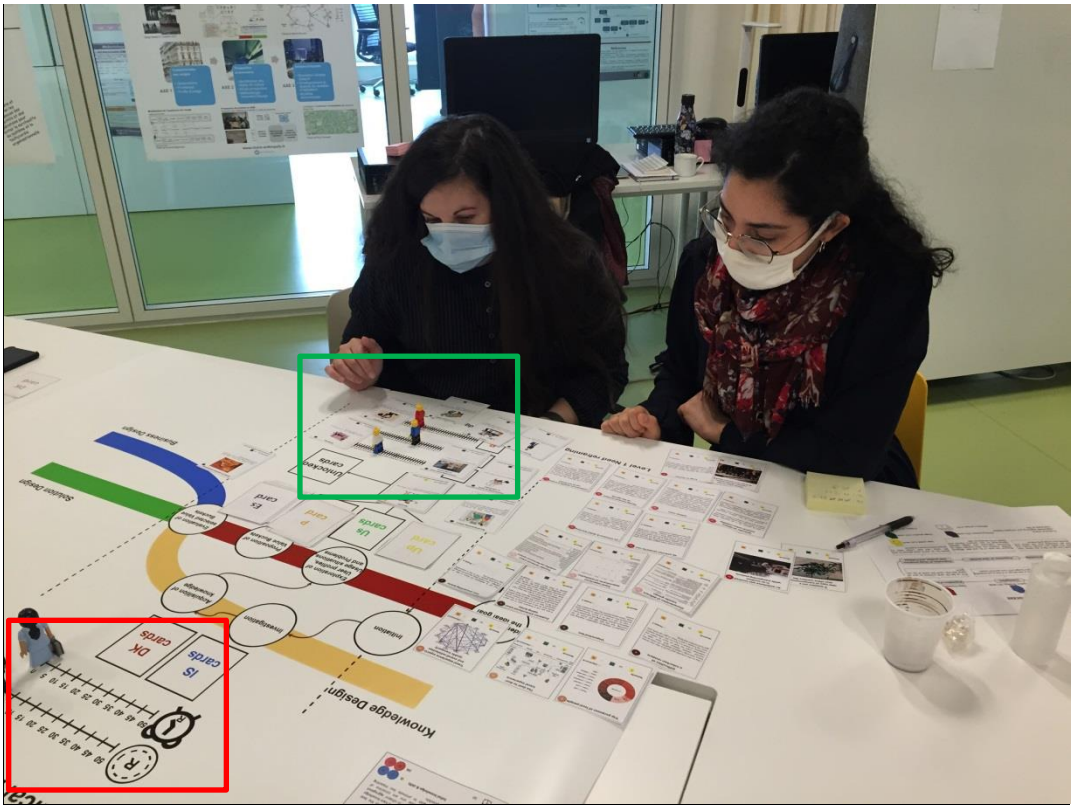


Figure 9.6: Indicators for RID clocks and RID coins (in red) and indicators for the number of Up, Us, and P collected points (in green)

Game challenge 3: Acquisition of knowledge

Participants were now allowed to view all *DK cards*. Depending on the color and number of the relevant *DK cards* shown on their *IS cards*, they randomly picked up all the obtainable *DK cards*. Then, participants were asked to read the contained information on their *DK cards* carefully to get ready for unlocking some *Up/Us/P* categories in the next step. Participants got the reward points of *Up/Us/P* from each *DK card*. They calculated each type's total score and indicated the results on the game board (green area in Figure 9.6).

During the second validation session with Team 3, we merged the two stages of buying *IS cards* and picking and reading *DK cards* immediately for more strategic reasoning on the next investigation strategy that could be the most appropriate for the next play. By judging the reliability and richness of the information on the card, they made a better choice. Such a change helps to improve the authenticity of the game. Because in reality, people will analyze what additional knowledge they lack, this will determine their next investigation activities.

Game challenge 4: Exploration of Usage situations, User profiles, and Problems

Participants read all the *Us*, *Up*, and *P cards*. For selecting a card, it requires the team to spend five reward points of the corresponding type gained before. Each team in the first session team chose some cards that they considered are consistent with their company mission,

as well as juicy in terms of contributions to Value Buckets. In the next step, they answered the unlocking questions related to their choice of cards. Facilitators (Figure 9.7) checked players' answers, and finally, Team #1 got all the cards of their choice, Team #2 lost one *Up card*, and Team 3 lost two *Us cards*.

In the first session, both teams spent much time on this challenge because they did not read the *DK cards* carefully in the previous stage. Therefore, in the second validation session, we emphasized the importance of the *DK cards* and set a strict time limit for each part of the game to put the participants under reasonable pressure like if they were responding to a quiz. We also provided them an answer sheet so they can clearly propose an answer that will be validated or not by the facilitator.

Figure 9.7: Unlocking Up, Us, and P cards

Game challenge 5: Proposition of Value Buckets

At the beginning of this challenge, each team received nine *Es cards* and three *efficiency profiles* of existing solutions. The trainer introduced the two props and asked each team to generate five value buckets by combining their unlocked *Up, Us, and P cards* with considering the usefulness and the opportunity (Figure 9.8). After a heated discussion, each team chose five value buckets, recorded them on the *template for VBs*, and handed them over to the trainer.

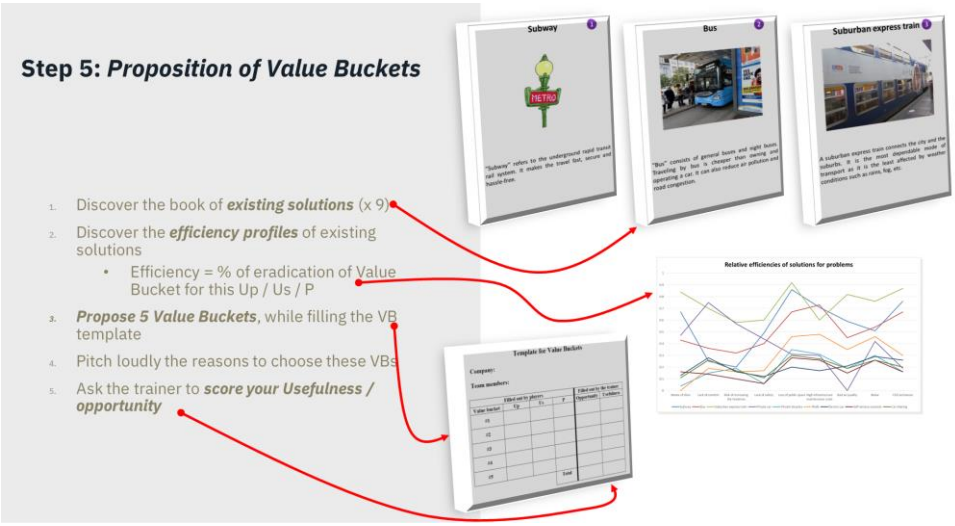


Figure 9.8: The introduction of the challenge "Proposition of value buckets"

Game challenge 6: Evaluation of the selected value buckets

Before the start of the sixth challenge, the participants had a 10 minute break. The trainer used this time to score each team's value buckets based on the hidden data introduced in Chapter 8 and display the results on a two-dimensional graph (red area in Figure 8.20). Figure 8.20 shows the 2D graph generated in the second validation session. The trainer compared the performance of Team #3 with the previous two teams. As shown in Figure 8.20, Team #1 and Team #3 got the same usefulness score, and the latter's opportunity score is higher. Team #2 Pareto-dominates the other two teams.

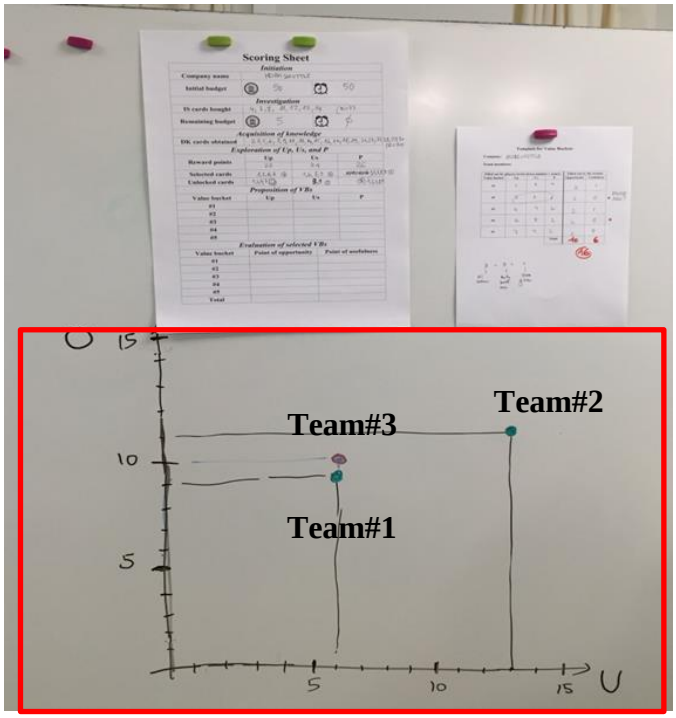


Figure 8.20 in Chapter 8: Evaluation of players' performance

In addition to scoring each team's performance, the trainer also explained the scoring

mechanism and indicated some possible good choices of VBs (Figure 9.9) for each team according to their company missions.

Figure 9.9: Value bucket recommendations

Participants finished the entire game session and were asked to have general debriefings, which constituted three parts. The trainer recorded all the feedbacks on the whiteboard (Figure 9.10).

- Report what they have lived land learned as ***trainees***;
- Feedback as ***experimented subjects*** on this potential future training solution for beginners;
- Feedback as ***experimented subjects*** on this game solution and necessary improvements.

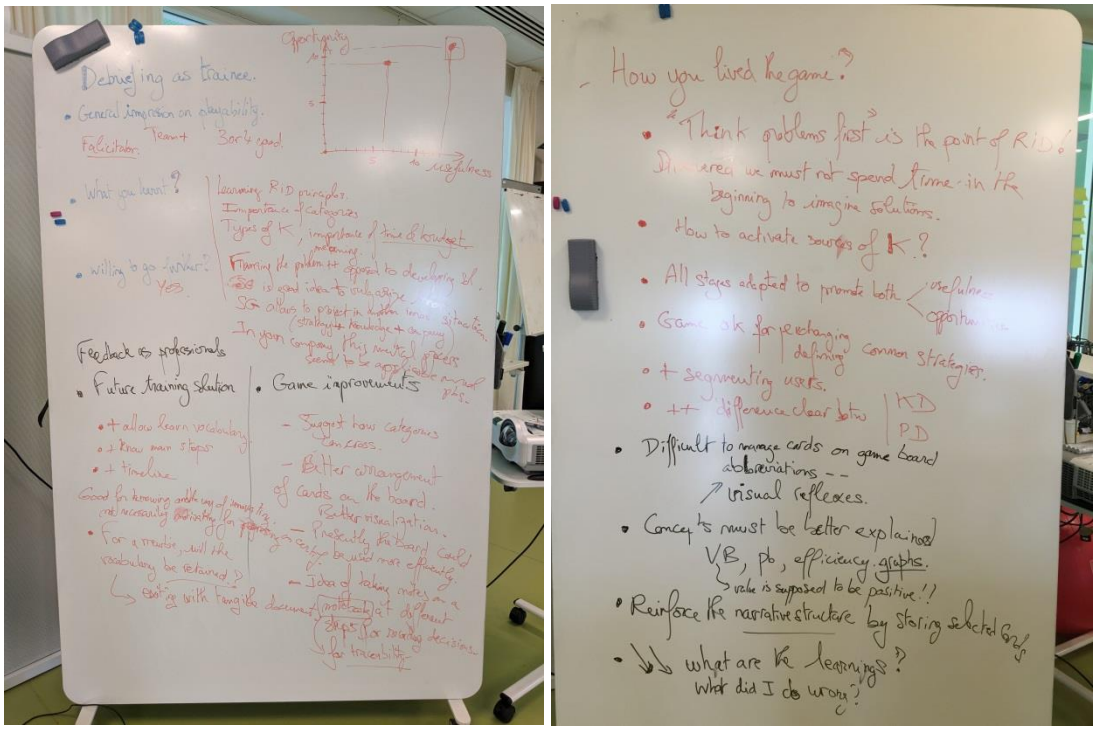


Figure 9.10: Debriefing results of the two validation sessions

The information gathered during the sessions and questionnaires' answers contribute to the validation of the RID game. These questions respect the validation sessions' objectives to understand participants' perceptions about the game's learning experience and gaming experience. Although these questions seem to overlap with the post questionnaires, we intended to collect their "fresh thoughts" when they had just finished playing the game. These valuable opinions are likely to be forgotten when the participants fill out the questionnaire after a few days. We present all the feedback provided by the participants in the next section.

In the first validation session, participants had already given some ideas for improving the RID game. To give the other three participants a better experience in the second session, we tried to modify the game based on these comments. Table 9.7 shows what had been improved before the second session.

Table 9.7: The RID game improvements after the first validation session

Improved objects	Description
DK card	• Increase the size of the card • Improve card colors to prevent confusion of DK cards of different categories
Up card	• Improve the color of the card to make it easier to read the content on the card
Company card	• Add a name to the back of the card to distinguish it from other cards
Efficiency profiles	• Increase the size of the figure
Game board	• Better visual representation of the entire RID process on the game board and to better show how the four dimensions of the value bucket are related in the game • Make better use of the space of the table board so that it can receive all the cards
Gameplay	• Set time limits to each game challenge • Integrate the two first game challenges: after purchasing a IS card, the player can immediately obtain the DK cards related to it
Unlocking questions sheet	• Update the question sheet with cells for answers
Introduction of the game	• A more visual support for the steps, allocated times, and subsequent steps throughout the game. • A better explanation of game rules and the function of each card

For example, the size of *deep knowledge (DK) cards* is too small to look at their content. We solved this problem by increasing their size to A5. Figure 9.11 compares the prototype before and after the improvement of the *DK card*.

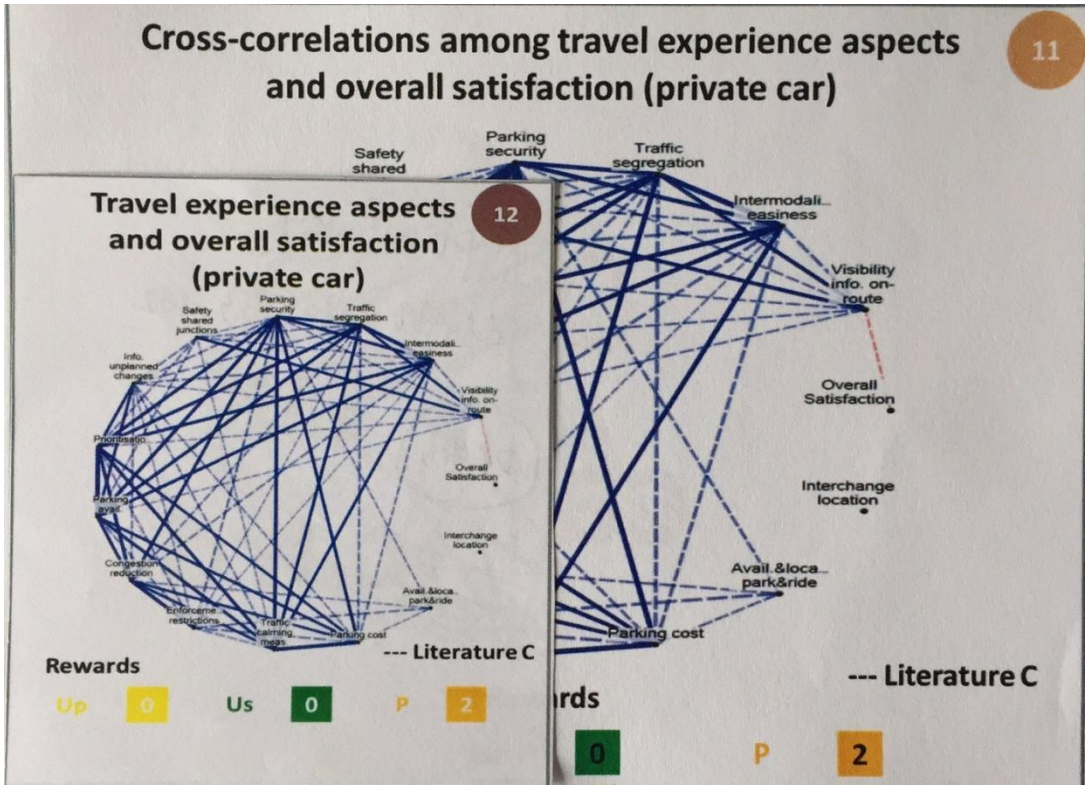
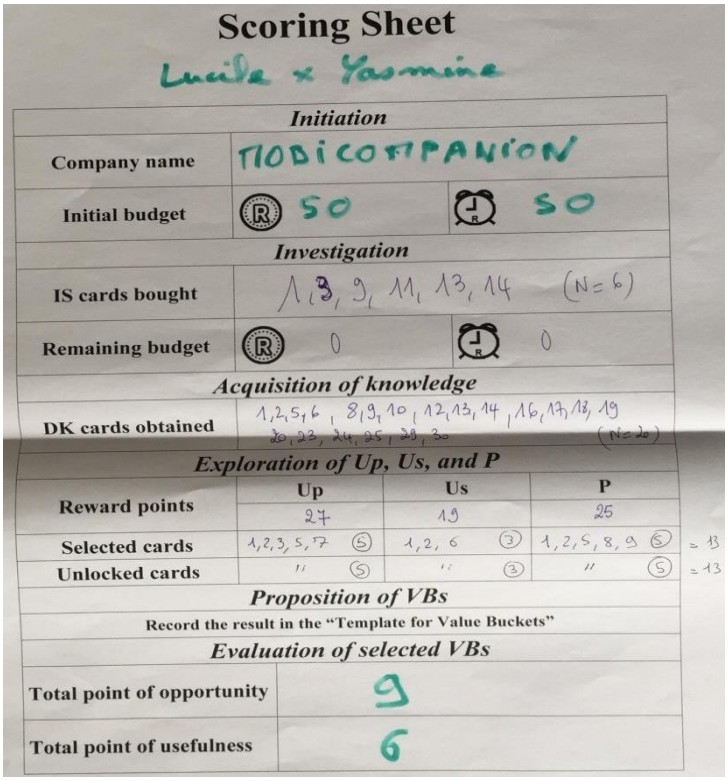


Figure 9.11: Prototype improvement of DK cards

Furthermore, taking advantage of therecordings of all choices of cards made by the team on the scoring sheet (Figure 9.12), we found that the number of cards unlocked by participants is consistent with what we expected (see subsection 8.4.2). This *scoring sheet* is a powerful tool that can be used to replay the team's entire game process, just like a customer journey map, which records in detail the team's decisions in each game challenge and the results obtained. So it provides us with evidence to validate the interfaces between different game challenges. One player suggested also that this traceability should be extended to players who could be asked to fill continuously a notebook with the rationale of their choices at each challenge, so as to revisit more easily what they did afterwards. This is a smart suggestion that intend to implement.



Scoring Sheet

Lucile x Yasmine

Initiation		
Company name	TIOBICOMPANION	
Initial budget	(R) 50	50
Investigation		
IS cards bought	1, 3, 9, 11, 13, 14 (N=6)	
Remaining budget	(R) 0	0
Acquisition of knowledge		
DK cards obtained	1,2,5,6, 8,9,10, 12,13,14, 16,17,18,19 20,23, 24, 25, 29, 33 (N=20)	
Exploration of Up, Us, and P		
Reward points	**Up**	**Us**	**P**
	27	19	25
Selected cards	1,2,3,5,7 (5)	1,2,6 (3)	1,2,5,8,9 (5) = 13
Unlocked cards	" (5)	" (3)	" (5) = 13
Proposition of VBs		
Record the result in the "Template for Value Buckets"		
Evaluation of selected VBs		
Total point of opportunity	9	
Total point of usefulness	6	

Figure 9.12: Scoring sheet of MOBICOMPANION

9.4 Validation results of the RID game

This section first shows the scoring sheets filled by the three teams of the two validation sessions. We validate the gameplay of the level "*Knowledge design* & *Problem design*" and the interfaces between the six game challenges. Then we analyze the participants' feedbacks gathered from the questionnaires and the briefing sessions. Finally, some improvement suggestions of the game are listed, which will be one dimension of this study's future work.

9.4.1 Validation of the gameplay of the level "Knowledge design & Problem design"

In this subsection, we analyze the three scoring sheets to validate the gameplay of level 3. We use the scoring sheets to replay their game processes.

The team MOBICOMPANION (Figure 9.12) initially had 50 *RID clocks* and 50 *RID coins*. The players used all of their resources and bought six new *IS cards*. Thus, they owned eight *IS cards*, which allowed them to unlock 20 *DK cards*. Each card is a choice made after a heated debate among the members of the team. These *DK cards* belong to six categories: 4 *Testimony cards*, 3 *Scientific data-graph cards*, 3 *Scientific data-table cards*, 4 *Scientific data-quotation cards*, 3 *Media cards*, and *3 Observation cards*. Thanks to these cards, the

team got 27 *Up points*, 19 *Us points*, and *P points*. Then, they spent the points and selected 5 Up, 5 Us, and 5 P that should be concerned by their company. Since they carefully read the *DK cards*' content, they succeeded in answering all the trainer's unlocking questions. Thus, they unlock all the categories selected. In the next step, players received *Es cards* and three *efficiency profiles* of solutions, which led them to propose five value buckets to the trainer. Then the trainer evaluated the value buckets. Finally, the team got 9 points of opportunity and *6 points of usefulness*. At this point, players completed the entire game process following the guidance of the trainer.

Like the team presented above, the other two teams also successfully finished the game. The results they obtained in each game challenge are summarized in Table 9.8 and compared with the expected performances. The expected performances refer to the estimated number of different kinds of cards that players should get/unlock in each game challenge to realize the overall gameplay of level 3.

In the first game challenge, "initiation," the three teams selected different companies with the same initial budget. Then, they spent the budget to conduct the "investigation," each of them got around 7 *IS cards*, which meets our expectations. These *IS cards* allowed them to access around 20 *DK cards*. Even though the team MOBI & PARK got *18 DK cards*, this did not hinder their subsequent game, as the reward points brought by these *DK cards* had exceeded our expectations, that is, *20 points* of each type. During the fourth challenge, the two teams in the first session unlocked more than three categories of each dimension. The team MOBISHUTTLE only unlocked 2 *Us cards*. However, they got nine categories of other two dimensions, which were sufficient to proposing five value buckets required by the last game challenge.

Based on the above analysis, our prototype enables the gameplay we specified to achieve and provides a smooth experience, as the player always gets the results needed to start the next challenge from the previous challenge.

Even though the RID game could achieve the gameplay we specified, the participants pointed out a shortcoming in our evaluation. We evaluated them only for the value buckets they proposed at the end and ignored the decisions they made in the other game challenges. For example, which IS cards are consistent with their company mission and effective during the challenge "*Investigation*"? This feedback is essential for players, and we want to improve it in the future. Another limitation of the game is that one team failed to unlock a user profile because they miss one crucial DK card to answer the question, not because they made wrong choices, but because they were unlucky by picking random DK cards. It opens a perspective to improve the unlocking questions by making sure they are well connected to DK cards (and design more DK cards).

Table 9.8: Comparison between players' results with expected performances

	#1 MOBICOMPANION	**#2 MOBI & PARK**	**#3 MOBISHUTTLE**	**Expected performances**
Initial budget	50 RID clocks + 50 RID coins			-
IS cards owned	6	6	7	7
Remaining budget (RID clocks + RID coins)	0 + 0	0 + 15	0 + 5	0 + 0
DK cards obtained	20	18	20	20
Points of Up, Us, and P	27, 19, 25	24, 21, 21	22, 24, 26	20, 20, 20
Selected Up, Us, and P	5, 3, 5	4, 4, 4	4, 4, 5	4, 4, 4
Unlocked Up, Us, and P	5, 3 , 5	3, 4, 4	4, 2, 5	3, 3, 3
Score of opportunity	9	11	10	-
Score of usefulness	6	13	6	-

9.4.2 Relevance of participants

In the pre-questionnaires (Appendix H) for experienced people (Participants A, B, C, and D) and beginners (Participants E, F, and G), we set some questions (Q1 ~ Q4) to understand their relationship with innovation management. According to the results of the questionnaires:

- The current work position or educational background of all the experienced people is related to innovation management. For example, Participant A is an innovation consultant.
- All experienced people have expertise related to RID. They can easily list some essential RID concepts, like activity, innovation process, value bucket, ambition perimeter, usefulness, profitability, prototype design, knowledge design, etc.
- Three beginners are all PhD candidates and work in an industrial engineering department.
- Beginners almost have no previous knowledge about RID. Participants E and F have read one relevant literature, but they do not remember the specific content. However, they have good skills regarding urban mobility.
- Compared with experienced people, beginners seem to have less expertise related to commonly used innovation methodologies. Therefore, they have a more substantial need to participate in innovation training.

Based on the above analysis, all the participants have the appropriate educational/work background and motivation to learn RID. The four professionals are all engaged in work related to innovation management. They need to enrich their domain knowledge and enhance their competitiveness by learning the RID methodology. For the three doctoral students, innovation management is one of the primary disciplines in their research field. They should learn RID to consolidate the knowledge. Thus, the seven participants meet the characteristics of future potential users of the game. It is reasonable to involve them in the validation of the RID game, as they meet future potential users' characteristics.

9.4.3 Comparison of participants' attitudes before and after game

We set up two comparison questions in questionnaires to explore whether the participants' attitudes (efficiency and attractiveness of serious gaming) towards the RID game change significantly before and after playing the game.

Before playing the game

For experienced people:

- Three (out of four) of them perceive that an SG is *more effective* than a lecture course for learning RID. Participant A thinks, "SG is a relevant way of learning as you have a clear example of how it will work." She worries about many SGs

overemphasize fun but ignore their teaching goals. Participants B and C believe that SGs could provide a more exciting and active learning experience.

- Participant D considers an SG is *as effective as* a lecture course for learning RID. He believes that serious games can stimulate people's motivation to learn. However, lecture courses usually support viewing the course material again to make the knowledge more resilient.
- Two experienced people have *a lot of motivation* to experience the RID game. The other two have *full motivation*.

Before playing the game, all the experienced people believe that the SG could serve as an effective educational tool for RID. They have much motivation and are willing to experience the RID game.

For beginners:

- Participants E and F think serious gaming is an *effective* teaching approach. However, although they have experienced several SGs, they only left good memories and did not master the knowledge that these games wanted to teach.
- Participant G perceives serious gaming as *extremely effective*. She feels that SGs can stimulate attention and interest. They are beneficial for developing reasoning/logical and decision-making skills.
- Based on the consideration of the effectiveness of SGs, Participants E and F have a moderate motivation to learn RID by playing an SG. Participant G has full motivation.

Before playing the game, beginners think SG could be effective for learning RID. However, compared with experienced people, they seem to have less motivation to experience the RID game. They are unfamiliar with RID, so they probably want to learn it in a more reliable way, e.g., long-term project-based learning.

After playing the game

For experienced people:

- As shown in Figure 9.13, Participants A, B, C, D have different perceptions of the effectiveness of two approaches for learning RID. Participant D thinks SG is less effective than a lecture course because "RID introduces a number of concepts and a vision that is different from some methods of innovation. He is not sure that a beginner is able to capture the spirit of the method through the serious game only." We agree that the RID methodology consists of many complex concepts that cannot be sufficiently imparted to new learners only by one-day SG. This is why we regard the game as an introductory tool for beginners to experience and practice RID simply. It reminds us that we must give more critical RID knowledge to learners when using this game for training.

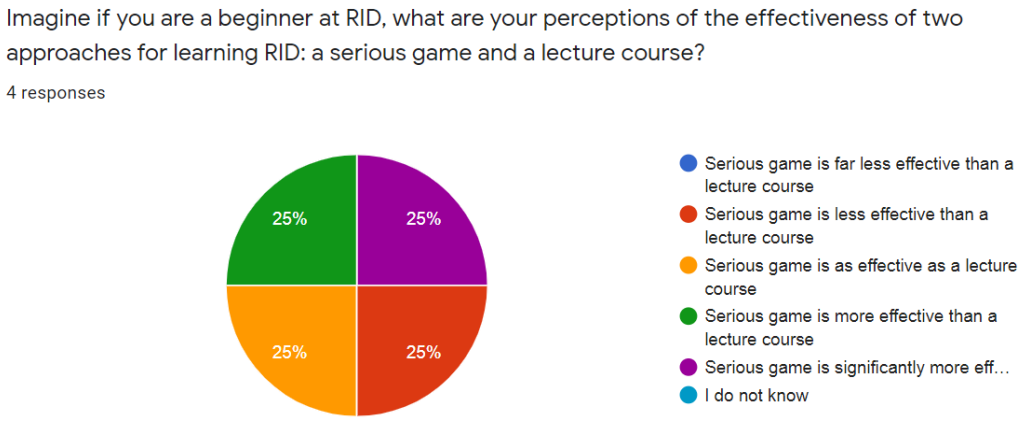


Figure 9.13: Responses of the question about serious games effectives

- Participants A and C have *a lot of motivation* when playing the RID game. The other two have *full motivation*.

After playing the game, experienced people's attitudes (**positive**) towards the RID game's effectiveness and attractiveness do not change a lot. This shows the RID game is a useful and motivating approach to learning RID, which meets their expectations. Participants believe that each team should be composed of three to four players, speeding up the game process and helping the team make more reasonable decisions. They do not have any particular views on the competitiveness between teams, as the competition between the two teams is only reflected in the final evaluation of the value buckets. Both teams appreciate the game mechanic "cooperation" used in the RID game, which allows them to cope with challenges together rather than alone.

For beginners:

- Participant E and G evaluate the effectiveness of serious gaming in teaching RID as *extremely effective*. Participant F chooses *very effective*. We can find that the three beginners have a higher evaluation of the effectiveness of the SG after experiencing the RID game. They think that our game is a quick, immersive, simple, and excellent way of learning RID.
- About the motivation when experiencing the RID game, Participants E, F, G have a higher motivation than estimated by themselves before playing.
- All the beginners are willing to learn more about RID, especially by the RID game's remaining levels.

The attitudes of beginners towards the RID game's effectiveness and attractiveness become more positive after playing the game. This proves that the game has offered them a playful learning journey. Industrial engineering (IE) methodologies like RID are complex and difficult to understand for beginners. However, we let them gradually study RID by completing a virtual project (*urban mobility*) in the form of a team, which eases their learning. The beginners also think it is suitable to have three players in each team. They all liked to play with others during the RID game.

9.4.4 Knowledge developed by the RID game

To further evaluate the RID game's effectiveness, we asked specific questions (in questionnaires and during the sessions) to understand what knowledge participants have really learned. We summarize all the relevant answers in Table 9. Indeed, these concepts are part of the designated design purposes of game level 3.

Table 9.9: Knowledge covered by the RID game

• Deep knowledge • Investigation strategy • Problem • Existing solution • Value bucket • Efficiency	• Knowledge design • Problem design • Usefulness • Opportunity • User profile • Usage situation

Besides RID concepts, participants have reported their other learning outcomes.

For experienced people:

- Improve the understanding of the RID's mindset through "manipulating" and "visualizing" different RID concepts.
- Review the different steps of the progression of RID methodology.
- Two criteria for prioritizing value buckets: usefulness and opportunity.
- Practice the RID methodology in a more user-friendly way.

We are excited to know that the RID game designed for beginners can even bring some value to experienced people. It may be used as a practical tool to help practitioners recall methodology in the future.

For beginners:

- Participants E and F said that the RID game changes their way of thinking. As engineers, they used to think about solutions directly. However, after learning RID, they recognized the importance of the identification of problems and they discovered how it can be beneficial to dedicate time to just investigate and set the innovation problem.
- Participant G thinks the playing of the RID game could lead and stimulate the analysis of real problems.

RID is a usage-driven and activity-centered innovation methodology, which pays much attention to exploring users' problems and unstated needs. The three beginners already grasped the characteristics of RID.

9.4.5 Quantitative analysis of gaming experience

In the post-questionnaires, we set a question (a series of fourteen statements) to quantitatively evaluate the gaming experience's seven aspects (immersion, flow, competence, positive and negative affect, tension, and challenge). The participants were asked to indicate (from 0-4) how they felt while playing the game for each item.

For the indicator *immersion*, the relevant items are "I was interested in the game's story" and "It felt like a rich experience." The average score provided by the seven participants is about 6.6 (the full score is 8), which indicates that we could still improve the plot of the game story or introduce the story in a more interesting way (instead of oral presentation).

For the indicator *flow*, the relevant items are "I lost track of time" and "I was deeply concentrated in the game." The average score is about 5.4. The participants could not totally engage in the game because we use the game mechanic "time pressure" (Graafland et al., 2014; Figure 9.14). We ask them to finish each game challenge in a limited duration in the second validation session. There are two reasons to apply this game mechanic. First, by observing the first validation session, we believed that it is necessary to improve the game's dynamics. So we set a time limit for each game challenge and tested it in the second session. Second, this mechanic can improve the authenticity of the game as it reflects the importance of project management.

For the indicator *competence*, the relevant items are "I felt skillful" and "I was fast at reaching the game's targets." The average score is about 4.6. The six game challenges that make up level three are totally different, and it takes time for them to master the gameplay before starting each challenge. So this score is reasonable.

For the indicator *positive affect*, the relevant items are "I thought it was fun" and "I enjoyed it." The average score is 6.7. All the participants had an exciting gaming experience. One participant even stated that this is the best game (educational and fun) he has ever played.

Figure 9.14: Time pressure in the RID game

For the indicator *negative affect*, the relevant items are "I thought about other things" and "I felt bored." The average score is 1.3, which also shows that they enjoyed it while playing the game.

For the indicator *tension*, the relevant items are "I felt annoyed" and "I felt frustrated." The average score is 0.6. Participants loved the interaction with others when playing the game. The only thing that makes them annoying is that the game session is too short. Participant B suggested extending the duration of the entire training session to four hours.

Finally, for the indicator *challenge*, the relevant items are "I felt challenged" "I had to put a lot of effort into it." The average score is 4.8. The score is good, which indicates that the RID game is neither too difficult nor so easy.

9.4.6 Feedback for improving the RID game

This subsection presents all the insights gained from participants for improving the game. We categorize them as shown in Table 9.10. According to the feedback from participants, we need to pay attention to each type of card's aesthetics. It is required to reinforce the introduction of the RID game. We need to make better use of the space on the game board and enhance the visualization of different RID concepts.

Table 9.10: Necessary improvements of the RID game

Objects to be improved	Description
Introduction to RID and the game	Provide more explanations of the game
	State the game mission clearly
	Introduce the RID concepts that appear in the game before playing
	Simplify the rules of the game or express them more clearly
Organization of the game session	Provide more time for players to read the three game instruction cards
	Extend the duration of the game session and also better allocate the time of each challenge
Mental journey in the RID serious game	Allow players to take notes during the game to record their decisions and related reasons, to enhance the traceability of the game
Game board	Make the relationship between the four dimensions of the value bucket more clearly reflected on the game board
	Better plan the placement area of game cards on the board game board. Each type of card should be placed near its related game challenge to reflect the reasoning process contained in RID
	Better use of game board space and visualize the game board to reflect the RID process's different tasks fully
	Divide the area "Selected cards" on the game board into "Selected Up," "Selected Us," and "Selected P.
	Divide the area "Unlocked cards" on the game board into "Unlocked Up," "Unlocked Us," and "Unlocked P"
	Use full name of different RID concepts on the game board
DK card	Use more distinctive card colors
	Add the serial number on both sides of the card
	Make the information on the card more accessible through simplification and visualization
Other suggestions	Customize the game owing to the users' needs
	Use different shapes for Us, Up, P, and Es cards, making it easier to differentiate them
	Explain clearly to the player the mechanism for scoring the value bucket
Evaluation	At the end of the game, provide players with more precise feedback regarding their choices at each stage
	At the end of the game, clearly state what the game wants to teach to help players deepen their memory

9.5 Conclusion

This chapter introduces how we conducted the verification and validation of the RID game. We adopted the validation method "pre- and post-test" and invited seven participants to play the game in two validation sessions. The participants had two distinct roles: future trainee and experimental subjects. Each role requires them to provide relevant feedback regarding the RID game's learning experience and gaming experience. The analysis of their testimony and answers to questionnaires proves that the game imparts some important RID concepts to

participants in a fun way. Also, it stimulates their motivation to further learning RID. The participants perceive the game is well-designed and presents the different stages of the RID process in a structured way. To sum up, the RID game has achieved its design purposes, but of course, it demands further improvements based on participants' helpful suggestions.

Chapter 10. General discussion

The last chapter aims to present the general discussion of the thesis. It first summarizes our research's major findings and compares them to the relevant previous studies in the literature. Then, the integration of the findings in other contexts is discussed. Finally, it clarifies the limitations of the proposals and outlines the perspectives of the research.

10.1 Major findings of the study

In this research project, we investigated **how to design serious games (SGs) for learning, experiencing, or practicing methodologies in the field of industrial engineering (IE)**. The present work's major findings that respond to each research question (RQ) are described as follows.

Response to RQ 1: What are the invariant elements that make up a serious game? How to describe and structure them?

By analyzing the state of the art in SGs design and evaluation, we identified one of the previous studies' gaps: the existing design methodologies employ the specialized vocabulary of serious gaming directly without providing their definitions. It makes it difficult for novice SG designers like IE teachers without game design expertise to understand and apply SG design methodologies. Thus, an easy-to-understand methodology should first clearly define these terms, i.e., different SG design elements.

To address this issue, we proposed a **design language for SGs** in Chapter 4. This language describes and structures the design objects that make up an SG. There are eight generic design objects (***design purposes, design constraints, story, gameplay, game props, evaluation, aesthetics, and information***). To distinguish the same design objects in the three systematic layers (***game system layer, game level layer, and game challenge layer***) of an SG, we generated a series of derived vocabulary (e.g., ***the information of the game level, the design purposes of the game challenge, game mechanics, learning mechanics,*** and etc.) We also used a game (*Consortio*) applied to open innovation education to illustrate each object. This design language includes a **Game Mechanics Space (Appendix A)** created for defining and exemplifying 72 commonly used game mechanics. With this tool, SG designers can understand game mechanics and get inspiration for designing their own games from existing video games and serious games.

Comparing with the acknowledged SGDA framework (Mitgutsch & Alvarado, 2012), our language (Figure 4.9) contains three new design objects: evaluation, game props, and design constraints. Each design object is connected to the relevant systematic layer, making novice SG designers easily understand design objects' evolution as the design layer goes down. The design language for SGs could serve as a useful tool for explaining the internal structure of an SG.

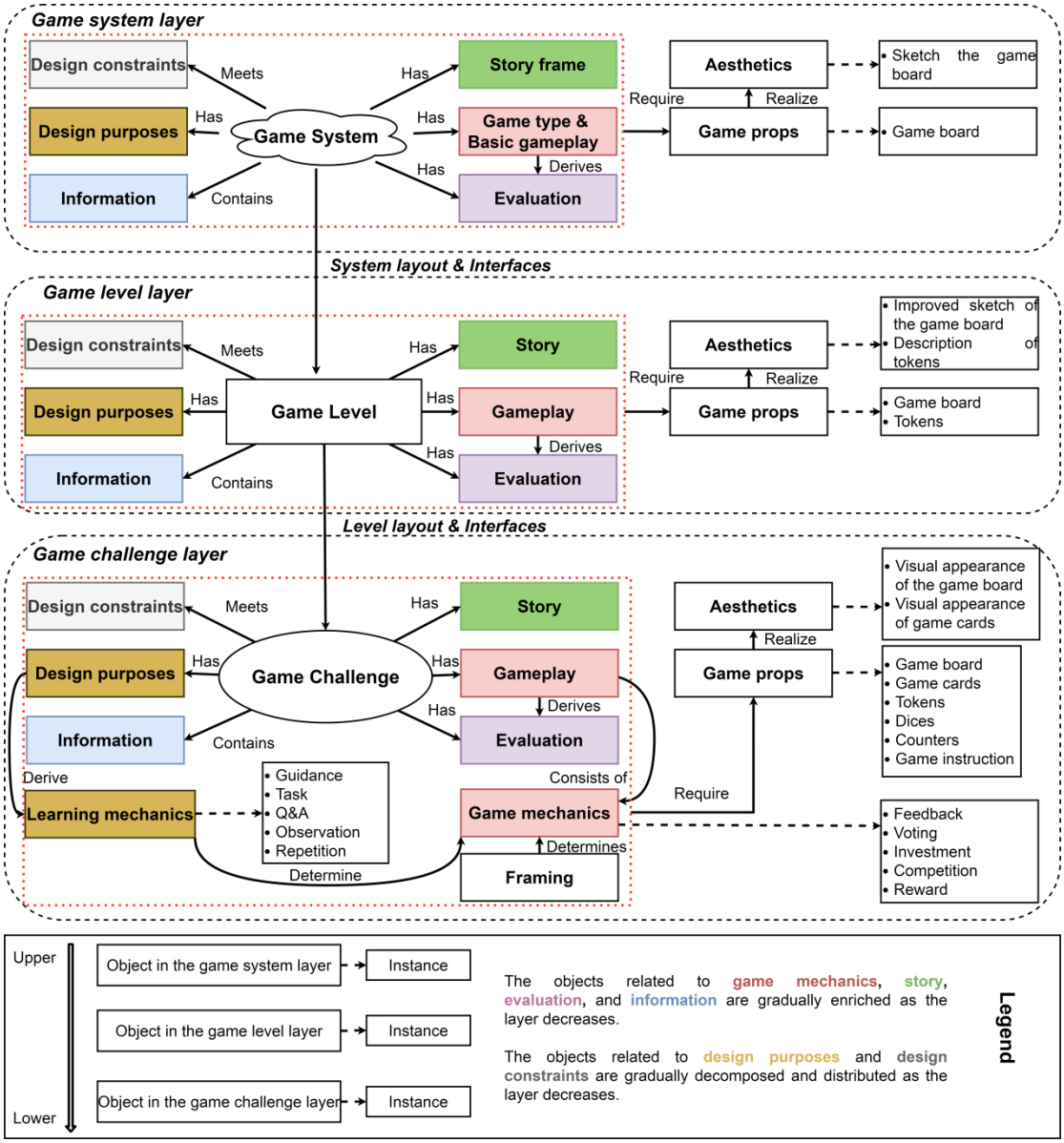


Figure 4.9: Graphical representation of a design language for serious games

<u>Response to RQ 2:</u> What is a comprehensive and easy-to-understand design methodology of serious games for novices? How to design and validate serious games based on such methodology?

To answer this question, we put ourselves in the shoes of novices who are interested in designing SGs but have no relevant gaming expertise to examine previous studies. There are

two other research gaps: 1) most of the design methodologies are not comprehensive. For example, some of them only focus on the conceptual design phase; 2) these methodologies do not provide sufficient guidance and description of the SG design process (work packages, expected outcomes, and participants). We advocate that a comprehensive and easy-to-understand design methodology should have the following characteristics:

- Provide precise definitions of all objects related to the design of SGs;
- Provide a detailed and clear description of tasks, expected outcomes, and participants of each design stage;
- Provide instructions on how to validate the outcomes of each design stage;
- Provide comprehensive guidance that covers the design and evaluation of SGs.

With these objectives in mind, in Chapter 5, we proposed **a generic V-model based design framework for SGs (Figure 4.9)**, which associates the participatory design approach and the standard V-model used for software development (Rook, 1986). The generic V-model makes up all the limitations mentioned above of previous research. It covers the full life cycle of SGs. The proposed framework emphasizes the importance of pre-validation and pre-verification activities to guarantee the quality of SGs. It also clearly states the work packages, expected deliverables, and participants of each stage.

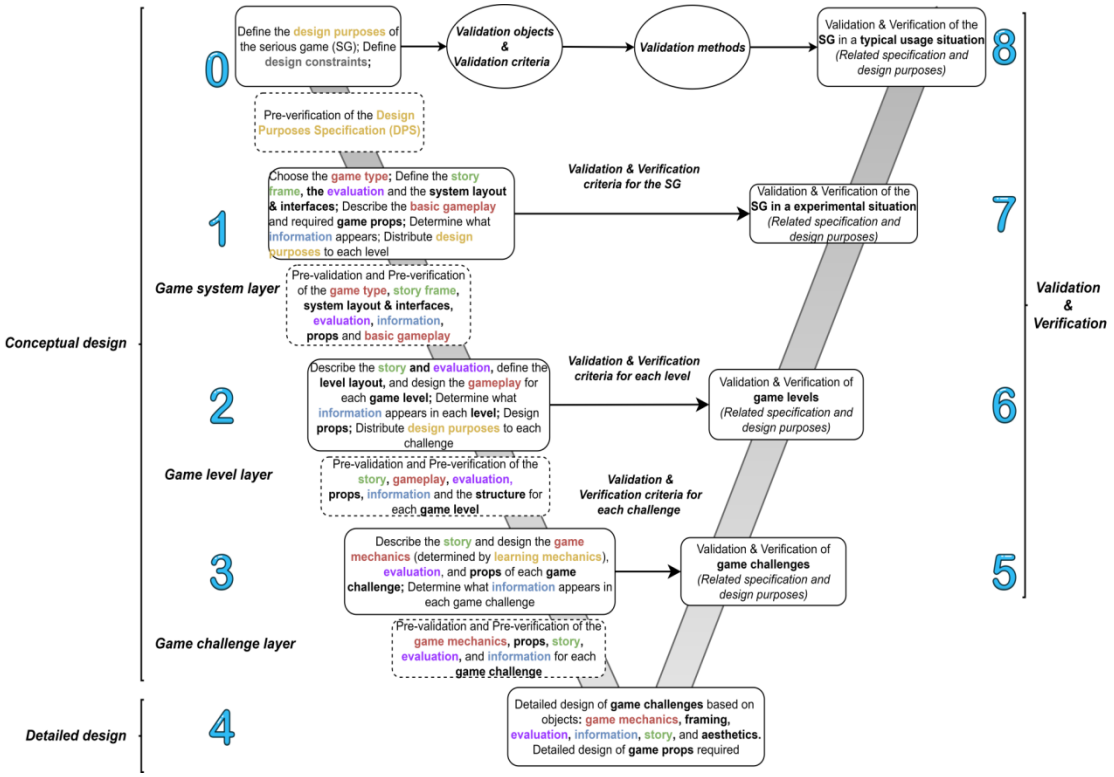


Figure 5.2: Generic V-model for SG design

<u>Response to RQ 3:</u> How to describe and structure all relevant objects for a given industrial engineering methodology?

So far, no research has investigated the design and evaluation methodology of SGs in IE. Without the guidance of these customized methodologies that take into account the specificities of IE methodologies teaching, SG design is still a time-consuming and complicated process. Novice SG designers lack supporting tools to integrate better IE methodologies into SGs.

Before proposing such a solution, we should first understand the specificities of teaching IE methodologies, i.e., what should be taught for a given IE methodology, so as to be able to name IE descriptive elements as learning objectives for SGs. In Chapter 6, we put forward **a descriptive language for IE methodologies** based on seven objects: ***objective of the methodology, process description, performances, competencies, principles, concepts, and methods & tools.*** Seven experts from academia successfully implemented the language on twelve IE methodologies. According to validation results, experts felt at ease and confident to provide sufficient materials about their designated IE methodologies with the proposed descriptive language, proving that it is a useful tool for describing any IE methodologies briefly but sufficiently.

<u>Response to RQ 4:</u> How to design effective serious games that balance fun and learning to teach industrial engineering methodologies?

After proposing a generic V-model based design framework and understanding what should be taught for a given IE methodology, we integrated these two contributions, resulting in **an adapted V-model for IE games** (Chapter 7). We explained how the seven descriptive elements of the IE methodology inspire the creation of different SG design objects.

We validated the adapted V-model by validating its practical application. **An SG on Radical Innovation Design methodology** (Chapters 8 and 9) has been (partially) designed for this intention. We provide a detailed description of the conceptual design process and the validation process of the RID game. Our shared design experience of the RID game can help novice SG designers strengthen their understanding of the proposed framework. We employed the tool "personas" (Pruitt & Adlin, 2006) to understand and characterize SG users' archetypes in the RID game design process. In doing so, we could better identify users' needs to define the problem's scope, that is, the RID game's design purposes. Designers can also apply personas to complete the same task. Furthermore, we established **a quantitative scale for defining and prioritizing design purposes** (Chapter 8) in a broad context: all training for IE methodologies using SGs. It should help designers of these SGs define design purposes and write the design purposes specification (DPS) document.
We invited seven participants who have the characteristics of the RID game's potential future users to experience the game in a typical usage situation. They perceived the RID game as an immersive and practical approach to learn such a complex innovation methodology. The RID

game imparts the core concepts of the methodology to participants and stimulates their motivation for further learning. The design process of the RID game is strictly following the proposed adapted V-model. By proving the effectiveness of the game, we can partially validate our proposal.

10.2 Comparison between the proposed frameworks with previous studies

This section compares the proposed V-model-based framework with other existing SG design methodologies introduced in Chapter 2. Our framework is particularly adapted for people with no prior knowledge and competencies in SG design than others because it describes an IE game's entire design process in detail from four perspectives.

First, the proposed V-model includes all SG design objects identified in Chapter 4 and is established based on the systematic structure of SGs (game system layer, game level layer, and game challenge layer). This information clearly explains the architecture and composition of an SG.

Second, it divides the design process of SGs into nine successive (sometimes iterative) stages and clarifies the work packages that need to be completed in each stage as well as the related expected outcomes. The content of each work package is specified based on design objects so that it is straightforward for designers to understand how these design objects evolve.

Third, the framework encompasses a participatory design approach. It illustrates all the actors (designers, technical writers, teachers, experienced serious game designers, potential users, pedagogical experts, and game players) who may be involved in the SG design process and their tasks. Designers who follow the proposed model can choose appropriate co-designers to form a team according to their needs before starting to create the game.

The last and most important aspect is that we explain how each descriptive element of a given IE methodology inspires related SG design objects. For example, IE methodologies usually contain some performance indicators to evaluate the results obtained, which are also useful for measuring players' performance in SGs. "Usefulness" is a performance indicator used by the RID methodology to prioritize the identified value buckets. In the RID game, the trainer scores the value buckets selected by players based on the same indicator. These guidelines make it possible for novice SG designers, such as teachers of IE methodologies, to design the related SGs.

The proposed V-model has two versions: a generic one for all kinds of SGs (introduced in Chapter 5) and an adapted version for IE games (introduced in Chapter 7). It is a practical design framework that involves steps to elaborate on the SG design process. Compared with the existing SG design frameworks/models/methodologies (Mariais et al., 2012; Barbosa et al., 2014; Carvalho et al., 2015; Corrigan et al., 2015; Ismail & Ibrahim, 2017; Silva, 2020), the V-model includes 20 typical design stages and adds pre-verification and pre-validation

activities to emphasize the importance of the quality of staged outcomes.

In our model, the validation of SGs is planned along with design stages, which offer the possibilities to backtrack. Moreover, the validation is no longer only for the entire game system but also for each game level and even each game challenge. Doing so can guarantee the quality of the entire game. If one game challenge fails to meet its designated design purposes, designers will improve it and make revalidation. Although doing so may extend the time for the development of an SG, it ensures the game's quality. The comparison of the time consumption to design SGs following the proposed V-model and other methodologies can be a valuable research topic to further explore.

We agree with Mitgutsch & Alvarado (2012) that SGs are purpose-based game systems. All the other SG design objects should be configured in relation to design purposes. However, the existing methods do not answer how to design other objects according to the design purposes. In the adapted V-model for IE games, we clearly respond to this question. For example, the design object "story" should be imagined based on the reality that offers players the opportunity to practice the related IE methodology. The story of the game Consortio is about a virtual open innovation project that different companies in the same eco-system constitute a consortium, and they need to maximize the value through collaboration. Because of this plot design, players will have the chance to use different open innovation strategies (design purposes of Consortio) to cooperate with others to achieve a win-win situation.

As mentioned in Chapter 2, most of the existing design methods were put forward for digital SGs. Whether it is a physical game or a digital game, our model can serve them all, as it is developed based on the generic SG design elements and the acknowledged SG structure.

We think that the proposed model is user-friendly, especially for novice SG designers. All the prior knowledge required to comprehend and apply the model has been provided along with the model. Users can understand different SG design objects according to the definitions and examples presented in Chapter 4. The Game Mechanics Space (Figure 9.1; Schonfeld, 2010; Arnab et al., 2015; Marczewski, 2017) will give them a comprehensive understanding of the notion of game mechanics.

Game Mechanics								
Access [B]	Action points [A]	Anarchy [B]	Anonymity [B]	Appointment [A,C]	Assessment [A]	Badges [A,B]	Behavioral Momentum [A]	Boss Battles [B]
Capture [A]	Care-taking [B]	Cascading information [A]	Challenges [A,B,C]	Collaboration [A]	Community Discovery [B]	Competition [A,B]	Consequences [B]	Cooperation [A]
Customization [B]	Development tools [B]	Easter eggs [B]	Exploration [A,C]	Feedback [A,B,C]	Fixed reward schedule [B,C]	Flow [B]	Free lunch [B]	Game turns [A]
Sharing [B]	Guilds [B]	Infinite gameplay [A,C]	Investment [B]	Leader board [A,B,C]	Learning [B]	Levels [B]	Light touch [B]	Lottery [B,C]
Meta-game [A,C]	Movement [A]	Modifiers [C]	Mystery box [B]	Ownership [A,B,C]	Pareto Optimal [A]	Pavlovian interactions [A]	Progress [A,B,C]	Protégé effect [A]
Purpose [B]	Q&A [A]	Quests [B]	Random reward [B]	Rare content [B]	Realism [A]	Real-time vs Delayed [C]	Resource management [A]	Role-play [A]
Scarcity [B]	Status [A,C]	Strategy [A,B]	Narrative [A]	Social discovery [B]	Social network [B]	Social pressure [B]	Social status [B]	Theme [B,C]
Grids [A]	Time dependent reward [B,C]	Time pressure [A,B]	Tokens [A,B,C]	Tutorial [A,B]	Urgent optimism [A,C]	Virality [A]	Virtual economy [B]	Voting [B]
Remark	[A] If the game mechanic has been identified from (Arnab et al., 2015); [B] If the game mechanic has been identified from (Marczewski, 2017); [C] If the game mechanic has been identified from (Schonfeld, 2010).							

Figure 10.1: Game mechanics space

The V-model has the same advantage as the methods of Marfisi-Schottman et al. (2010) and Aslan (2016). They all adopt the participatory design (PD) approach and explain who the SG project stakeholders are. It is convenient for the initiator to recruit people and form a design team. PD approach facilitates the creation of significant interactive content (Tobar-Muñoz et al., 2016). One thing to note is that when organizing PD sessions to design SGs, it is necessary to ensure that co-designers fully understand the expected outcomes and design objectives.

Although we do not contribute to SG evaluation methods, we emphasize that the validation of SGs needs to focus on two aspects, i.e., **the expected learning experience and gaming experience**. Users of our model could find effective methods from the literature discussed in Chapter 2. For example, a survey or questionnaire is usually used to measure players' motivation while playing games (Doukianou et al., 2014; Evans et al., 2015). Some quizzes can be produced to understand the player's mastery of certain knowledge or skills (Tawadrous et al., 2017).

10.3 Adaptation to other contexts

In this research, we show particular interest in the design of SGs used in IE. However, we consider that the proposed generic V-model also works in other contexts, i.e., design SGs of teaching other subjects.

The reason is that this model is developed based on a series of elementary SGs design objects and the hierarchical structure of SGs. First, all employed design objects are shared vocabulary

in the serious gaming field, identified from the literature (Younis & Loh, 2010; Mitgutsch & Alvarado, 2012; Bellotti et al., 2013). Second, the three systematic layers of an SG are a common way designers use to decompose their games (Coenen et al., 2010; Barbosa et al., 2014; Libe et al., 2020). These games across different topics like foreign language learning, personal skills development, medical decision making, etc. In short, the **generic V-model** does not comprise any object that particularly belongs to IE methodologies.

The process of introducing different descriptive elements of IE methodologies into the generic V-model to obtain an adapted V-model presented in this thesis is a good illustration of how to extend the use of the generic model to other fields. The user of the model should first determine all the knowledge related to a certain subject, then classify the obtained results, just as this research divides all teaching objects of IE methodologies into seven categories (competencies, principles, etc.). For the next step, the user should brainstorm how each identified category can inspire the design of different SG design objects.

For example, if we want to design a game on flood risk management for the public. At least two kinds of relevant knowledge (Plate, 2003) that the game should convey: 1) the flood management process and 2) economic, people, and environmental consequences if flooding occurs. They may be the **design purposes** of such a game. The flood management process describes all the right behaviors that people should perform before, when, and after flooding. These behaviors can inspire the general **gameplay**'s design: *Players live in a rural area with the possibility of flood within 24 hours. They need to make the best use of their flood management knowledge to minimize the damage caused by floods. If the player behaves correctly, he can get points. Otherwise, he will get nothing*. Based on this gameplay, a scoring system for **evaluating** the player's performance has been established. The higher the score, the better he has mitigated the disaster caused by flooding. When evaluating the player's performance, the knowledge about the economic, people, and environmental consequences of flooding is also useful to indicate the consequences of the players' behaviors. With this simple example, we want to encourage users to fully play to their imagination and integrate their professional knowledge into the game.

10.4 Limitations

Regarding the contributions of this thesis elaborated in section 10.1, some limits need to be mentioned:

- Due to time constraints, we have not been able to design the whole RID game based on the proposed framework. Only the third level of the game has been designed and validated. Whether the game can achieve all the design purposes set is to be validated.
- Because of COVID-19, we only involved seven people in validating the game in a physical setting. We should invite more people to test the game and improve the game based on their feedback. Moreover, when evaluating the game's effectiveness,

we only analyzed whether the players have learned some concepts without assessing their mastery levels.

- The proposed framework has been applied only on one IE methodology. Even if we have highlighted our work's generalization potential, it has not been proven that this work is easily applicable for designing SGs on other subjects (e.g., world languages, computer science, chemistry, etc.) in higher education. We expect readers to apply the proposed model and give us feedback about its adaptability.
- The proposed framework provides many details to ease the understanding of novice designers. However, it has not been proven whether novice SG designers can directly use it to design SGs. If not, a toolkit could be developed to support novice SG designers. By the way, we have not studied whether the framework is also well situated for non-novices.
- The proposed framework requires users to choose suitable validation methods (observation, questionnaire, interview, quiz, etc.) from literature according to the objects (long-term knowledge retention, motivations, attitudes, engagement, learning satisfaction, etc.) they want to validate. However, this task is challenging to be completed by novice designers themselves.

10.5 Perspectives

The following aspects deserve to explore in the future for making up for the limitations of the research:

- To improve the current version of the RID game based on the collected feedback and then continue designing the RID game. We expect to use the RID game in a one-day innovation management training for university students or startupers. Therefore, we need to deploy the game in both contexts and then conduct the validation. It is necessary to combine both objective and subjective measures to validate the complete game. Only by doing so can the validity of the proposed framework that supports the RID game design be better proved. After validating the RID game in both contexts, we also want to apply the framework to design other IE games so as to evaluate the adaptability of the proposed framework.
- The proposed V-model is developed mainly for novice SG designers. We need to let novices implement the model and gather their feedback to improve it. The framework also needs to be validated by experienced serious game designers.
- To complement the proposed framework by considering the design of digital SGs, i.e., understanding how to transform the specifications generated in the conceptual design phase to the software. Also, it is interesting to explore which kind of SGs is a better choice for teaching IE methodologies.

Therefore, future work will mainly focus on two aspects: 1) strengthen the proposed design framework by collecting the feedback from novices and SG experts, 2) extend its application.

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Appendices

Appendix A: Review of game mechanics for serious educational game design

1. Identification of sources

Game mechanics are always considered to be an important part of SG so that we believe they can give us inspiration for designing RID serious game. This report covers no less than 70 different mechanics that are used in a game context, more specifically, their definitions and examples are given. These game mechanics are mainly collected through three sources and they will be introduced in detail below. For ease of reading, we coded them as shown in Table 1:

Table. 1 Code of sources

Type of source	Name of source	Code	Number of game mechanics	Reference
Journal paper	«Mapping Learning and Game Mechanics for Serious Games Analysis»	A	38	[Arnab et al., 2015]
Website	«Gamified.UK»	B	52	[Marczewski, 2017]
Website	«SCVNGR's Secret Game Mechanics Playdeck»	C	47	[Schonfeld, 2010]

1.1 Introduction of Source A

Arnab et al. (2015) proposed a LM-GM model. Figure 1 depicts the components of the model, namely the learning mechanics (LMs, represented as nodes in the left side of the picture) and the game mechanics (GMs, represented as nodes in the right side of the picture). The LM nodes illustrated in Figure 1 are a non-exhaustive list of learning mechanics that have been extracted from literature and discussions with educational theorists on 21st century pedagogy, considering a variety of educational theories (e.g., constructivism, behaviourism, personalism), in particular those closer to game education (Keller, 1983; Gagne, Briggs, & Wager, 1992; Papert & Harel, 1991; Brainerd, 1978). In the same manner, the GM nodes were obtained by reviewing articles on game mechanics and dynamics, and they represent the backbone of many game theories (Jarvinen, 2008; Sicart, 2008; Bellotti et al., 2009a, 2009b; Connolly et al., 2012). There are 31 learning mechanics and 38 game mechanics in the LM-GM model.

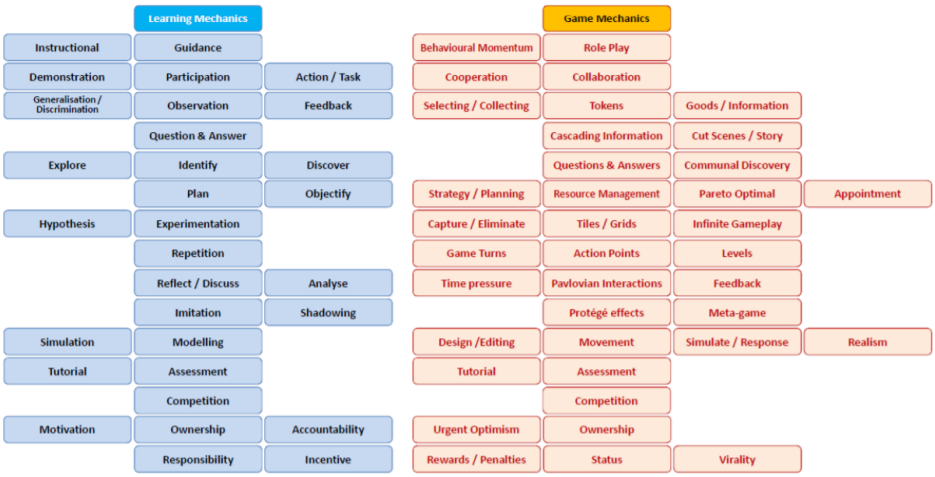

Figure. 1 LM&GM model (Arnab et al., 2015)

LM-GM model could be used to aid SG analysis (i.e., identifying and assessing the main features and components of a SG), design (i.e., thinking of what components could constitute a new SG) and specification (i.e., specifying the components of a SG and their relationships).

Further, a classification work (Table 2) had been done which was based on Bloom's theory (Bloom, 1956) and organised in line with the digital taxonomy of Anderson, Krathwohl, and Bloom (2001). As an example, this table emphasises upon task-centred learning rather than cognitive learning.

Table. 2 Classifications based on Bloom's ordered thinking skills

Game mechanics	Thinking skills	Learning mechanics
Design/Editing Status Infinite Gameplay Strategy/Planning Ownership Tile/Grids Prot ég é Effect	Creating	Accountability Ownership Planning Responsibility
Action Points Game Turns Assessment Pareto Optimal Collaboration Rewards/Penalties Communal Discovery Urgent Optimism Resource Management	Evaluating	Assessment Reflect/Discuss Collaboration Hypothesis Incentive Motivation
Feedback Meta-game Realism	Analysing	Analyse Identify Experimentation Observation Feedback Shadowing
Capture/Elimination Progression Competition Selecting/Collecting Cooperation Simulate/Response Movement Time Pressure	Applying	Action/Task Imitation Competition Simulation Cooperation Demonstration
Appointment Role-play Cascading Information Tutorial Questions and Answers	Understanding	Objectify Tutorial Participation Questions and Answers
Cut scenes/Story Behavioural Monmentum Tokens Pavlovian Interactions Virality Goods/Information	Retention	Discover Guidance Explore Instruction Generalisation Repetition

1.2 Introduction of Source B

Source B provides 52 game mechanics that support various user types and can enhance the gamification designs. Marczewski (2017) classified these mechancis into 8 categories based on the different user types as shown in Table 3.

Table. 3 Classifications based on Marczewski's player and user types hexed

User Types	Game mechanics
General	On-boarding / Tutorials Signposting Loss Aversion Progress/Feedback Theme Narrative/Story Curiosity/Mystery Box Time Pressure Scarcity Strategy Flow Consequences Investment
Schedule	Random Rewards Fixed Reward Schedule Time Dependent Rewards
Socializers	Guilds/Teams Social Network Social Status Social Discovery Social Pressure Competition
Free Spirits	Exploration Branching Choices Easter Eggs Unlockable Creativity Tools Customization
Achievers	Challenges Certificates Learning/New Skills Quests Levels/Progression Boss Battles
Philanthropists	Meaning/Purpose Care-taking Access Collect & Trade Gifting/Sharing Sharing Knowledge
Players	Points/Experience Points Physical Rewards Leaderboards Badges/Achievements

	Virtual Economy	Lottery/Game of Chance
Disruptors	Innovation Platform Development Tools Light Touch	Voting/Voice Anonymity Anarchy

There are four basic intrinsic types; Achiever, Socialiser, Philanthropist and Free Spirit. They are motivated by Relatedness, Autonomy, Mastery and Purpose – RAMP. The other two types, whose motivations are a little less black and white are Disruptor and Player. Following are the brief definitions of each type of users according to Marczewski (2015):

- Socialisers are motivated by Relatedness. They want to interact with others and create social connections.
- Free Spirits are motivated by Autonomy and self-expression. They want to create and explore.
- Achievers are motivated by Mastery. They are looking to learn new things and improve themselves. They want challenges to overcome.
- Philanthropists are motivated by Purpose and Meaning. This group is altruistic, wanting to give to other people and enrich the lives of others in some way with no expectation of reward.
- Players are motivated by Rewards. They will do what is needed of them to collect rewards from a system. They are in it for themselves.
- Disruptors are motivated by Change. In general, they want to disrupt your system, either directly or through other users to force positive or negative change.

1.3 Introduction of Source C

SCVNGR, which makes a mobile game with real-world challenges, has a playdeck. It is a deck of cards listing nearly 50 different game mechanics that can be mixed and matched to create the foundation for different types of games. Most of these game mechanics had been already applied within the SCVNGR game layer. Following table shows all of game mechanics involved:

Table. 4 SCVNGR's Game Mechanics Playdeck

Initial Letter	Game mechanics
A	Achievement Appointment Dynamic Avoidance
B	Behavioral Contrast Behavioral Momentum Blissful Productivity
C	Cascading Information Theory Chain Schedules Communal Discovery Companion Gaming Contingency Countdown Cross Situational Leader-boards
D	Disincentives
E	Endless Games Envy Epic Meaning Extinction
F	Fixed Interval Reward Schedules Fixed Ratio Reward Schedule Free Lunch Fun Once, Fun Always
I	Interval Reward Schedules
L	Lottery Loyalty
M	Meta Game Micro Leader-boards Modifiers Moral Hazard of Game Play
O	Ownership
P	Pride Privacy Progression Dynamic
R	Ratio Reward Schedules Reinforcer Real-time v. Delayed Mechanics Response Reward Schedules Rolling Physical Goods

S	Shell game Social Fabric of Games Status
U	Urgent Optimism
V	Variable Interval Reward Schedules Viral Game Mechanics Virtual Items

2. Panel of games

Based on the above three sources of information, we further found examples to help illustrate how these game mechanics are used in a game context. Here are 11 members in the panel of games as shown in Table 5.

Table. 5 The composition of the panel of games

Classification criteria	**Design purpose**		**Carrier**		**Number of player**	
Name of games	**Education or training**	**Pure entertainment**	**Board game**	**Video game**	**Single-player game**	**Multiplayer game**
Consortio	√	×	√	×	×	√
RID serious game	√	×	√	×	×	√
PLAY'INN	√	×	×	√	×	√
The Sims	×	√	×	√	√	√
Super Mario Bros.	×	√	×	√	√	√
World of Warcraft	×	√	×	√	√	√
League of Legends	×	√	×	√	√	√
Defense of the Ancients 2	×	√	×	√	√	√
Monopoly	×	√	√	×	×	√
Rich 4	×	√	×	√	√	√
FarmVille	×	√	×	√	√	√

There are just three serious games (designed for a non-entertainment based purpose) used which is a drawback, but this does not violate the objective of this article: create a game mechanics space, define each game mechanic and then illustrate the usage of them. The other eight regular games (designed for pure entertainment) were selected based on serveral reasons, like classic (Super Mario Bros. and Monopoly), the number of players (The Sims, Farmville and Rich 4), the number of game mechanics applied (World of Warcraft and Defense of the Ancients 2), etc. The following sections give a brief introduction to these games.

2.1 Consortio

Consortio is a serious game developed by the Rhizome team, board game. It was designed to help companies understand open innovation, grasp open innovation tools and apply them to formulate strategies. To date, it has been used to train more than 200 enterprises.

Figure. 2 Open innovation training session (Rhizome, 2015a)

2.2 RID serious game

RID serious game was designed by LGI, board game. The intention of the game designer is to facilitate the learning of RID methodology. The existing version of RID serious game was constituted by 8 micro-games, although some of them are still in the prototype stage, we can find examples of successful use of the game mechanics.

Figure. 3 Game boards of RID serious game

2.3 PLAY'INN

PLAY'INN is a serious game designed by TOTAL. It focuses on spreading and promoting innovative culture. In the game, here are 24 levels which mean that difficulty of the game gradually increased. It has been used to train more than 20,000 employees in TOTAL.

Figure. 4 PLAY'INN (Paquet, 2017)

2.4 The Sims

The Sims is a life simulation game series that was developed by Maxis and The Sims Studio. The franchise has sold nearly 200 million copies worldwide, and it is one of the best-selling video games series of all time. The games in The Sims series are largely sandbox games, in which the player has been freed from traditional video game structure and direction. The player creates virtual people called «Sims» and places them in houses and helps direct their moods and satisfy their desires.

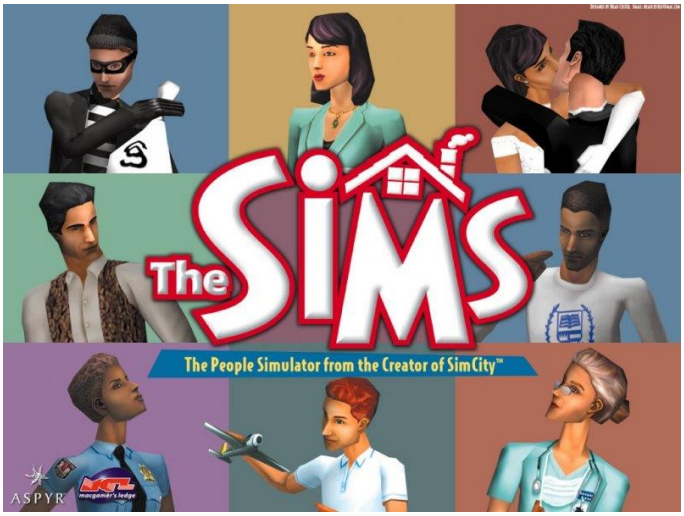

Figure. 5 The Sims-The People Simulator from the Creator of SimCity

2.5 Super Mario Bros.

Super Mario Bros. is a platform video game developed and published by Nintendo. The game has been highly influential, popularizing the side-scrolling genre. In 2005, IGN's poll named it as The Greatest Game of All Time. The game also sold enormously well, and was the best-selling game of all time for

approximately three decades, until Wii Sports took that title. In Super Mario Bros., the player controls Mario and in a two-player game, a second player controls Mario's brother Luigi as he travels through the Mushroom Kingdom in order to rescue Princess Toadstool from the antagonist Bowser.

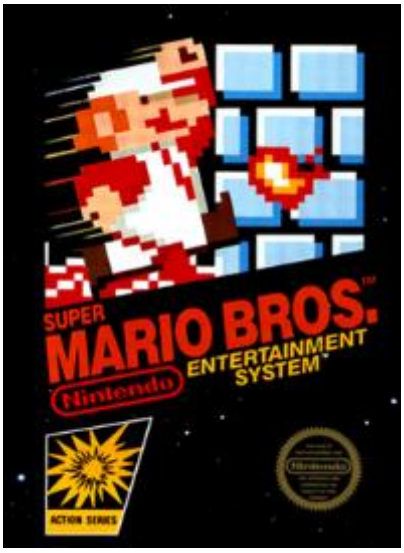

Figure. 6 Super Mario Bros

2.6 World of Warcraft (WoW)

World of Warcraft is a massively multiplayer online role-playing game (MMORPG) released in 2004 by Blizzard Entertainment. With a peak of 12 million subscriptions in October 2010 and Blizzard's final report of 5.5 million subscriptions in October 2015, World of Warcraft remains the world's most-subscribed MMORPG, and holds the Guinness World Record for the most popular MMORPG by subscribers. Although WoW is just an entertainment game, it has successfully applied a variety of game mechanics.

Figure. 7 Orc warriors in the WoW

2.7 League of Legends (LoL)

League of Legends is a multiplayer online battle arena video game developed and published by Riot Games. The game follows a freemium model and is supported by microtransactions. In LoL, players assume the role of an unseen «summoner» that controls a «champion» with unique abilities and battle against a team of other players or computer-controlled champions. LoL was generally well received upon its release in 2009, and has since grown in popularity, with an active and expansive fanbase. By July 2012, League of Legends was the most played PC game in North America and Europe in terms of the number of hours played.

Figure. 8 League of Legends

2.8 Defense of the Ancients 2 (DOTA 2)

DOTA 2 is a free-to-play multiplayer online battle arena (MOBA) video game developed and published by Valve Corporation. DOTA 2 is played in matches between two teams of five players, with each team occupying and defending their own separate base on the map. DOTA 2 is a source of inspiration for the LoL, therefore, the game mechanics applied by both games are basically the same. DOTA 2 has a widespread and active competitive scene, with teams from across the world playing professionally in various leagues and tournaments. Premium DOTA 2 tournaments often have prize pools totaling millions of U.S. dollars, the highest of any eSport. The following picture shows that the prize pool of Ti 6 (The international 2016) has surpassed 16 million dollars.

Figure. 9 TI6 prize pool surpass $16M mark

2.9 Monopoly

Monopoly is a board game where players roll two six-sided dice to move around the game-board buying and trading properties, and develop them with houses and hotels. Monopoly has become a part of international popular culture, having been locally licensed in more than 103 countries and printed in more than thirty-seven languages.

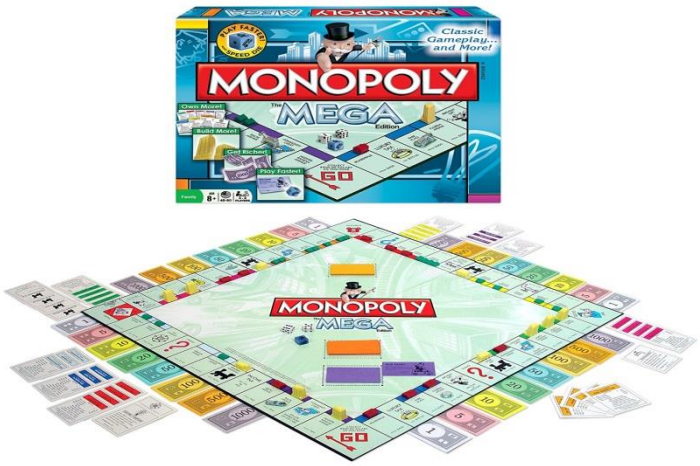

Figure. 10 Monopoly: The Mega Edition

2.10 Rich 4

Rich 4 is a video game that was inspired by Monopoly. It was designed and published by Softstar Entertainment INc. It is a turn-based game and each turn player will roll dices then move around the virtual map. It has a considerable fan base in the Chinese market.

Figure. 11 Rich 4

2.11 FarmVille

FarmVille is a farming simulation social network game developed by Zynga in 2009. Its gameplay involves various aspects of farm management such as plowing land, planting, growing, and harvesting crops, harvesting trees and raising livestock. After its launch on Facebook in 2009, FarmVille became the most popular game on the site, and held that position for over two years.

Figure. 12 Facebook Homepage of FarmVille

3. Game mechanics

The following is the definition of game mechanic found from literature:

① Using concepts from object-oriented programming, as methods invoked by agents, designed for

interaction with the game state (Sicart, 2008).

② A game mechanic is simply any part of the rule system of a game that covers one, and only one, possible kind of interaction that takes place during the game, be it general or specific (Lundgren & Björk, 2003).

According to these two definitions, we think game mechanics are the methods that could cause interaction between player and game state.

This section detailed introduce the definitions of game mechanics which have been identified and also provides examples of each them. When comparing Table 2, Table 3 and Table 4, it is obvious that they have overlapping parts. Table 6 shows the «union set» of them. Some game mechanics may have different names in different sources, for example, «feedback» from source A and B shares the same meaning with «progress» from source C; the essence of «infinite gameplay» from source A and «endless games» from source C is the same.

Table. 6 Game mechanics

Game mechanics (from A to Z)					
Access [B]	Action Points [A]	Anarchy [B]	Anonymity [B]	Appointment [A,C]	Assessment [A]
Badges/Achievements [A,B]	Behavioral Momentum [A]	Boss Battles [B]	Capture/ Eliminate [A]	Care-taking [B]	Cascading information [A]
Challenges [A,B,C]	Collaboration [A]	Communal Discovery [B]	Competition [A,B]	Consequences [B]	Cooperation [A]
Customization [B]	Development Tools [B]	Easter Eggs [B]	Exploration [A,C]	Feedback [A,B,C]	Fixed Reward Schedule [B,C]
Flow [B]	Free Lunch [B]	Game Turns [A]	Gifting/Sharing [B]	Guilds/Teams [B]	Infinite Gameplay [A,C]
Investment [B]	Leaderboard [A,B,C]	Learning/ New Skills [B]	Levels [B]	Light Touch [B]	Lottery [B,C]
Meta-Game [A,C]	Movement [A]	Modifiers [C]	Mystery Box [B]	Ownership [A,B,C]	Pareto Optimal [A]
Pavlovian Interactions [A]	Progress [A,B,C]	Protégé Effect [A]	Purpose [B]	Questions & Answers [A]	Quests [B]
Random Reward [B]	Rare Content [B]	Realism [A]	Real-time vs Delayed [C]	Resource Management [A]	Role-Play [A]
Scarcity [B]	Status [A,C]	Strategy [A,B]	Story/Narrative [A]	Social Discovery [B]	Social Network [B]
Social Pressure [B]	Social Status [B]	Theme [B,C]	Tiles/Grids [A]	Time Dependent Reward [B,C]	Time pressure [A,B]
Tokens [A,B,C]	Tutorial [A,B]	Urgent Optimism [A,C]	Virality [A]	Virtual Economy [B]	Voting/Voice [B]
Remark	[A] if the game mechanic has been identified from source A; [B] if the game mechanic has been identified from source B; [C] if the game mechanic has been identified from source C.				

- Progress: Progress comes in many forms and has many mechanics available. All types of user need some sort of measure of progress, but some types work better than others. (Marczewski, 2017)

  Example: Consortio. Counters which represent the real-time CPR of consortium.

Figure. 13 CPR counters

- Theme: Give your gamification a theme, often linked with narrative. Can be anything from company values to werewolves. Add a little fantasy and just make sure users can make sense of it. (Marczewski, 2017)

  Example: Consortio is a serious game for which the theme is open innovation.

Figure. 14 Open Innovation: A different way to innovate (Rhizome, 2015b)

- Narrative / Story: Tell your story and let people tell theirs. Use gamification to strengthen understanding of your story by involving people. (Marczewski, 2017)

  Example: RID serious game (Micro–game «Match up! »). Players need to match usage fields and problems based on their own experience.

Figure. 15 Tutorial of Micro-game «Match up! »

- Curiosity / Mystery Box: Curiosity is a strong force. Not everything has to be fully explained, a little mystery may encourage people in new directions. (Marczewski, 2017)
  Example: The Sims. There are three kinds of mystery boxes, when you have enough golden keys you can open them and get random items.

Figure. 16 Mystery Box Shop

- Scarcity: Making something rare can make it all the more desirable. (Marczewski, 2017)
  Example: WoW. The chance of getting legendary equipment (better attributes) is small.

Figure. 17 Legendary Equipment in WoW

- Strategy: Make people think about what they are doing, why they are doing it and how it might affect the outcomes of the game (Oxford Dictionary, 2018).
  Example: Consortio. Players need to define a strategy of collaboration within the consortium.

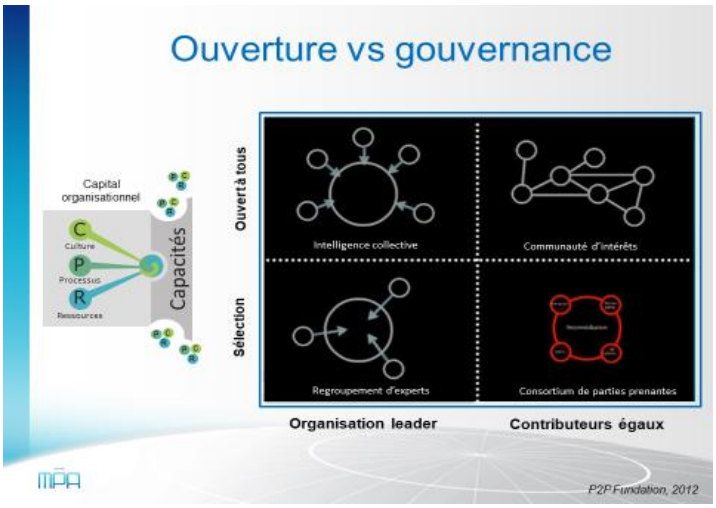

Figure. 18 Ouverture vs Gouvernance (Rhizome, 2015b)

- Flow: Getting the perceived levels of challenge and skill just right can lead to a state of flow. Balance is the key. (Engeser & Rheinberg, 2008)
  Example: WoW. Each task has a corresponding and reasonable level requirement.

Figure. 19 110-level mission: «Eye of Azshara: Termination Claws»

- Consequences: If the user gets things wrong, what are the consequences? Do they lose a life, points or items they have earned? (Marczewski, 2017)

  Example: Consortio. Ignore intellectual property will lead to lose all the concepts and prototypes.

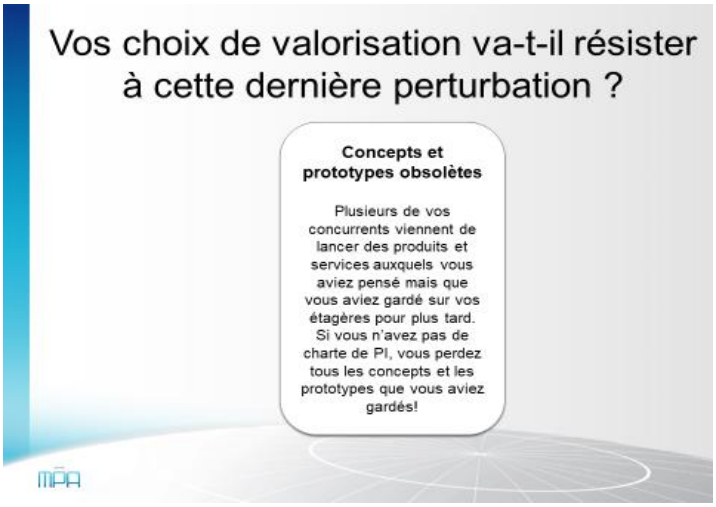

Figure. 20 Perturbation Card «Concepts et prototypes obsolètes» (Rhizome, 2015b)

- Investment: When people invest time, effort, emotions or money, they will value the outcomes all the more. (Marczewski, 2017)

  Example: WoW. Players need to pay money to buy game time and spend plenty of time on upgrading level of character.

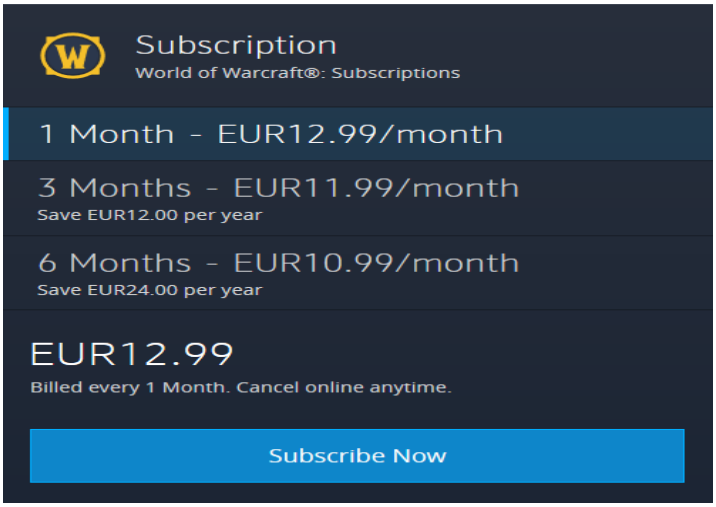

Figure. 21 Game fees of WoW

- Random Rewards: Surprise and delight people with unexpected rewards. Keep them on their toes and maybe even make them smile. (Marczewski, 2017)

  Example: WoW. There is the concept of «loot» or «drops» which are random rewards that appear once the player achieves a win-state or defeats an enemy.

Figure. 22 Equipment drops

- Fixed Reward Schedule: Reward people based on defined actions and events. First activity, level up, progression. Useful during on-boarding and to celebrate milestone events. (Marczewski, 2017)

  Example: Consortio. After «design phase», players calculate the value created which can be regarded as fixed reward.

Figure. 23 Value Output Calculation (Rhizome, 2015b)

- Time Dependent Rewards: Events that happen at specific times (birthdays etc.) or are only available for set period of time (e.g. come back each day for a reward). Users have to be there to benefit. (Marczewski, 2017)

  Example: League of Legends. The game provides birthday gift to players just around that day.

Figure. 24 Birthday Gift in LoL

- Guilds / Teams: Let people build close-knit guilds or teams. Small groups can be much more effective than large sprawling ones. Create platforms for collaboration but also pave the way for team based competitions. (Marczewski, 2017)

  Example: WoW. One player can start a guild and recruit other players.

Figure. 25 Guild Conference

- Social Network: Allow people to connect and be social with an easy to use and accessible social network. It is can be more fun to play with other people than to play on your own. (Marczewski, 2017)

  Example: WOW. The game offer a social network with rich features, including: different kinds of chat channels, item trading system and so on.

Figure. 26 Chat Channels

- Social Status: Status can lead to greater visibility for people, creating opportunities to create new relationships. It can also feel good. You can make use of feedback mechanics such as leaderboards and certificates. (Marczewski, 2017)

  Example: WoW. There exists a leaderboard of «3v3 Arena» mode which could reflect the players' strength.

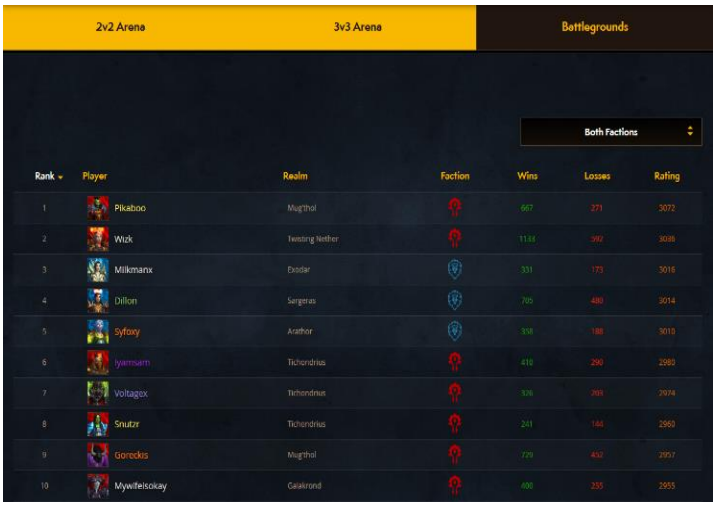

Figure. 27 Leaderboard of 3V3 Arena

- Social Discovery: A way to find people and be found is an essential to building new relationships. Matching people based on interests and status can all help get people started. (Marczewski, 2017)

  Example: WoW. There is an in-game friend system which can help players make relationship with others.

Figure. 28 Friends List

- Social Pressure: People often don't like feeling they are the odd one out. In a social environment this can be used to encourage people to be like their friends. Can demotivate if expectations are unrealistic. (Marczewski, 2017)

  Example: WoW. From the friends list used in the game, players could know the level of each friend. No one wants to be the last one.

- Exploration: Give your Free Spirits room to move and explore. If you are creating virtual worlds, consider that they will want to find the boundaries and give them something to find. (Marczewski, 2017)

  Example: WoW. Players can control their own avatars to explore every corner of the map.

Figure. 29 Global Map used in WoW

- Easter Eggs: Easter eggs are a fun way to reward and surprise people for just having a look around. For some, the harder they are to find, the more exciting it is! (Marczewski, 2017)

  Example: Call of Duty: Black Ops 2 – retro arcade. On the creepy Nuke Town map, if you shoot the heads off all the dummies within 30 seconds, you get to sit down at an old Atari console and play a selection of retro Activision titles, including Pitfall and River Raid.

Figure. 30 Easter Eggs in Call of Duty: Black Ops 2

- Unlockable / Rare Content: Add to the feeling of self-expression and value, by offering unlockable or rare content for free spirits to make use of. Link to Easter eggs and exploration as well as achievement. (Marczewski, 2017)

  Example: See the example of «Easter eggs».

- Customization: Give players the tools to customize their experience. From avatars to the environment, let them express themselves and choose how they will present themselves to others. (Marczewski, 2017)

  Example: WoW. At the beginning of the game, player need to create a new avatar based on their preferences.

Figure. 31 Character Creation

- Challenges: Challenges help keep people interested, testing their knowledge and allowing them to apply it. Overcoming challenges will make people feel they have earned their achievement. (Marczewski, 2017)

  Example: PLAY'INN. Players need to generate different ideas based on the physical laws to finish each level.

Figure.32 Level 1 of PLAY'INN

- Learning / New Skills: What better way to achieve mastery than to learn something new? Give your users the opportunity to learn and expand. (Marczewski, 2017)

  Example: Consortio. Players could learn and then apply new knowledge around open innovation throughout the game.

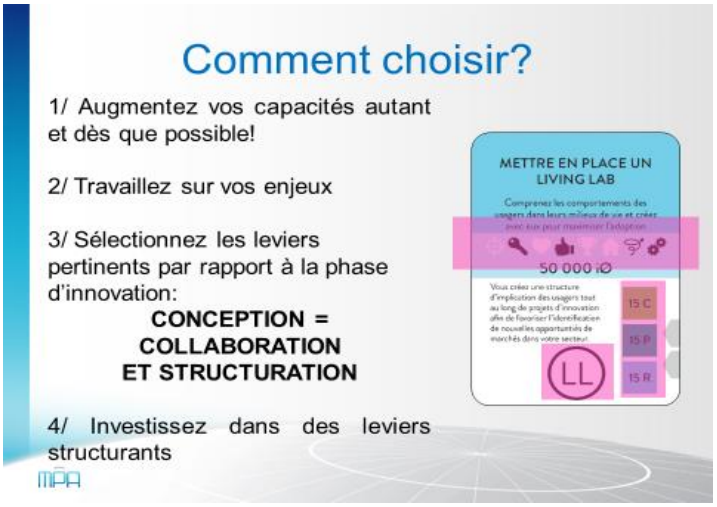

Figure. 33 How to select open innovation tools (Rhizome, 2015b)

- Quests: Quests give users a fixed goal to achieve. Often made up from a series of linked challenges, multiplying the feeling of achievement. (Marczewski, 2017)

  Example: Consortio. During each phase, players need to select good open innovation tools within limited time.

Figure. 34 Quest: Select capacity development card (Rhizome, 2015b)

- Boss Battles: Boss battles are a chance to consolidate everything you have learned and mastered in one epic challenge. Usually signals the end of the journey – and the beginning of a new one. (Marczewski, 2017)

  Example: WoW. At the end of each instance dungeon, players need to beat the boss to win generous rewards.

Figure. 35 Boss Battle Scene

- Meaning / Purpose: Some just need to understand the meaning or the purpose of what they are doing (epic or otherwise). (Marczewski, 2017)

  Example: Consortio. In the game, players aware of that they are dedicated to a project based on the new freezing technology.

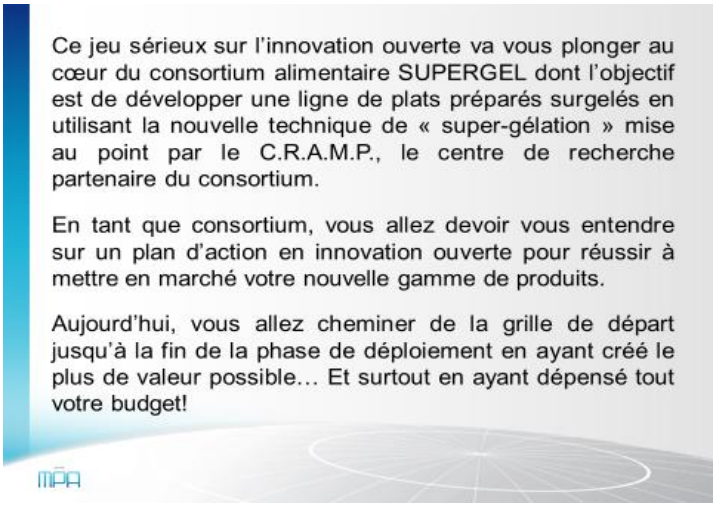

Figure. 36 Introduction of Open Innovation Project (Rhizome, 2015b)

- Care-taking: Looking after other people can be very fulfilling. Create roles for administrators, moderators, curators etc. Allow users to take a parental role. (Marczewski, 2017)

  Example: The Sims. Take care of and educate children is one of the challenges in the game.

Figure. 37 Parental Education Scene

- Access: Access to more features and abilities in a system can give people more ways to help others and to contribute. It also helps make them feel valued. More meaningful if earned. (Marczewski, 2017)

  Example: WoW. Player could let his avatar learn professional skill like «Tailoring», then he can make backpacks for others to use.

Figure. 38 Professional skill Tailoring

- Gifting / Sharing: Allow gifting or sharing of items to other people to help them achieve their goals. Whilst a form of altruism, the potential for reciprocity can be a strong motivator. (Marczewski, 2017)

  Example: see the example of «access». WoW provides an in-game gift giving system.

- Voting / Voice: Give people a voice and let them know that it is being heard. Change is much easier if everyone is on the same page. (Marczewski, 2017)

  Example: DOTA2. For each year, the designer will create a new suit for the hero who has won the most votes from the player.

Figure. 39 Arcana Vote Between Pudge and Rubick

- Development Tools: Think modifications rather than hacking and breaking. Let them develop new add-ons to improve and build on the system. (Marczewski, 2017)

  Example: DOTA2. From the earliest version «6.70» to the latest version «7.10», the game has undergone more than 60 updates; each update contains a large number of modifications.

Figure. 40 The 7.07 Update

- Anonymity: If you want to encourage total freedom and lack of inhibitions, allow your users to remain anonymous. Be very, very careful as anonymity can bring out the worst in people. (Marczewski, 2017)

  Example: WoW. In the personal character creation phase, each player can give a name to their avatar.

Figure. 41 Role naming

- Light Touch: Whilst you must have rules, if you are encouraging disruption, apply them with a light touch. See how things play out before jumping in. Keep a watchful eye and listen to the feedback of users. (Marczewski, 2017)

  Example: No example.

- Anarchy: Sometimes you just have to burn it all to the ground and start again. Sit back, throw the rule book out of the window and see what happens! Consider running short «no rules» events. (Marczewski, 2017)

  Example: No Example.

- Leaderboard / Ladder: Leaderboards come in different flavors, most commonly relative or absolute. Commonly used to show people how they compare to others and so others can see them. Not for everyone. (Marczewski, 2017)

  Example: See the example of «Social Status».

- Badges / Achievements: Badges and achievements are a form of feedback. Award them to people for accomplishments. Use them wisely and in a meaningful way to make them more appreciated. (Marczewski, 2017)

  Example: WoW. Here are 5722 achievements used in the game, when the player complete a task or reach a certain standard, he will get the corresponding achievement.

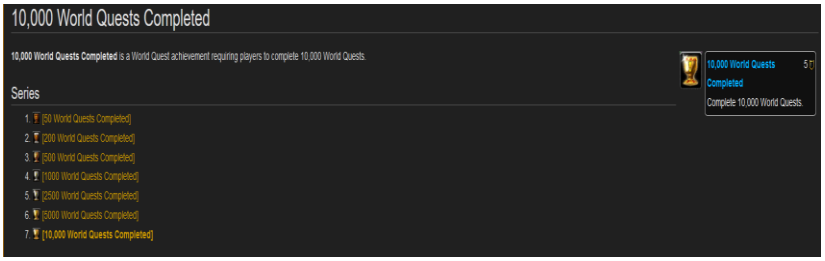

Figure.42 Badge of «10,000 World Quests Completed»

- Virtual Economy: Create a virtual economy and allow people to spend their virtual currency on real or virtual goods. Look into the legalities of this type of system and consider the long term financial costs! (Marczewski, 2017)

  Example: WoW. The game has a virtual economic system and there are three kinds of curren-

cies: gold coins, silver coins, copper coins. Players can use the currency to make trades with other players or NPC.

Figure. 43 Virtual Currency System in WoW

- Lottery / Game of Chance: Lotteries and games of chance are a way to win rewards with very little effort from the user. You have to be in it, to win it though! (Marczewski, 2017)

  Example: WoW. The game offers an add-on that lets you set up a guild lottery or raffle. The info such as price per ticket the amount of money in the lottery/raffle is up to you.

Figure. 44 Guild Lottery

- Free Lunch: A dynamic in which a player feels that they are getting something for free due to someone else having done work. It's critical that work is perceived to have been done (just not by the player in question) to avoid breaching trust in the scenario. The player must feel that they've «lucked» into something. (Marczewski, 2017)

  Example: Groupon (collective buying website). By virtue of 100 other people having bought the deal, you get it for cheap.

- Modifiers: An item that when used affects other actions. Generally modifiers are earned after having completed a series of challenges or core functions. (Marczewski, 2017)

  Example: Rich 4. The game contains many fun mini games and one of them is «shooting balloon». In this game, when a player breaks a «×2» balloon, his follow-up score will double.

Figure. 45 Shooting Balloon Game

- Ownership: The act of controlling something, having it be your property. (Marczewski, 2017)
  Example: Monopoly. Buy houses and hotels which can be regarded as self-property.

Figure. 46 Player property in Monopoly

- Real-time vs Delayed Mechanics: Real-time information flow is uninhibited by delay. Delayed information is only released after a certain interval. (Marczewski, 2017)
  Example: Super Mario Bros. Real-time scores cause instant reaction. At the end of each level, players will know the total score they have earned.

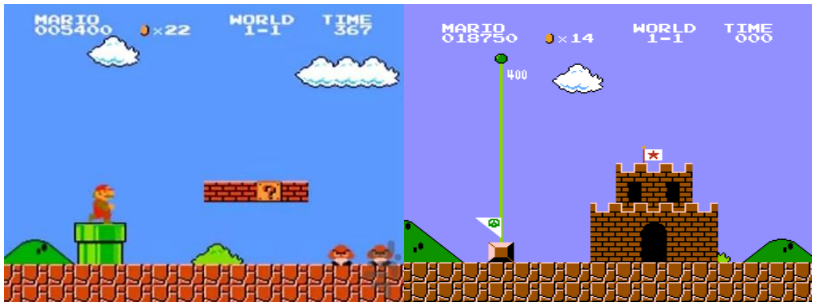

Figure. 47 Game scenes of Super Mario Bros.

- Role Play: In a role–play, the participants play a «role» in specific situation or scenario. They can play their own part or someone else's in a safe environment where they can act, experiment, learn and teach with no risks of irreversible consequences (Ladousse, 1987).
  Example: Consortio. In the game, here are 8 player selectable characters.

Figure. 48 Food Enterprise-ROSTARD & FILS (Rhizome, 2015b)

- Behavioral Momentum: The tendency of players to keep doing what they have been doing (Narayanan, 2014).
  Example: WoW. Player can level a skill called «mining» by repeating the process mining.

Figure. 49 Mining

- Collaboration: In a collaborative game, all the participants work together as a team, sharing the pay-offs and outcomes; if the team wins or loses everyone wins or loses. A team is an organization in which the kind of information each person has can differ, but the interests and beliefs are the same (Marschak et al., 1972).
  Example: Consortio. Six players represent different organizations formed a team to jointly determine the future direction of the consortium.

Figure.50 Consortio Session-Consortium Formation

- Cooperation: A cooperative game models a situation where two or more individuals have interests that are «neither completely opposed nor completely coincident»(Nash, 2002).
  Example: Consortio. Each member of the consortium has different personal goals, but they all hold one collective goal that to create more wealth for the consortium.

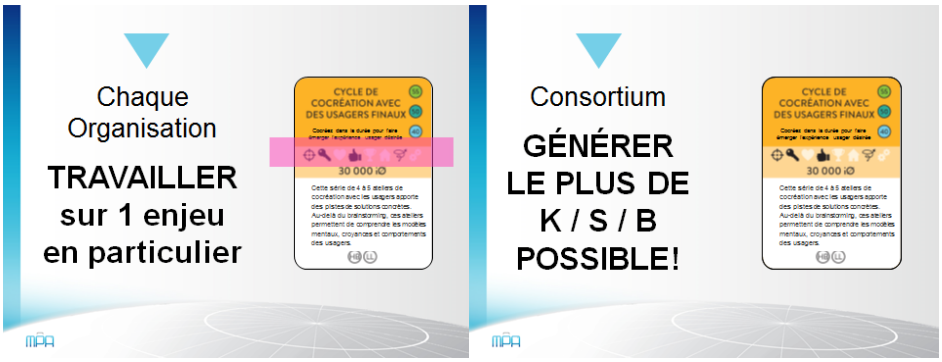

Figure. 51 Collective goal and personal goal (Rhizome, 2015b)

- Tokens: A player's representative on the game board made of a piece of material made to look like a known object (such as a scale model of a person, animal, or inanimate object) or otherwise general symbol. In some modern board games, such as Clue, there are other pieces that are not a player's representative (i.e. weapons) (Wikipedia, 2017).
  Example: Monopoly. At the beginning of the game, players need to select tokens (silver boots) represent themselves. During the game, players could use money to buy houses (green houses).

Figure. 52 Tokens used in Monopoly

- Cascading information: Information should be released in the minimum possible snippets to gain the appropriate level of understanding at each point during a game narrative (Narayanan, 2014).

  Example: Consortio. Before each card selection, the trainer will give corresponding guidance information to players instead of giving them all at the beginning.

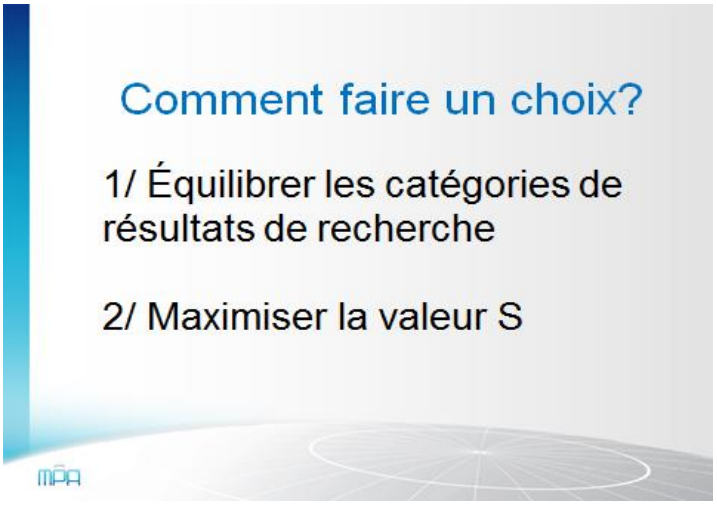

Figure. 53 Research card selection (Rhizome, 2015b)

- Cut Scenes / Story: A cut scene or event scene (sometimes in-game cinematic or in-game movie) is a sequence in a video game that is not interactive, breaking up the gameplay. Such scenes could be used to show conversations between characters, to the player, set the mood, reward the player, introduce new gameplay elements, show the effects of a player's actions, create emotional connections, improve pacing or foreshadow future events (Hancock & Hugh, 2002; Aaron & Marcus, 2014).

  Example: Super Marie Bros. When the player completes all the levels in the «World 1», here is going to have a NPC telling Mario that «Unfortunately, we were in the wrong castle fighting the wrong bowser. Oh well, on to World 2!» and then player will begin to adventure in «World 2».

Figure. 54 Scene of «World 1»

- Questions & Answers: Put forward the question and explore the answer.

  Example: Consortio. We can consider that each card selection as a challenge and after make choices the trainer will give the feedback which represents the answer.

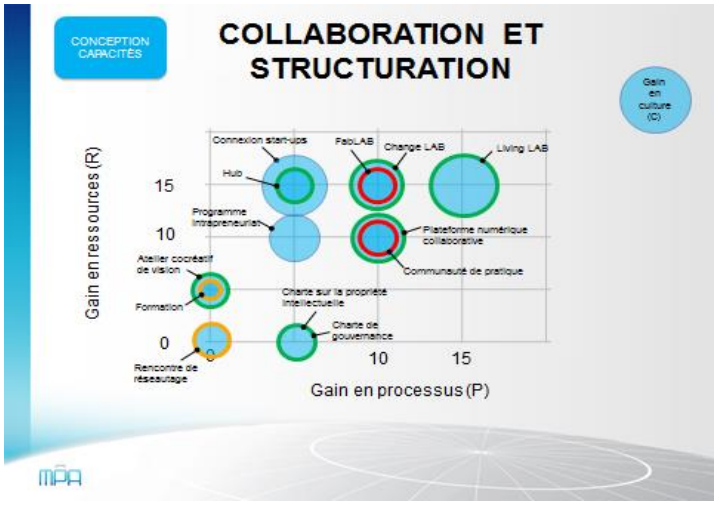

Figure. 55 Immediate Feedback of trainer (Rhizome, 2015b)

- Communal Discovery: An entire community is rallied to work together to solve a riddle, a problem or a challenge (Erick, 2010).

  Example: Consortio. All members of the consortium select open innovation tools through negotiation based on personal goals and trainer's guidance.

Figure. 56 Consortio Session-Card Selection

- Resource Management: While playing a resource management game, the player tries to reach a certain goal by carefully distributing limited resources (Jong et al., 2005).
  Example: Consortio. Each organization has a certain budget, and players need to make reasonable investments during the project.

Figure. 57 Consortio Session- Investment Management

- Pareto Optimal: Pareto efficiency captures the idea that an outcome is clearly inefficient if it is possible to achieve an improvement «on all fronts» simultaneously (Aumann & Dombb, 2010).
  Example: In game theory an outcome of a game is (weakly) Pareto optimal if there is no other outcome in which all players are (strictly) better off.
- Strategy / Planning: Make plan of action designed to achieve a long-term or overall aim.
  Example: Consortio. Players need to plan of how to make good use of limited budget so as to achieve personal goals.

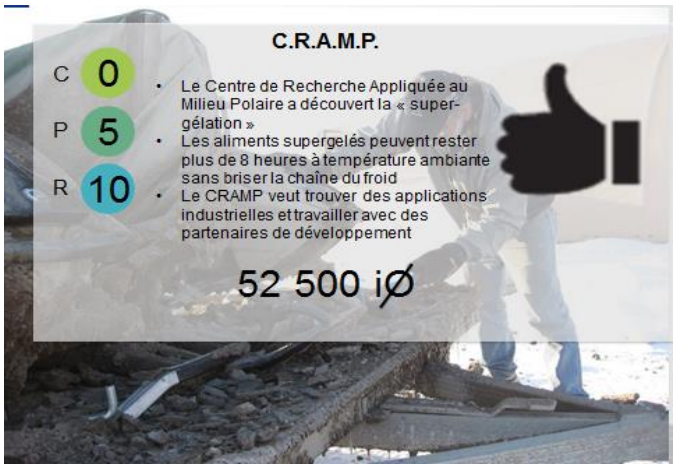

Figure. 58 Basic Introduction of C.R.A.M.P (Rhizome, 2015b)

- Appointment: A mechanic in which to succeed a player must return at a predefined time to take a predetermined action (Baek et al., 2013).

  Example: FarmVille. When planting a crop in a farming game, that crop might not be ready to harvest for 4 hours. The expectation is that players leave the game, and then come back when that crop is ready to be harvest.

Figure. 59 Growing Process of Watermelon

- Tiles / Grids: Based on how players or elements in games move from one point to another, tile based movement allow players to move and explore a world which is divided into tiles in turns and amount of tiles moved. Physics based movement provides a greater sense of immersion as players feel as though they are inside the game environment (Baek et al., 2013).

  Example: Monopoly. Players roll two six-sided dices to move around the game-board which is constituted by several grids.

Figure. 60 Tile based movement in Monopoly

- Capture / Eliminate: The strength of the player is defined by how many points or counters the player has captured. This is the most prominent in action, strategic or war based games (Baek et al., 2013).

  Example: Consortio. At the end of the game, the trainer will evaluate the performance of each group based on the relationship between its investment and income.

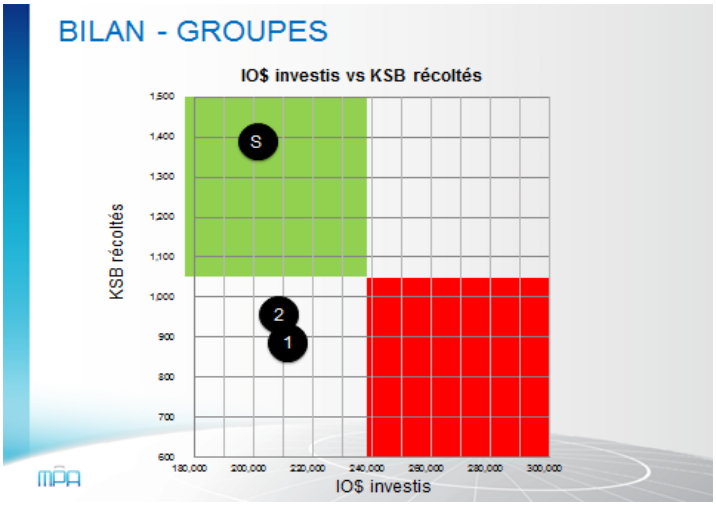

Figure. 61 Overall Feedback of trainer (Rhizome, 2015b)

- Infinite Gameplay: Game that have no explicit end. Most applicable to casual games that can refresh their content or games where a static (but positive) state is a reward of its own (Baek et al., 2013).

  Example: FarmVille. Players will never fail or achieve a final victory so that they can always develop their own manor.

Figure. 62 The development of farm on level 11 and level 50

- Action Points: Control what the user may do during their turn in the game by allocating them a budget of 'action points'. Actions points allow users' time to think of their next and future moves, the game gets the users into a strategical mind set when playing (Baek et al., 2013).
  Example: Monopoly. This game has a simple action point allowance system: each round, the player can only roll two dices once. However, when you move to jail, you will lose the action point in the next round.

Figure. 63 Action points in Monopoly

- Game Turns: A segment of the game set aside for certain actions to happen before moving on to the next turn, where the sequence of events can largely be repeated (Baek et al., 2013).
  Example: Monopoly. Each turn, players must roll dices in the same order to move their tokens.

- Levels: Designing levels for games include but are not limited to designing the challenges, environment, player experience, resulting narrative, layout and various other aspects. In short, a level designer creates the world that the level is in and decides what the experience the player will have in that level (Hedvall & Claesson, 2015).
  Example: PLAY'INN. It is constituted by 3 universes (ideation, prototyping and deployment) which include 24 levels. At each level, players will encounter new challenges.

Figure. 64 PLAY'INN Scenes

- Pavlovian Interactions: Follows the methodology «easy to learn, hard to master». Meaning the game is simple to pick up and play, however, increases its difficulty as the user advances through the game. Used to «hook» gamers due to its replay value and challenging environment (Baek et al., 2013).

  Example: PLAY'INN. 24 levels in the game represent 24 difficulty levels, players start from the simplest level and the difficulty of gameplay will increase gradually.
- Time pressure: Players need to make the right decision within the time frame.

  Example: Consortio. Players must choose the right open innovation tool within the specified time.

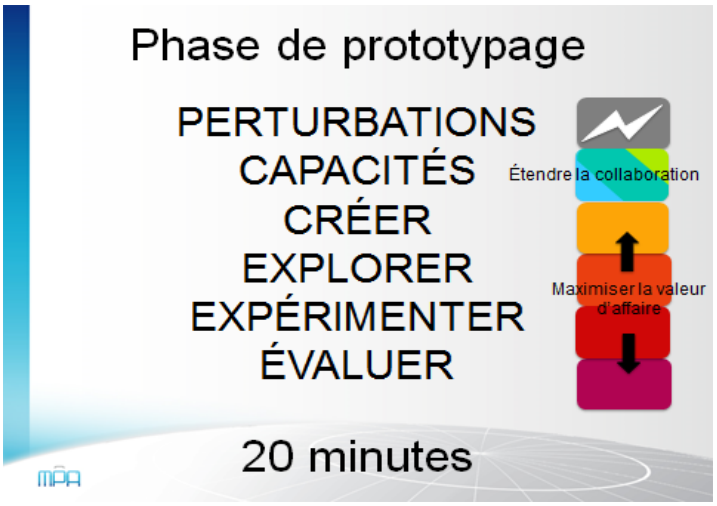

Figure. 65 Prototype Phase in Consortio (Rhizome, 2015b)

- Feedback: Shows the user what they have just done, and gives them instant gratification (the feel-good factor) of things happening after they have completed a task. Allows the user to feel understood by the game; by giving a user power, the game fulfils a natural human desire (Baek et al., 2013).

  Example: Consortio. The counters (CPR) used in the game will give the player immediate feedback.

Figure. 66 Game Board of Consortio

- Meta-Game: Rewards or improvements that can be earned during the actual game-play and/or outside of it, that carries over to repeat plays (Baek et al., 2013).
  Example: Consortio. The player's good performance in the game often means that he can better apply the knowledge acquired from the game to reality.

- Movement: It is based on how players or elements in games move from one point to another. There is essentially one kind of movement strategy employed in games that can arguably be seen as two separate types. It's called tile based movement. Most of us are very familiar with it, because we have seen in games such as Monopoly or Checkers. The movement of a character or game element is defined by tiles placed on a board. Sometimes this movement is determined by turns or randomized by dice. Some games employ this exactly as demonstrated in Monopoly; for example, the game Civilization allows players to move and explore a world which is divided into tiles. The movement of each game entity is determined by the turn and amount of tiles it can move. The other type of movement is «real-time» or «physics based». Games that employ this movement technique resemble worlds and behaviors very close to how we perceive physics based movement in the real world (Louchart & Lim, 2011).
  Example: See the example of «Tiles / Grids».
- Realism: Realism in computer games is achieved in many different ways. Perhaps the most direct and cognitively closest is in the graphical quality of games. The first thing people notice about a computer game is how real the graphics look. The importance of perception to us is captured in the old adage «seeing is believing» (Low, 2011).
  Example: Consortio. Each section of the game corresponds to the design and development process of product or service in reality.

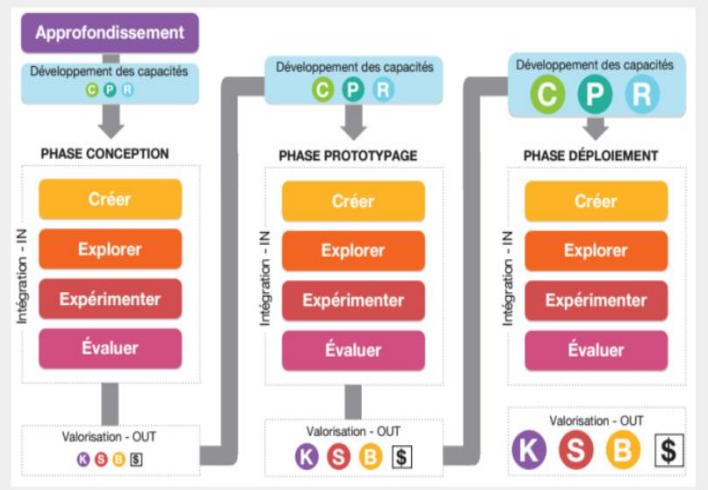

Fig 67 Open Innovation Cycle (Rhizome, 2015a)

- Assessment: Assessments are used to evaluate the learning outcomes and engaging in competition can result in higher thinking orders. It ensues creativity and ownership of knowledge while inculcating a responsible use of that knowledge (Louchart & Lim, 2011).
  Example: No example.
- Tutorial: Explain the game mechanism to guide the players.

Example: Consortio. At the beginning of the game, the trainer introduced five rules that must be followed.

Figure. 68 Tutorial of Game Rules (Rhizome, 2015b)

- Competition: Challenges or competitions in a game environment are events or tasks users must complete to reach goals individually, as a group or in a head-to-head contest. (Gartner, 2012)

  Example: Consortio. At the end of the game, the trainer will compare the value created by each group.

Figure. 69 Scoreboard

- Urgent Optimism: Indicates extreme self-motivation with a desire to act immediately to tackle an obstacle combined with the belief that we have a reasonable hope of success (Baek et al., 2013).

Example: WoW. In order to kill the boss, players continue to complete the task, rapid upgrade so as to enhance the ability of their role.

- Status: Provide a sense of belonging or meaningful empowerment. Multiple forms of status, such as titles, levels, tiers, rank not just globally but also locally within a community (Baek et al., 2013).

  Example: WoW. In the game, as the player's character level increases, they will unlock new skills.

Figure. 70 Warrior Talents

- Virality: Mechanic to grow player base which if done right should enrich gameplay. It is also designed to reinforce retention (Louchart & Lim, 2011).

  Example: WoW. When the level of player is greater than 30, he can recruit a friend to play together and both of them will earn free game time and multiple in-game items.

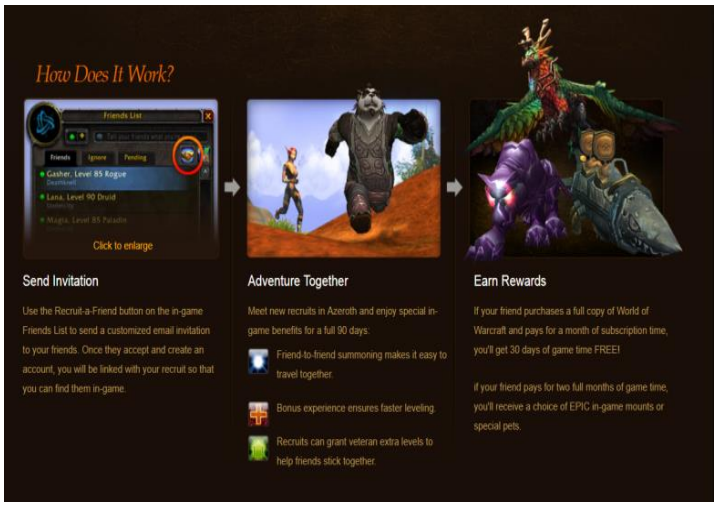

Figure. 71 Recruit a Friend

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Appendix B: RID textbook and ontology

This document is a condensed textbook for the RID methodology. The objective is to collect the salient points of RID - how we can describe it, what can be learned and taught - so as to result in a descriptive language of RID. For that, we consulted and extracted what was considered the most structuring and original aspects of RID, like adapted vocabulary, cognitive concepts (or constructs), process description – tasks, deliverables, performances, tools, methods, principles, paradigms. We did it from the RID Guidebook v13.0 [1], which has been produced by Prof. Yannou in that spirit. Second, we also adopted the competency framework for "radical innovation in need seeker strategy" proposed by Moubdi et al. [2], which is absent from the RID Guidebook. Then, Prof. Yannou validated that this textbook was representative of the typical RID corpus. Finally, an ontology was proposed to highlight and deposit the different objects that compose the RID methodology so that it can be used as a store to define the game's mechanics and scenarios.

1. Index of the RID Guidebook v13.0

The index of the RID Guidebook v13.0 [1] is the first object to consider as it is supposed to address all the methodological aspects (Table 1).

Table 1: Index of the RID Guidebook v13.0 [1]

1. Activity centered design 2. Activity field 3. Activity theory 4. Ambition perimeter 5. Behavioral charter 6. Blue ocean 7. Book of knowledge 8. Business design (sub process) 9. Business design (BMC-RID) 10. Certification levels 11. Concept (proof of) 12. Conceptual solution 13. Creativity (concept creativity) 14. Creativity (RID creativity tool) 15. Creativity (scenario creativity) 16. Deep knowledge 17. Disruption 18. Existing solution 19. Exploration – exploitation 20. Focused creativity	21. Humanism and essential values 22. Idea 23. Ideal goal 24. Ideality 25. Ideation (in RID process) 26. Ideation (in two steps) 27. Initial idea 28. Innovation 29. Innovation dossier 30. Innovation process 31. Innovation methodology (the main ones) 32. Innovation methodology (Unique Selling Propositions of RID) 33. Innovation methodology (RID versus Design Thinking) 34. Innovation intensity and radicality 35. Investigation 36. Kano analysis 37. Knowledge design 38. Need seeker strategy 39. Newness 40. Observation of usage	41. Philosophy of innovation 42. Problem and solution co-evolution 43. Problems (definition) 44. Problems (causality graph) 45. Problems (covered) 46. Problems (naming) 47. Problem design 48. Problem Setting and Problem Solving 49. Profitability 50. Prototyping 51. Prove It Seminar 52. Qualify and Quantify 53. Radical Innovation Design® 54. Reframing 55. Reframing (tables) 56. Representation of usage scenarios 57. RID data streaming 58. RID process (general) 59. RID process (details) 60. SAPIGE® method (the two-stage idea selection process)	61. SAPIGE® method (the 360° innovation diagnostics and incubated coaching) 62. Serious game 63. Set-based thinking 64. Solution design 65. Thinking inside the box 66. Traceability 67. UDIP model of designing 68. UNPC innovativeness indicators 69. UNPC monitor tool 70. Usage coverage 71. Usage driven design 72. Usage scenario (definition) 73. Usage scenario (dreamt) 74. Usage situation (existing) 75. Usage situation (covered) 76. Usefulness 77. User profile 78. Validation 79. Value bucket (definition) 80. Value bucket (the four segmentations) 81. Value bucket (the algorithm) 82. Value bucket (matrix manipulations) 83. Value Buckets driven design

2. Process description

Description of tasks and deliverables

2.1 The general breakdown

The RID process is at the heart of the Radical Innovation Design® methodology. In contrast to the traditional linear Design Thinking process, the RID process is a much more structured X-shaped process resulting in fewer design backward loops. This is due to its *set-based thinking exploration-exploitation* principle. The RID process is split into two parts: *problem setting* and *problem solving*, the former consisting of *knowledge design* and *problem design*, and the latter of *solution design* and *business design* (Figure 1).

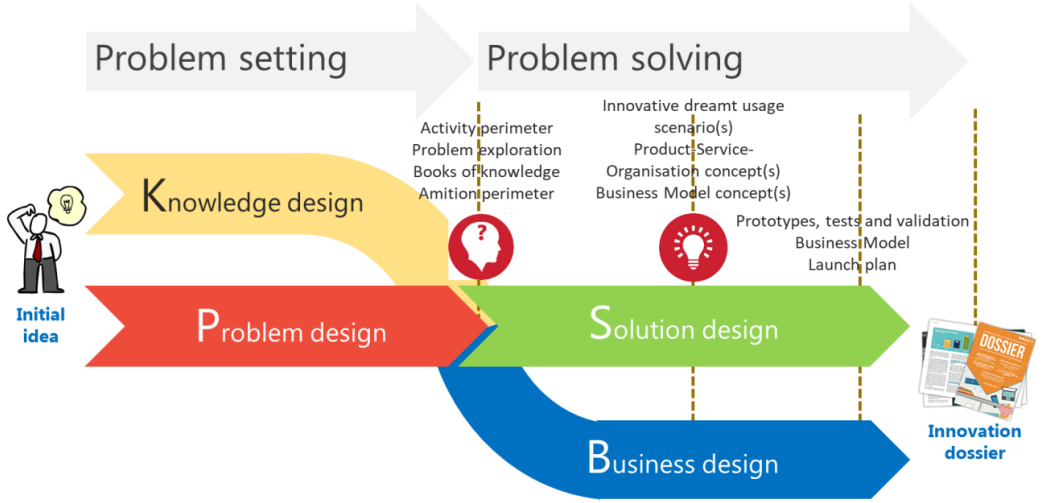

Figure 1: General breakdown of the RID process along with the main deliverables

2.2 The detailed representation

1) Knowledge design

Knowledge design is one of the 4 fundamental sub-processes of the RID process. It allows the innovation project to start with a multidisciplinary group in an organized way. Three results are produced: (a) an outline of the knowledge, skills and expertise relevant to the project, (b) an increase in this *deep knowledge* through efficient *investigation strategies* and action plans, (c) the whole resulting in the writing and presentation of *books of knowledge*. The main tasks in this RID sub-process are: list deep knowledge items, list investigation strategies, organize investigation (selection & breakdown), and deliver books of knowledge (Figure 2).

Figure 2: The Knowledge Design detailed process

2) Problem design

Problem design is one of the 4 fundamental sub-processes of the RID process (Figure 3). This is the stage at which problems are structured, exploiting the investigation results to formulate the overall goal of the user's activity improvement (*ideal goal*), the exact areas to target (*value buckets*) and the areas to adopt into the innovation project objectives (*ambition perimeter*).

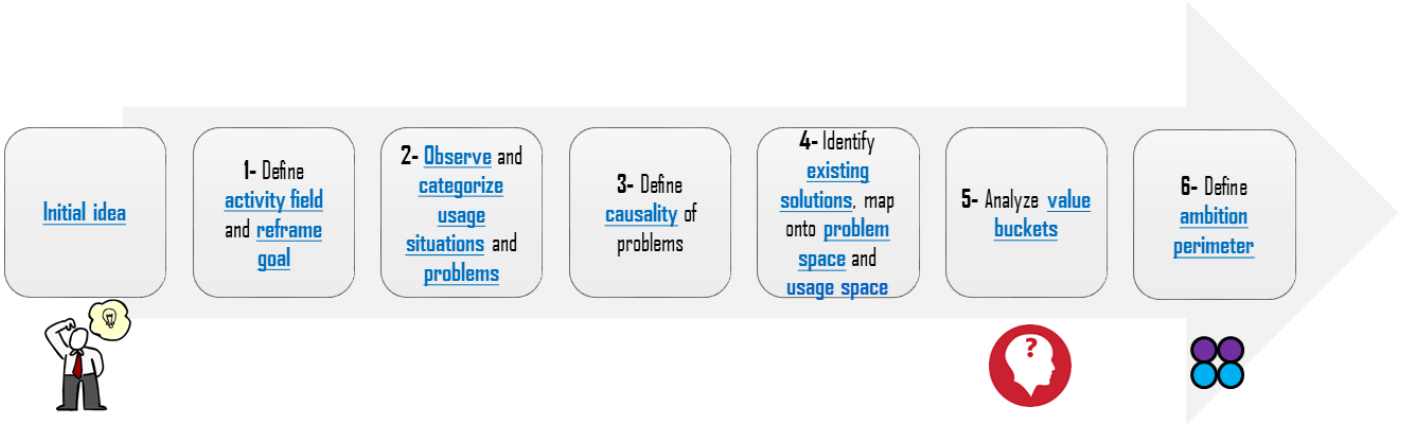

Figure 3: The Problem Design detailed process

It is broken down into 6 stages, as detailed in Table 2.

Table 2: The breakdown of the Problem Design

1. Define activity field and reframe goal	1.1. Define the activity field and possible activity sub-categories. 1.2. List and define all the value beneficiaries and possible other stakeholders of the present value chains. Among value beneficiaries, define with accuracy user profiles. 1.3. Reframe the ideal goal (the question "for what purpose?").
2. Observe and categorize usage situations and problems	2.1. Define and perform a series of observation experiments (on typical usage situations) to complete primary investigations. 2.2. Derive qualitative and quantitative data from problems: circumstances, probability of occurrence, causes, consequences and their severity. 2.3. Proceed to the segmentation of a reasonable number of usage situation segments. 2.4. Proceed to the segmentation of a reasonable number of problem segments. 2.5. Define size of usage situations (after their probability of occurrence).
3. Define causality of problems	3.1. Define measurement units for problems. 3.2. Define causes and consequences and link them in a comprehensive causal graph. 3.3. If necessary, loop back to problem segmentation (2.4.). 3.4. Define importance of problems after gravity of their consequences.

4. Identify existing solutions, map onto problem space and usage space	4.1. Categorize existing solutions by relevance with categories of problems and usage situations. 4.2. Map existing solutions onto problems graphically, resulting in covered problems. 4.3. Map existing solutions onto usage situations graphically, resulting in covered usage situations.
5. Analyze value buckets	5.1. Define the four input matrices: (A) Profiles X Situations, (A') Situations X Problems, (B) Solutions X Problems, and (C) Situations X Solutions. 5.2. Validate the 4 matrices against data and experts. Trace the rationale for filling the matrices. 5.3. Apply the DSM-Value-Bucket algorithm. 5.4. Interpret and illustrate the resulting high value VBs with project members and experts. 5.5. If necessary, loop back, revising the matrices until you get satisfactory and stable results.
6. Define ambition perimeter	6.1. Define extra Kano features (KFs) in addition to identified VBs. 6.2. Perform a Kano survey on the internet. 6.3. Compare the VB ranking and the Kano ranking, resulting in preferred generalized (RID and Kano) value buckets, while eliciting heuristics used. 6.4. Propose subsets of VBs and KFs as project objectives to the project contractor. 6.5. Negotiate the final ambition perimeter with the contractor, taking considerations into account such as: company strategy and portfolio, consistency and harmony of VBs/KFs.

3) Solution design

Solution design is one of the 4 fundamental sub-processes of the RID process (Figure 4). It allows the ideation of the conceptual product-service solution from the ambition perimeter in two steps. Next, the concept is designed in details, prototyped, experimented, validated, and the RID project is reported in order to prepare for a Go/NoGo decision.

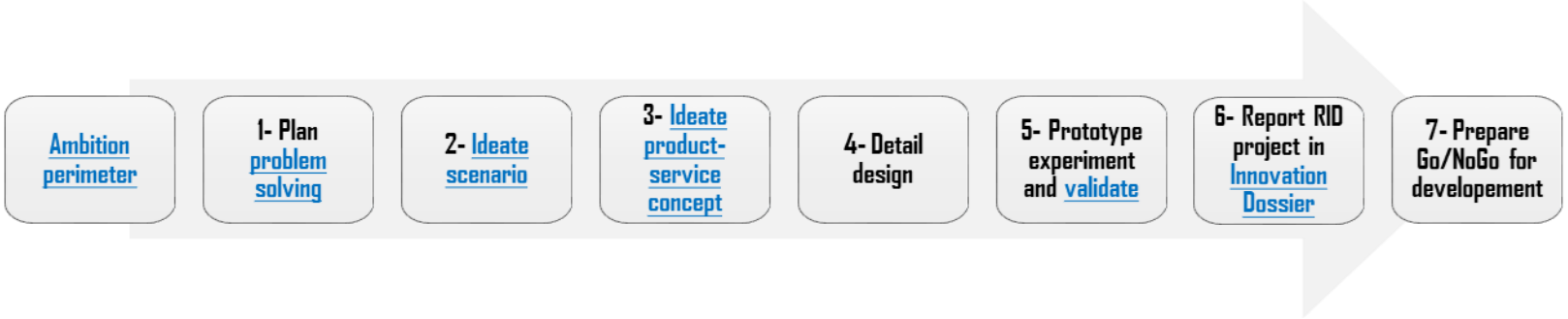

Figure 4: The Solution Design detailed process

Solution design is decomposed into 7 stages, each stage consisting of further stages.

Table 3: The breakdown of the Solution Design

1. Plan problem solving	1.1. Plan the problem solving.
2. Ideate scenario	2.1. For each VB or Kano feature of the ambition perimeter, proceed to a brainstorm, possibly using the RID creativity tool to shift the existing usage situations and problems of VBs to gain inspiration. 2.2. Mature ideas with UNPC monitor tool, and choose the most promising ideas. 2.3. Assemble combinations of ideas into coherent dreamt usage scenarios. 2.4. Mature dreamt usage scenarios with UNPC monitor tool. 2.5. Choose one or several preferred dreamt usage scenarios with the RID project contractor.
3. Ideate product-service concept	3.1. For each preferred dreamt usage scenario, proceed to a brainstorm. 3.2. Mature ideas with UNPC monitor tool. 3.3. Choose one or more preferred dreamt usage scenarios with the RID project contractor.
4. Detail design	4.1. Design in detail.
5. Prototype experiment and validate	5.1. Design a prototype and an experiment which are likely to clearly exhibit revealed behaviors and VBs for the most important VBs. 5.2. Carry out the experiment and assess revealed VBs. 5.3. Compare revealed VBs to those (targeted VBs) of the ambition perimeter. 5.4. Validate the solution or loopback.
6. Report RID project in innovation dossier	6.1. Report the RID project in the Innovation dossier, including the results of the Business Design sub-process. This report must not only contain final results, but also most of the design alternatives and decision processes at any stage.
7. Prepare for a Go/NoGo decision	7.1. Construct the launch plan of your Product-Service-Business-model innovation and argue the benefits for the company.

4) Business design

Business design is one of the 4 fundamental sub-processes of the RID process. It involves innovatively designing the business model alongside the conceptual product-service-organization (PSO) solution developed in the solution design sub-process. It is broken down into 5 stages (Table 4). The first one involves initiating the Business Model Canvas (BMC) using the RID ambition perimeter. This use of BMC along with the UNPC innovativeness indicators is called BMC-RID.

Table 4: The breakdown of the Business Design

1. Initiate BMC	Start BMC by filling the two blocks “value proposition” (VP) and “customer segment” (CS) with items of ambition perimeter.		
2. Maturate VP and CS blocks	Make sure that UN (out of UNPC) has been made green for these 2 blocks by sufficient concept maturation (with UNPC monitor tool).		
3.1 Ideate other blocks	Complete the 7 remaining blocks of BMC (possibly innovative)	Elaborate a dreamt usage scenario of the BM block(s) Go to 3.1. or 4.2	3.2 Scenario creativity (in Solution Design sub-process)
4.1 Maturate blocks	Make as green as you can the UNPC indicators of the 9 BMC blocks	Elaborate a conceptual solution of the BM block(s) Go to 3.1	4.2 Concept creativity (in Solution Design sub-process)
Forth and back with Solution design			
5. Recommend	Summarize and make recommendations		

2.3 The actigram representation

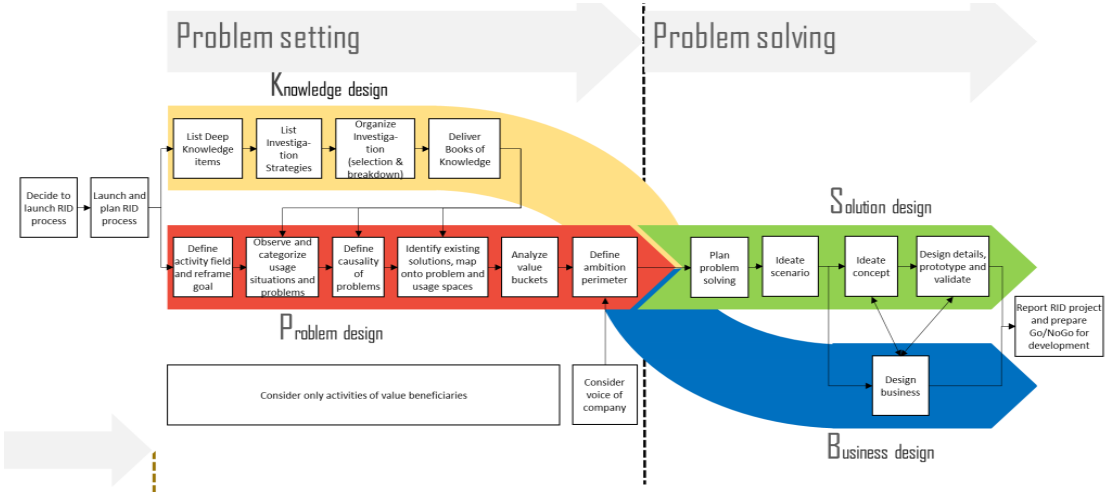

Figure 5: Actigram representation of the RID process

Figure 5 illustrates the main tasks of the 4 sub-processes on a same DNA-shape process representation. Let us note that not all the tasks described before are represented (for instance no detail here on the Business Design). One interesting thing is that one clearly shows that, once the company has define the activity to study, there is no influence of it on the problem design until the definition of the ambition perimeter.

2.4 Navigation dashboard of the RID CSCW system

The following diagram (Figure 6) shows the navigation dashboard designed for the RID CSCW system. Each function button corresponds to an elementary panel of the RID platform. The yellow rectangles physically locate the 6 comparison criteria with Design Thinking (see sub-section 3.1). This navigation dashboard was designed based on the actigram. It keeps most of the RID tasks, which were then named by the terms from the index of the RID Guidebook v13.0 [1]. “Brainstorming” is not a RID task but a group creativity technique that is commonly used in the RID process, especially in Solution Design; the corresponding button being intended for users of the RID platform to record their creativity results.

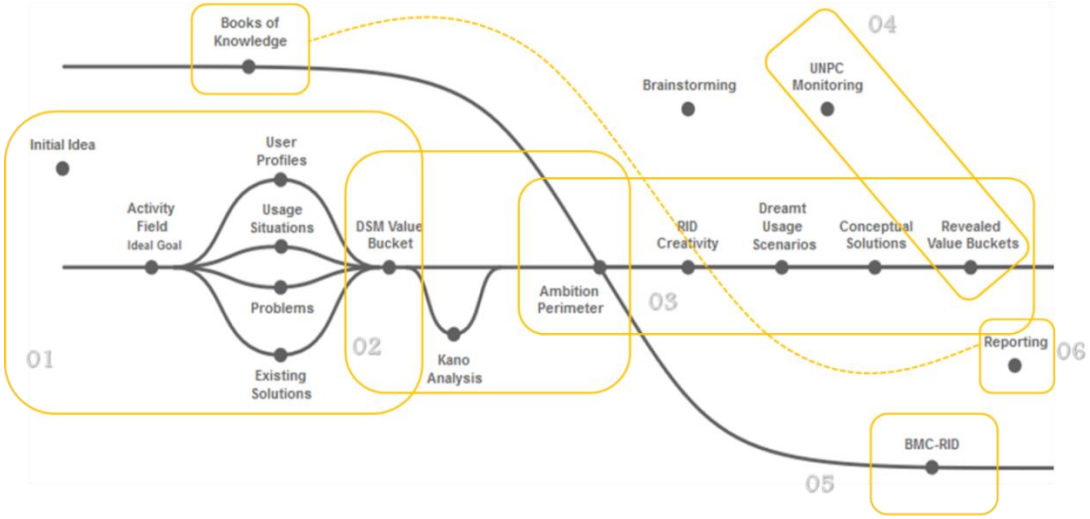

Figure 6: Navigation dashboard of the RID CSCW system

2.5 The usage-driven representation

RID is a usage driven innovative design methodology, as it starts with the observation and segmentation of usage (within an activity field) and the design of new usages in accordance with an ideal goal, and ends with the validation of the revealed usage of the chosen product-service-organization solution and its business model. The primary objective is to help with users' activities. Figure 7 describes how usage drives the whole RID process.

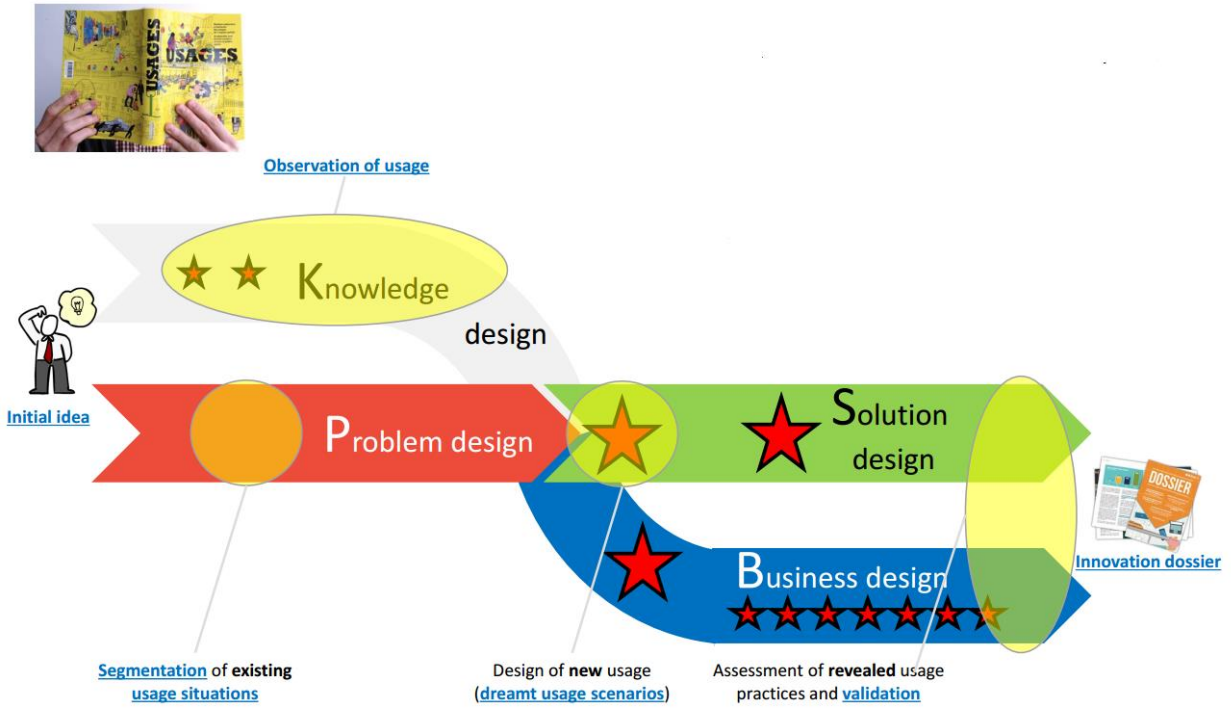

Figure 7: A usage-driven representation if the RID process

Description of the specificities of the RID process --- Activity-centered

2.6 The activity-centered representation

In accordance with Activity Theory, RID considers any innovative design in need seeker mode as the improvement of an activity system. This is why the activity and its outcomes are meticulously observed in order to define the innovation brief for the design of the future activity and then for the design of the new tool that improves the activity's outcomes. The following figure highlights another characteristic of the RID process, activity-centered. It is based on the general breakdown but focuses more on describing how activity is treated in the RID process.

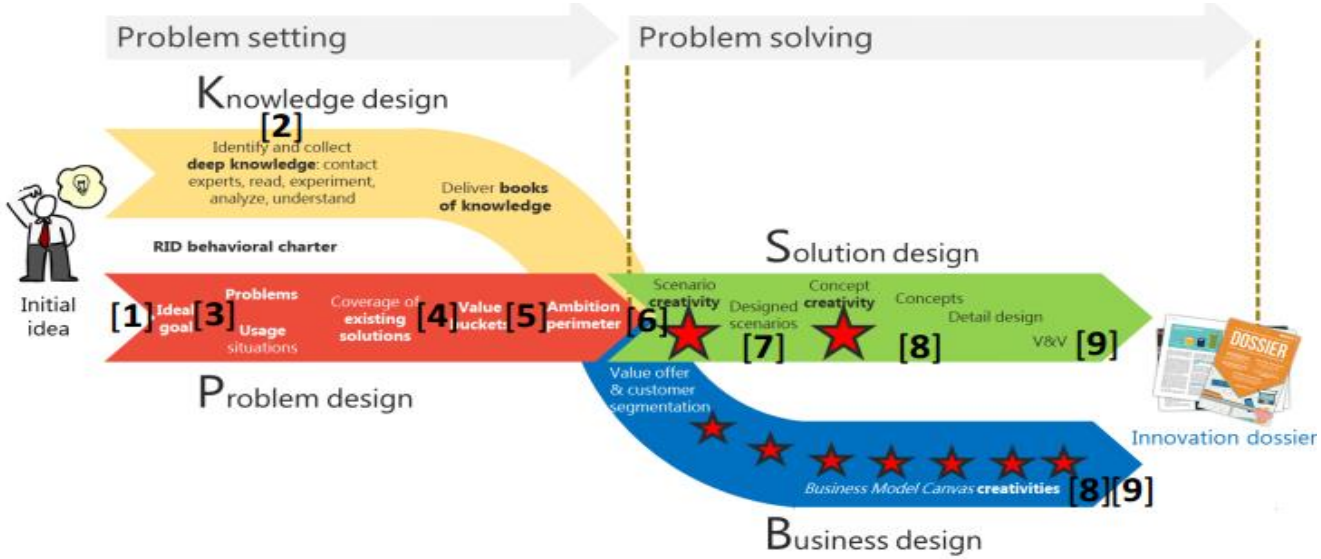

Figure 8: An activity-centered representation of the RID process

An activity-centered RID process follows the below procedure:

① Define users and activity field (also mentioned in ideal goal);

② Analyze present activity, i.e.: goal, generic tool (most widespread existing solution) if any, rules, community, division of labor (done in Knowledge design);
③ Define ideal goal from initial idea and previous stage (also mentioned in ideal goal)
④ Analyze other adapted tools (called existing solutions)
⑤ Analyze outcome of present activity (during problem design, leading to value buckets)
⑥ Define innovation brief (called ambition perimeter)
⑦ Design future activity (done using scenario creativity)
⑧ Design one or more tools adapted to future activity (done by concept creativity)
⑨ Prototype, test and validate outcome of future activity with the selected tool (during detail design and Validation & Verification)

Not only RID is a methodology which is usage driven and activity centered, but it is strongly integrated around its core concept of Value Bucket. Indeed, 9 key moments have been identified on the RID process which use the semantics of *value buckets* and *activity* to act and process results. Figure 9 is an evolved version of Figure 8.

Figure 9: An evolved activity and value bucket centered representation of the RID process

2.7 The representation as a transformation of activity

In accordance with Activity Theory [6], RID considers any innovative design in need seeker mode as the improvement of an activity system. This is why the existing activity and its outcomes are first meticulously observed through the human *activity system model* by Engeström [6]. From this observation (see Figure 10), the innovation specifications for the design of the future activity are derived in the form of targeted value buckets. Value buckets then serve as starting points for ideation of an activity dreamt usage scenario and, beyond, of an innovative Product-Service-Organization system that improves the activity's outcomes. This representation is similar to the activity-centered representation; they describe how an existing activity transforms into the new activity thanks to the RID process.

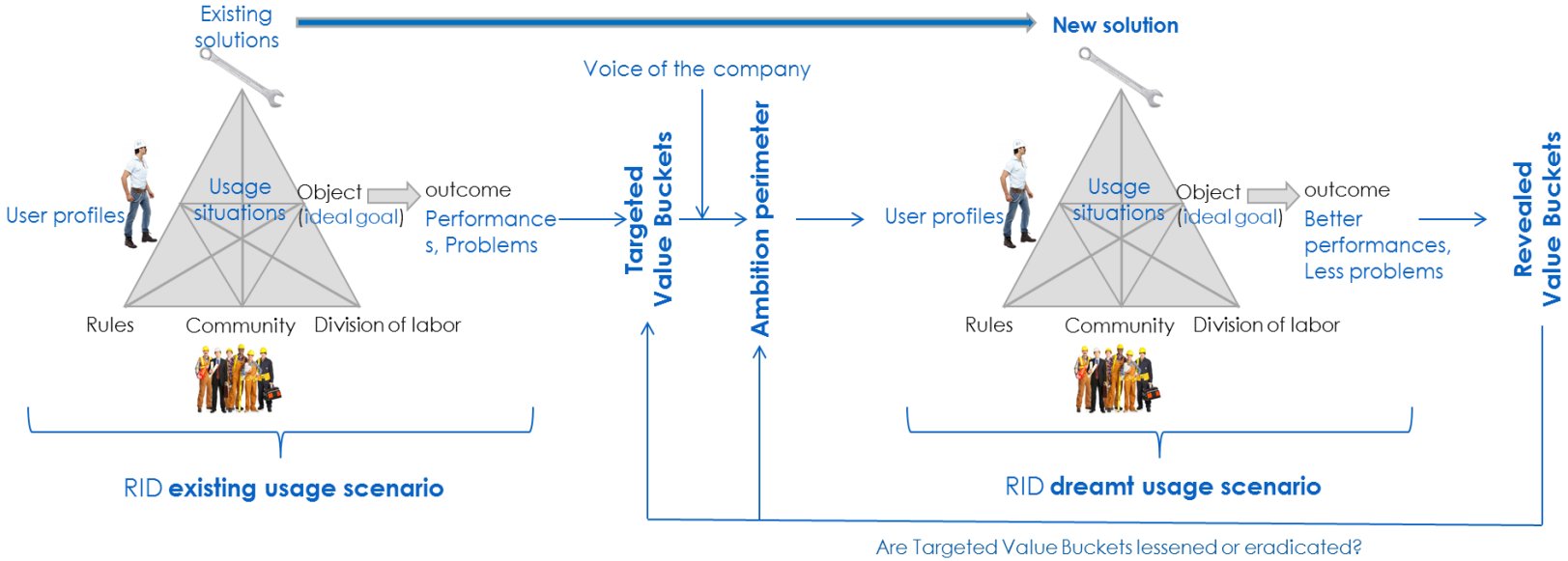

Figure 10: In RID, the innovative design of a Product-Service-Organization (PSO) is considered in RID as a transformation of a user activity system for which the PSO is the *mediating artefact* or *tool*.

Description of the data streaming

2.8 The data streaming representation

This representation describes how the data flows in the RID process (Figure 11). The initial idea proposed by the company is finally transformed into an innovation dossier thanks to the RID process. This is an interesting representation as the detailed graphical representation allows to understand the data structure and transformation along a series of mechanisms (DSM-VB algorithm, definition of macro-value-buckets, Kano analysis, definition of ambition perimeter, use of RID creativity tool, UNPC monitoring, use of BMC-RID, feedback on value created from the revealed value buckets).

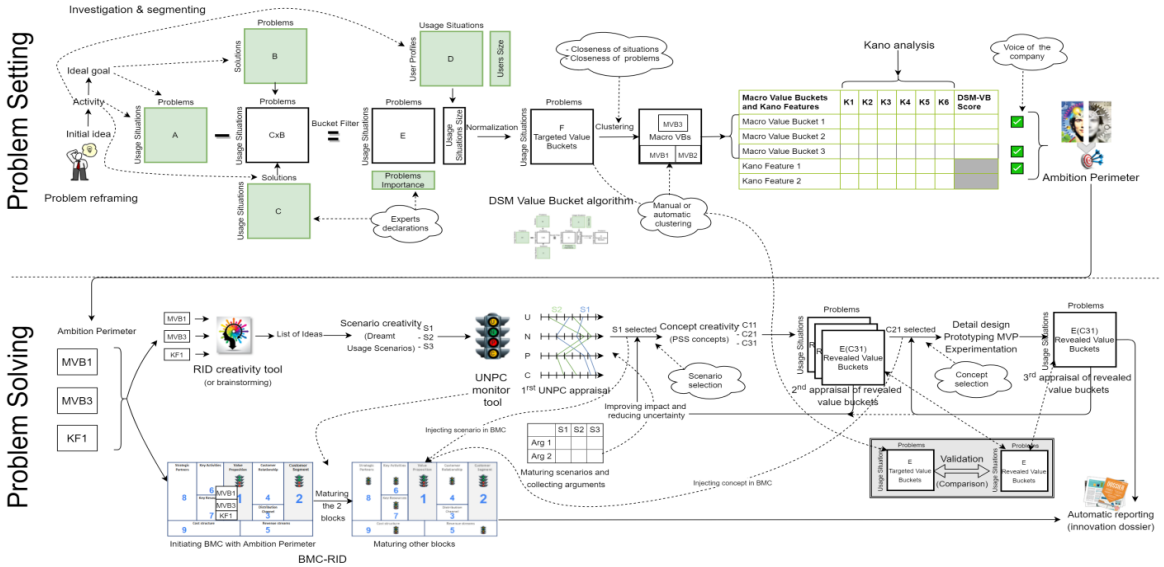

Figure 11: From initial idea to innovation dossier: The RID data streaming

2.9 The Usage-Driven Innovation Processes (UDIP) model

While the FBS model of designing (Gero, 1990) is acknowledged to be a useful framework for representing and analyzing design methods, the UDIP model – standing for Usage-Driven Innovation Processes - developed by Yannou, Cluzel and Lamé (2018) is an evolution of the FBS framework which better encompasses the specificities of usage-driven innovation processes like RID methodology. The UDIP model, which significantly differs from the FBS model, is more adapted to the fuzzy front-end of innovation. A significant step forward is the validation of the final design by comparison of revealed Value Buckets and targeted Value Buckets. The Usage-Driven Innovation Processes (UDIP) model (Figure 12) is a framework for analyzing innovative design methods. It describes the act of innovating with 10 design issues (or constructs) and 15 fundamental design processes linking these issues in a generic innovation process. Important evolutions of the FBS model incorporated in UDIP include:

① R (requirements) and F (functions) are banished from RID for being too artificial and interpretable by designers;

② I (initial idea), A (activity field), U (usage), P (problems), Ve (expected/targeted value buckets) and Vs (value buckets derived from structure or revealed) are introduced to enrich the traditional "task clarification";

③ The comparison is no longer between Be and Bs, but between Ve and Vs, i.e. expected and revealed value buckets.

It is interesting to note that the UDIP model is almost an ontology, which is relevant in our case as we try to come up with a RID ontology in this annex. Table 5 uses the UDIP model to divide and describe the RID process.

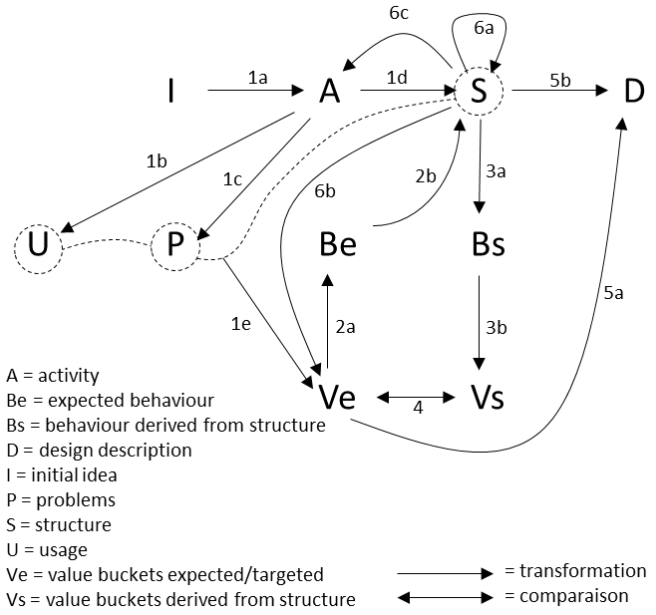

Figure 12: The UDIP model made of 10 design issues, 6 fundamental and 15 elementary processes

Table 5: The 15 elementary processes of UDIP model and their counterpart in RID process

Fundamental processes	Elementary processes	RID process	RID terms
Formulation	**Formulation 1a** transforms (initial) idea into activity (field) (I → A)	Problem reframing	Initial idea, Activity field, Reframing, Ideal goal, Transfer function approach, Transformation service approach
	Formulation 1b transforms activity into usage (A → U).	Usage investigation and modelling	Activity field, Usage situations, User profile, Usage scenarios
	Formulation 1c transforms activity into problems (A → P).	Problems investigation and modelling	Problems, Usage situations (existing), Ideal goal
	Formulation 1d transforms activity field into existing structures (solutions) (A → S).	Investigation of existing solutions	Existing product-service-systems solutions, Usage situations (covered), Causality graph
	Formulation 1e transforms usage, problems and existing structures (solutions) into expected value buckets ({U, P, S} → Ve).	DSM-Value-Bucket algorithm	Value buckets, DSM-Value-Bucket Algorithm, Kano analysis, Ambition perimeter, Usage situations, Problems, Existing solutions, Blue ocean, SAPIGE® method
Synthesis	**Synthesis 2a** transforms expected value buckets into expected behavior (Ve → Be).	Product-Service-Organization scenario and business model scenario ideation	Product-service solution, Ideation, Dreamt usage scenario, RID creativity tool, UNPC (usefulness, newness, profitability and concept) monitor tool, BMC-RID
	Synthesis 2b transforms expected behavior into structure (Be → S).	Product-Service-Organization scenario and business model scenario conceptual design	Dreamt usage scenario, Concept creativity, Conceptual solution, UNPC monitor tool, SAPIGE® method, BMC-RID
Analysis	**Analysis 3a** transforms structure into behavior derived from structure (S → Bs).	Simulation, prototyping and validation	Prototyping techniques, Revealed value buckets, Targeted value buckets
	Analysis 3b transforms behavior derived from structure into value buckets derived from structure (Bs → Vs).	Experimentation with the solution and assessment of the revealed value buckets	Usage situations, Observation techniques, Observation protocol

Evaluation	**Evaluation** compares expected value buckets with value buckets derived from structure (Ve ↔ Vs).	Comparison between the targeted value buckets and the revealed value buckets	Revealed value buckets, Targeted value buckets, Usage-Driven Innovation Processes (UDIP) model
Documentation	**Documentation 5a** transforms expected value buckets into documentation (Ve → D).	Documentation of the Books of knowledge and of the ambition perimeter	Deep knowledge, Investigation strategies, Books of knowledge, Activity field, Usage situations, Problems, Consequences and causes of the problems, Existing solutions, Ideal goal, Business models, Activity-centered design, Usage-driven design, User profile
	Documentation 5b transforms structure into documentation (S → D).	Technical documentation about the solution	Innovation dossier, Conceptual solution
Reformulation	**Reformulation 6a** transforms structure into new structure (S → S').	Another solution structure is tested	Solutions
	Reformulation 6b transforms structure into new expected value buckets (S → Ve').	Another subset of value buckets (ambition perimeter) is decided	Solutions, Targeted value buckets, Ambition perimeter
	Reformulation 6c transforms structure into new activity (S → A').	Another activity field is tested	Solutions, Activity field

2.10 The representation as a production process

In this representation of the RID process, the RID process is compared to a production process of innovative solutions (Figure 13). Once a problem is defined and a corresponding general solution – corresponding here to the PSO solution and the business model - is designed, the strategy is iteratively improved in optimizing interactively the problem and the general solution. This representation is consistent with the general breakdown: ① "define and optimize the problem" corresponds to "problem setting", ② "define and optimize the solution" corresponds at the same time to "solution design" and "business design", and ③ "define and optimize the strategy" steps back on this elementary forward process of innovative design, to reconsider possible adaptations of the Problem/General-solution context of the company. This iterative and adaptive process will be made possible with a computerization of the RID process.

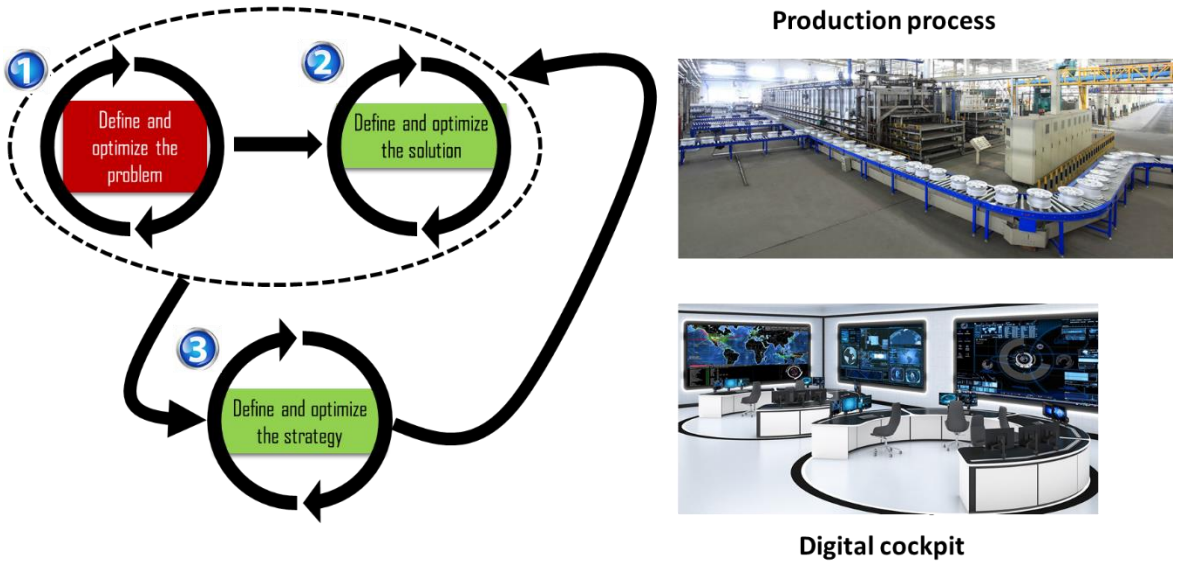

Figure 13: The RID process – a production process of innovative solutions

In Figure 14, the production process is decomposed into vital questions which should be answered by innovators. The digital cockpit corresponds to the assessment of the value created by the innovative solution in terms of augmented activity, as well as a positioning of the innovative solutions comparatively to the best-in-class existing solutions. These two last facilities allow making the final decision on the problem to choose and the final solution to adopt. This representation describes most tasks in the actigram using easy-to-understand questions. For example, the question “where one should innovate?” corresponds to the task “analyze value buckets”. Taking advantage of this representation, even novices can have a basic understanding of the RID process.

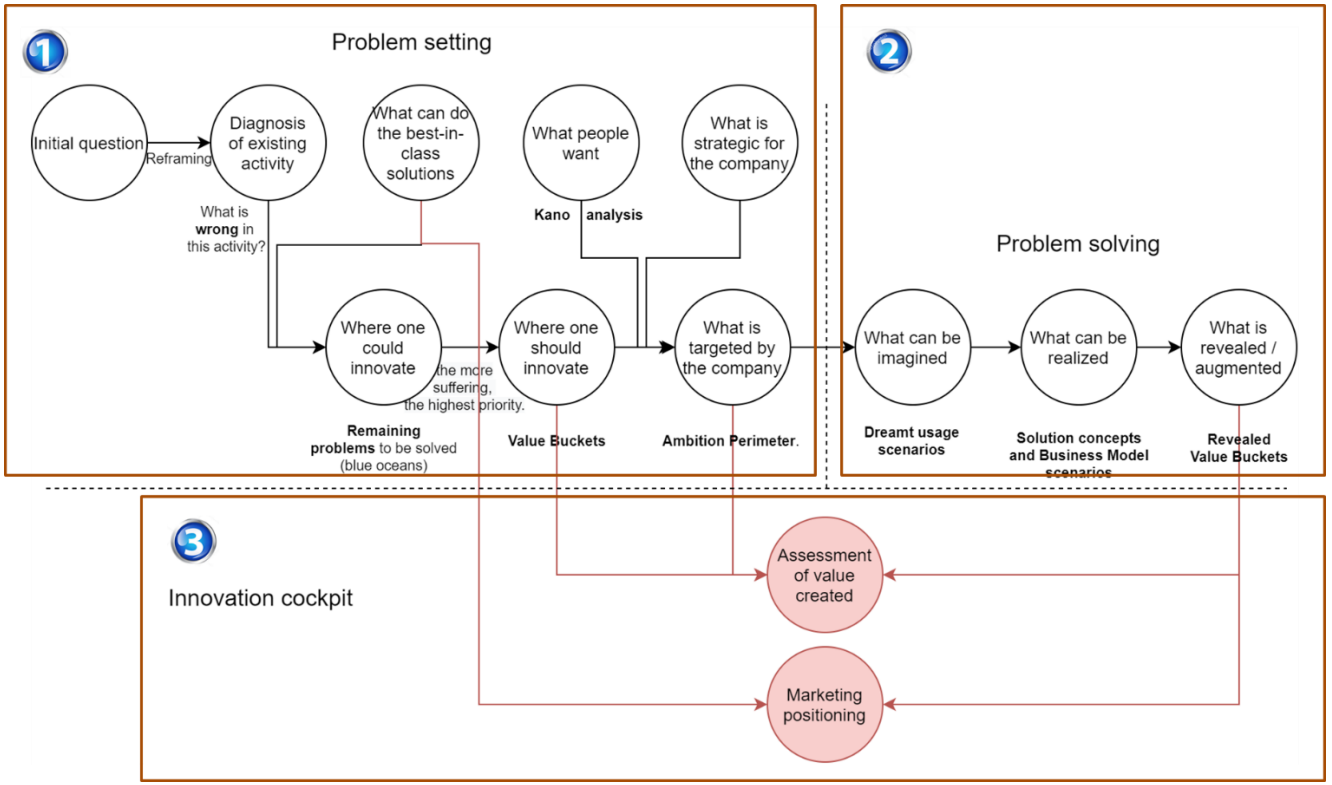

Figure 14: The production process made of vital questions

2.11 The problem and solution duality

The literature of design engineering describes a natural innovation process as a dialogue between problems formulations and solutions descriptions. An organized innovation process may even stimulate creativity. H. A. Simon was the first to theorize a design process with a preliminary problem setting stage. RID, in turn, recommends that problem setting precedes problem solving, without constraining the search space and limiting creativity, but in shorter lead times. While many authors see the innovation process as a

problem-solution co-evolution, few have suggested a clear transition from one to the other during the innovation project by advocating as complete an exploration of the problem as possible. However, this is the case with the Double Diamond design process (Council, 2005), created in 2005 by the UK Design Council, and with Radical Innovation Design®. The gap between the two parties is marked by the ambition perimeter, which traditionally corresponds to the project specification or design brief. RID perfectly matches the DD template with four diamonds corresponding to the four sub-processes: Knowledge design, Problem design, Solution design, and Business design (Figure 15).

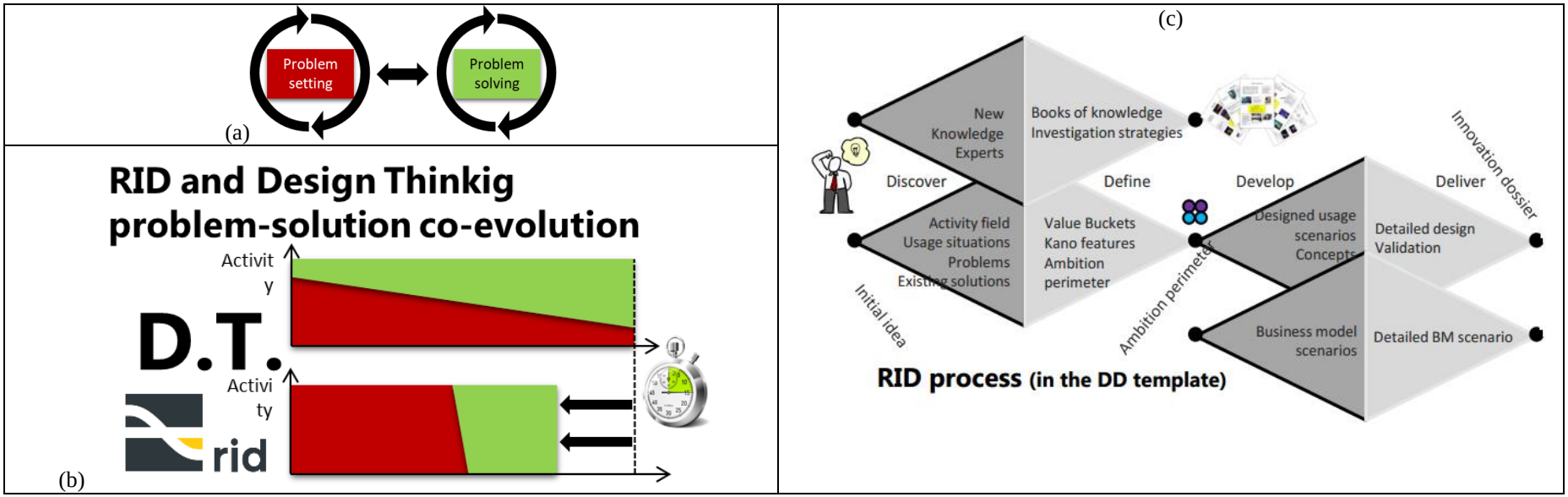

Figure 15: Problem and solution duality (a) The two cognitive processes (b) Lead times of problem setting and problem solving with RID and Design Thinking (c) The *Quadruple Diamond representation* of the RID process, inspired by the UK Double Diamond representation of the innovative design process.

3. Performances

Comparison of RID with known design methodologies

3.1 Comparison of innovation methodologies along design stages: Design Thinking (DT) and RID

The following diagram makes a comparison between the DT approach and the RID methodology. Six limitations of DT are now successfully addressed with RID.

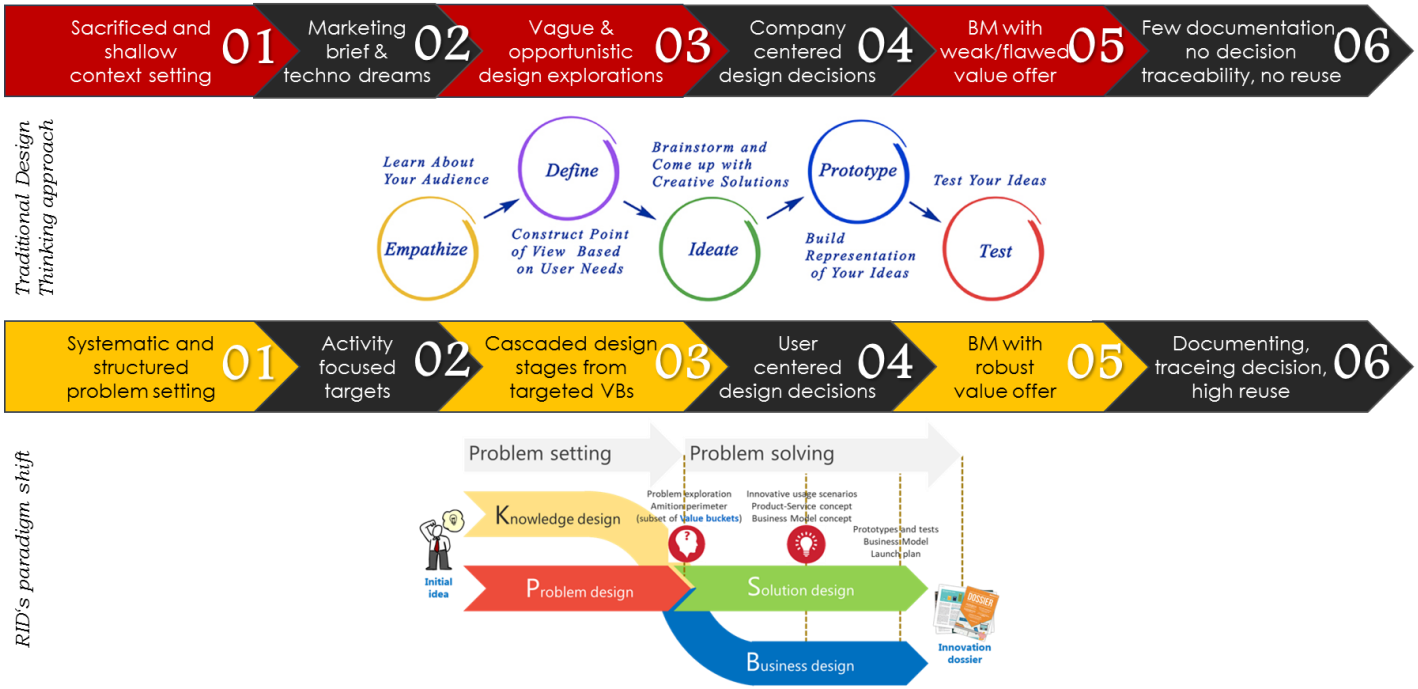

Figure 16: Comparison of innovation methodologies along design stages: Design Thinking (DT) and RID

3.2 Unique Selling Propositions (USP) of RID

RID methodology has the advantage of (1) integrating a set of existing innovation methodologies in a homogeneous framework; (2) improving deficient aspects of existing methodologies; (3) presenting a series of unique and exclusive selling propositions that allow companies to support need-seeker innovation projects. Table 6 details these advantages.

Table 6: Unique Selling Propositions (USP) of RID

Unique, Exclusive	Improvements on existing methodologies	Integration of existing methodologies
• Systemic approach from the activity field • The concept of "value buckets" qualifies and quantifies the innovation paths that are worth the effort; creativity is focused on qualified questions • Matrix approach based on the segmentation of 3 dimensions: problems x situations (of usage) x existing solutions • Capitalization and systematic and progressive exploration lead to an enhanced traceability of the innovation process • Usefulness first rather than "wow effect" and desirability	• A more structured Design Thinking style process • Approach deliberately driven by usage and centered on activity • An organized and systematic problem/solution dialectic • Enhanced monitoring of the problem setting • User profiling rather than personas • Ideation in two distinct steps: usage & UX (scenario creativity) and product-service architecture & business model (concept creativity) • The "value proposition" of the BMC starts with the selection and maturation of value buckets (see BMC-RID)	• Design Thinking • Kano Analysis • Knowledge mapping (K mindmaps) • Causal analysis (FMECA, TRIZ, Ishikawa diagram) • Ethnographic approaches (collection of insights, observation of situations, journey maps) • Business Model Canvas • UX design

Innovativeness Indicators

In the RID methodology, four innovativeness indicators were created to assess the value and the maturity of ideas in an innovation process. They are introduced in section 5.3.

4. Innovation competencies

A study by Booz & Company reveals that firms follow at least one of the following three innovation strategies: Need Seeker, Market Reader or Technology Driver, depending on whether the focus is on the customer, the market or the technology, respectively [7]. According to this study, "*following a Need Seeker strategy, although difficult, offers the greatest potential for superior performance in the long term*". RID is particularly well adapted to address need seeker projects, but it has been generalized for Technology Drivers in [8]. With a need seeker strategy, "*companies make a point of engaging customers directly to generate new ideas. They develop new products and services based on superior end-user understanding [7].*" The companies adopting a Need Seeker strategy are "*effective at both the ideation and conversion stages of innovation and they consistently outperform financially [7].*"

The following table presents most of general innovation competencies required by the RID process. They are derived from the competency framework proposed by Moubdi et al [2], which supports need seeker innovation. Each general innovation competency is then refined into multiple specific innovation competencies. In addition to these competencies, RID practitioners must have the three innovation behavioral competencies required by all elementary RID processes [2]:

1) Curiosity is a quality related to inquisitive thinking such as exploration, investigation, and learning [9]. RID practitioners need enough curiosity to do the exploration - exploitation.

2) Perseverance is defined within the field of positive psychology as the voluntary continuation of goal-directed action in spite of obstacles, difficulties, discouragement, boredom, tedium, or frustration [10]. Innovation is never an easy task. Without perseverance, even if you follow the most advanced innovation methodology, you cannot succeed.

3) Openness is an overarching concept or philosophy that is characterized by an emphasis on transparency and collaboration [11]. RID requires a collaboration attitude for innovation.

Table 7: Innovation competencies needed in a RID process/project

Elementary RID processes	General innovation competency	Specific innovation competency
Problem reframing	Ability to tackle the ill-structured problem	• Question the initial idea to identify relevant activity fields • Extract an ideal goal from the activity fields and the initial idea • Deduce a segmentation of user profiles from the activity fields
	Systems thinking skills	• Identify the value chain and the beneficiaries of the ideal goal and the activity fields

Usage investigation and modelling	Ability to tackle ill-structured problem	• Deduce a segmentation of usage situations from the activity fields
	Analytical skill	• Use deep knowledge to select the most relevant user profiles • Use deep knowledge to select the most relevant usage situations
	Knowledge management skills	• Define and implement investigation strategies to observe usages
Problems investigation and modelling	Ability to tackle ill-structured problem	• Deduce a segmentation of problems from the ideal goal
	Analytical skill	• Use deep knowledge to select the most relevant problems
	Systems thinking skills	• Build a causality graph to expand and refine the understanding of problems
Investigation of existing solutions	Ability to tackle ill-structured problem	• Deduce a segmentation of existing solutions from the activity fields and the ideal goal
	Analytical skill	• Use deep knowledge to select the most relevant existing solutions
Identification of value buckets	Analytical skill	• Analyze the value buckets and define macro value buckets • Use Kano analysis results to enrich the understanding of value buckets and select an ambition perimeter
	Problem-solution pairing	• Assembly the matrices and run the DSM-VB algorithm
	Systems thinking skills	• Define the ambition perimeter while considering overall coherence and strategic importance for the company
Product-Service-Organization scenario and business model scenario ideation	Analytical skill	• Use the UNPC indicators to assess the dreamt usage scenarios • Initiate the BMC-RID with the ambition perimeter
	Creativity	• Use the RID creativity tool to design dreamt usage scenarios
Product-Service-Organization scenario and business model scenario conceptual design	Creativity	• Conduct concept creativity for each dreamt usage scenario
	Analytical skill	• Maturate the BMC-RID with the monitor of innovation impact and certainty (with UNPC indicators)
Simulation, prototyping and validation	Experimenting and prototyping skills	• Develop and test the prototypes
Experimentation with the solution and assessment of the revealed value buckets	Analytical skill	• Analyze the performances of the structure under each typical usage situation
Comparison between the targeted value buckets and the revealed value buckets	Analytical skill	• Analyze the derived-from-structure value buckets • Compare expected and derived-from-structure value buckets
Documentation of the Books of knowledge and of the ambition perimeter	Knowledge management skills	• Organize the knowledge and skills acquisition (investigation) by identifying deep knowledge associated to the activity field and ideal goal

		• Organize the knowledge and skills acquisition (investigation) by defining relevant investigation strategies • Choose effective, inexpensive and fast actions to collect the deep knowledge • Share deep knowledge and books of knowledge with the RID team
	Synthesizing skills	• Create an action plan for collecting deep knowledge
	Collective intelligence	• Organize the project by defining roles and tasks • Share regularly the right amount of deep knowledge • Have a positive attitude of working with teammates
	Synthesizing skills	• Synthesize the deep knowledge collected in books of knowledge
Technical documentation	Synthesizing skills	• Synthesize all the RID deliverables and the decision making rationale
Another solution structure is tested	The innovation competencies required by "PSS and business model conceptual design" and "Simulation, prototyping and validation"	
Another subset of value buckets (ambition perimeter) is decided	The innovation competencies required by "Identification of value buckets" and the subsequent elementary RID processes	
Another activity field is tested	The innovation competencies required by "Observation of the behavior derived from the structure in given usage situations" and "Observation of the behavior derived from the structure in given usage situations"	

5. Principles and paradigms

5.1 Reframing by the problems/needs

Initial idea
Why? Response : ***Because… there are problems.*** They are the reasons or causes.
For what purpose? Response : ***For… solving some or all of these problems.*** It is the ideal goal regardless of the specific circumstances of the project and the company. This object has a strong legitimacy.
Sustainability: Will this need evolve or disappear in the short term?
Buildup in competence and knowledge of project team. It must be related to the reasons / causes and goals discussed.

Figure 17: "For What Purpose" table

It consists in a series of 3 questions: 1) Why?, 2) For what purpose?, and 3) How sustainable is the goal? The answer to "For what purpose?" provides the ideal goal. The other two questions are prompts to assess the value of this goal and its permanence over time. Two tools "flow transfer" and "transformation" help this reframing process.

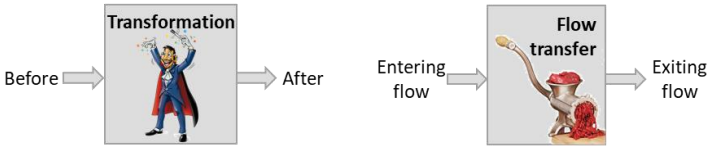

Figure 18: "Flow transfer" and "Transformation"

5.2 Reframing by the activity

One can reframe the initial innovation question around the notion of activity in 4 steps, see Figure 19.

1) **Define who the people you want to help in their activity are**
   - Consider only direct users and not stakeholders of a current economic value chain
2) **Define the fields of the activity in nature, space and time**
   - You must have started the investigation in the knowledge design process and know all the variants of the activity
3) **Imagine what can be an ideal activity**
   - You must have investigated all the expectations, key performance indicators, difficulties, usage conditions, psychological and sociological aspects surrounding the activity
4) **Formulate the ideal goal as a sentence with verb(s) and complements**
   - see advice for reframing

Figure 19: The procedure for reframing the question

5.3 The innovativeness indicators UNPC

UNPC stands for Usefulness - Newness - Profitability - Concept. The UNPC innovativeness indicators were created to assess the value and the maturity of ideas in a RID process, in order to make informed decisions about whether to continue with them and how to develop them. Usefulness corresponds to the intensity of one or a subset of value buckets and it is the most important indicator. Newness is composed of three aspects: 1) perceived newness by clients or end-users, 2) real technical newness, possibly patentable, and 3) usage newness. Profitability concerns expected profits for the company and customers. Proof of Concept is twofold: 1) For the users, it is proof that the conceptual solution or prototype functions effectively and efficiently in expected usage situations; 2) For the manufacturer, it is proof of technological and industrial feasibility.

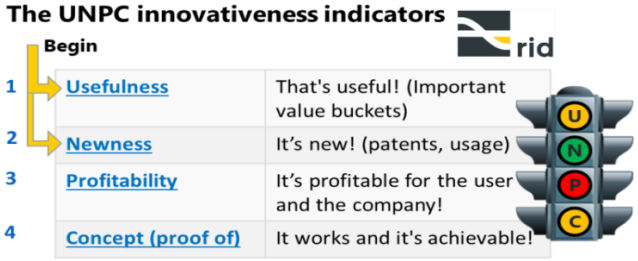

Figure 20: The UNPC innovativeness indicators

5.4 Nature of an idea

problem

1. Problem (a piece of the overall problem to solve), "pain", lack, dysfunction, dissatisfaction
2. Storytelling of some usage contexts and situations
3. Desired improvements in an activity, new activity

solution

4. Dreaming of a better world, of ideal services
5. New design principle
6. New design brief, concept, structure of solution. Use of component.
7. Detailed design solution and interaction scenarios
8. Precise business expectations
9. Fuzzy and futile business injunction "You must innovate within this product/business line!" (to be avoided)

Figure 21: Nature of an idea

5.5 Intensity of an idea

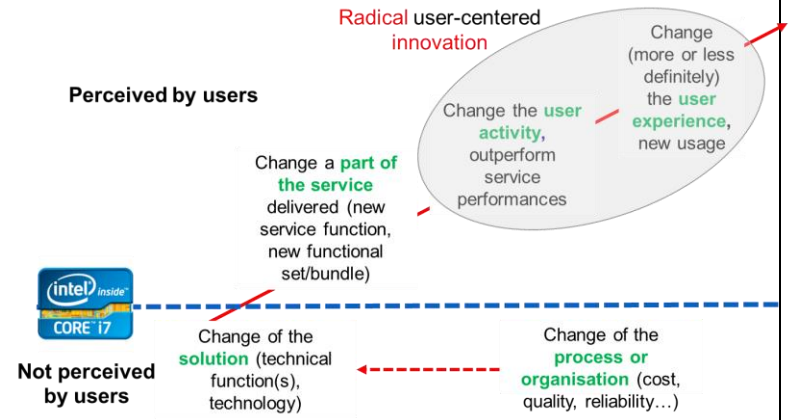

Figure 22: Intensity of an idea. For RID, a radical (user-centered) innovation necessarily impacts on user activity or experience.

5.6 RID philosophy of innovation

All innovation methodology is based on deep philosophical values and paradigms. RID has two sources of inspiration: Victor Papanek [13] and his criticisms of innovation frivolity, and Clayton Christensen [14, 15] and his quest to help with customers' activities (jobs). RID embodies humanist values, with the goal of designing a more sustainable world.

RID paradigms are expressed by (a) it is desirable and possible to qualify and quantify what people aspire to and do not want anymore (b) explore systematically worthy paths of highest expected values (c) make an informed choice of innovative solution afterwards. RID is then inspired by the rational decision process of Herbert Simon [16].

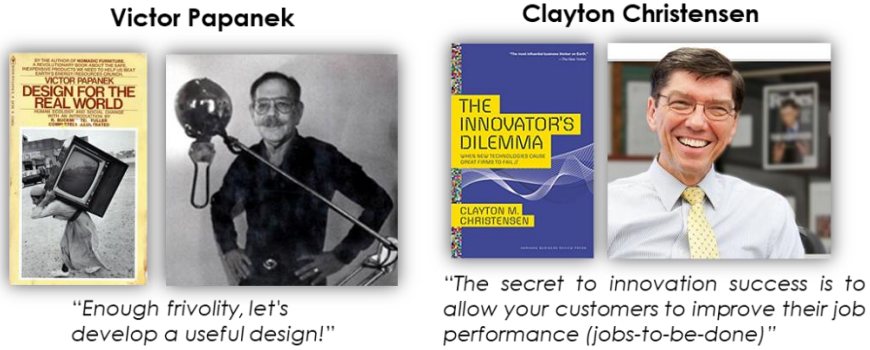

Figure 23: Inspiration for RID philosophy of innovation

5.7 Activity field and three rules of classicism

The activity field is the delimitation of activities that are involved in the RID project. It must be defined consistently in nature, space and time and possibly segmented in variants. As this delimitation may be highly variable, a guideline for defining an activity field consistently is to respect the three unities of Classicism as much as possible.

According to Boileau, the action should take place within twenty-four hours (time unit) in one place (unity of place) and should be incorporated as a single plot (unity of action).

5.8 Thinking inside the box

Figure 24: Thinking inside the box defined by an activity field

Instead of the traditional creativity motto "*thinking outside the box*", RID recommends "*thinking inside the box*", provided "*the box is large enough and well defined*". This avoids the fixation effect in set-based thinking approaches, preventing pollution by early ideas that are too precise. In addition, the delimitation of a legitimate box by reframing the initial idea into an ideal goal defined by the clear boundaries of the user activity, greatly encourages being creative under justified constraints.

5.9 Disruption

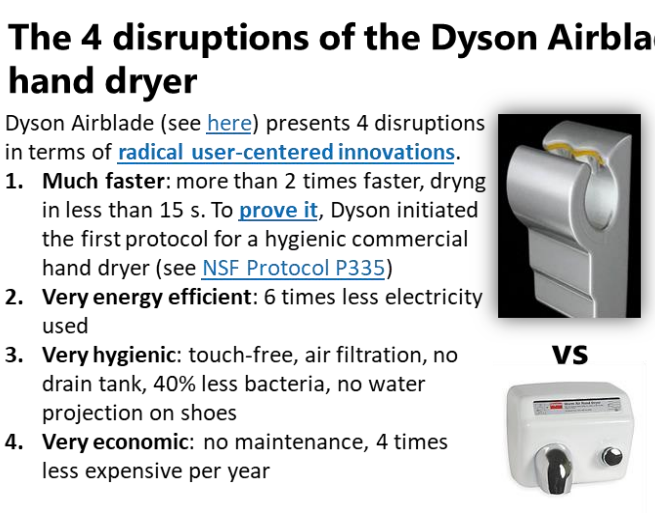

Figure 25: Dyson's need seeker innovation

In RID, a disruption is a radical user-centered innovation, i.e. an innovation that changes users' activity or experience. To that end, one needs a superior end-user understanding, by following a need seeker strategy. Radical Innovation Design® requires the objectification and prioritization of value buckets in order to start such an innovative process.

5.10 The four dimensions of a value bucket

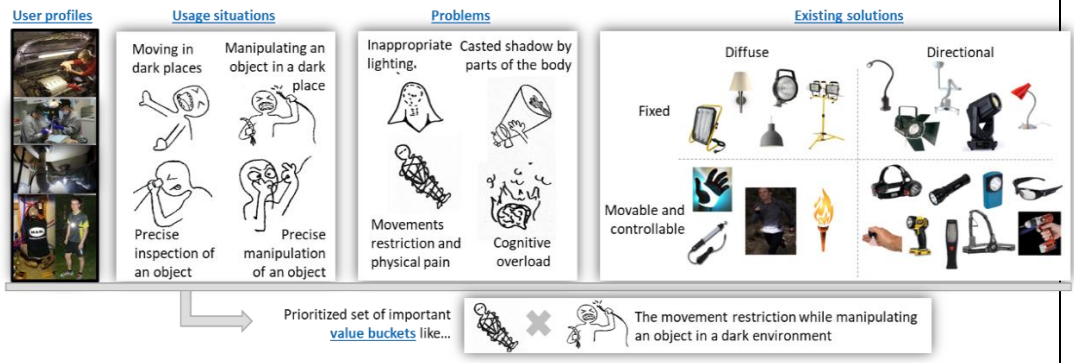

Figure 26: Example of a smart lighting for DIY activity

The computation of value buckets requires four segmentations, in order: user profiles, usage situations, problems and existing solutions. These segmentations follow certain modelling rules (see [12]), and the number of segments is typically between 3 and 12. The original algorithm DSM-Value-Bucket crosses these 4 categories of segments, resulting in a prioritized series of value buckets that are worth exploring further.

There are other RID principles and paradigms that have been introduced in section 2, like "initial idea," "need seeker strategy," "activity theory," "problem setting and problem solving," "problem and solution co-evolution," "set-based thinking." We will not repeat them in this section.

6. Methods and tools

Methods

6.1 Computation of the value buckets (DSM-VB algorithm)

The original DSM-Value-Bucket algorithm computes the matrix of value buckets from the definition of several entry matrices. The concept of value buckets qualifies and quantifies the innovation leads that are worth the effort. Creativity is focused on qualified questions, making ideation all the more effective.

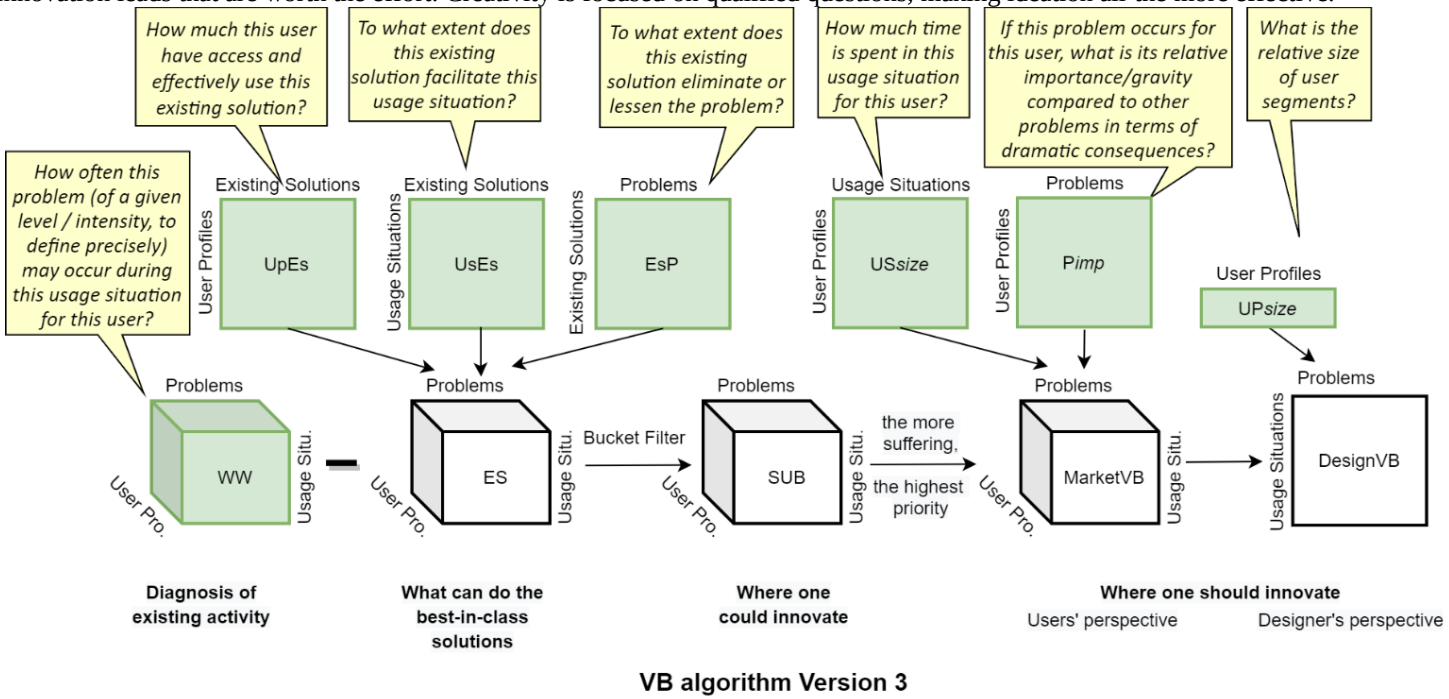

Figure 27: DSM-VB algorithm

6.2 Determination of the ambition perimeter

An ambition perimeter expresses the necessary compromise between (1) What is rationally good for people (expressed as the prioritized Value Buckets that produced by DSM-VB algorithm), (2) What people want (resulting from a Kano Analysis) and (3) The voice of the company. This triplet is RID's long-term value creation paradigm.

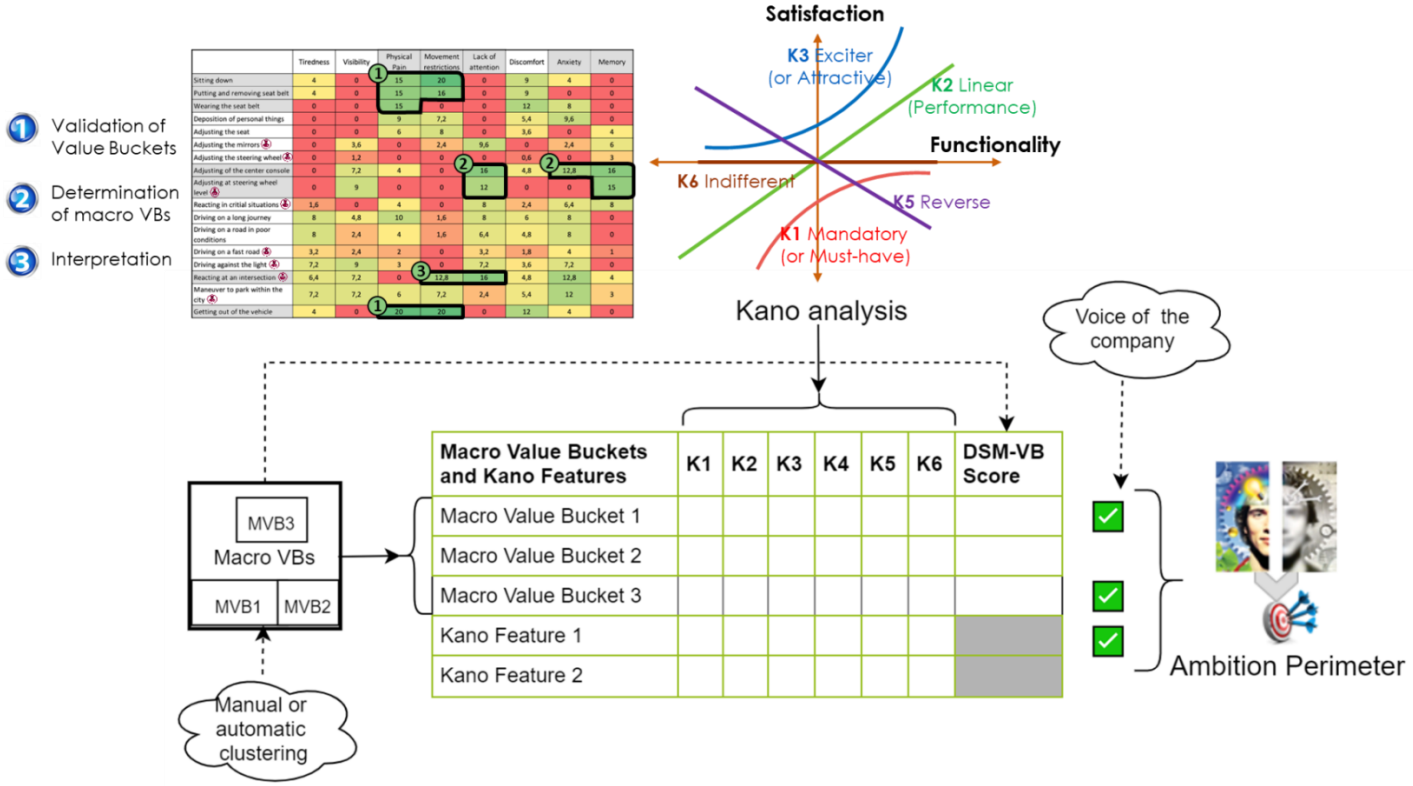

Figure 28: Generation of the ambition perimeter

6.3 The BMC-RID

The Business Model Canvas (BMC), by Osterwalder and Pigneur [17], is robustified through its initial combination with the RID ambition perimeter and its monitoring of innovation impact and certainty (with UNPC indicators).

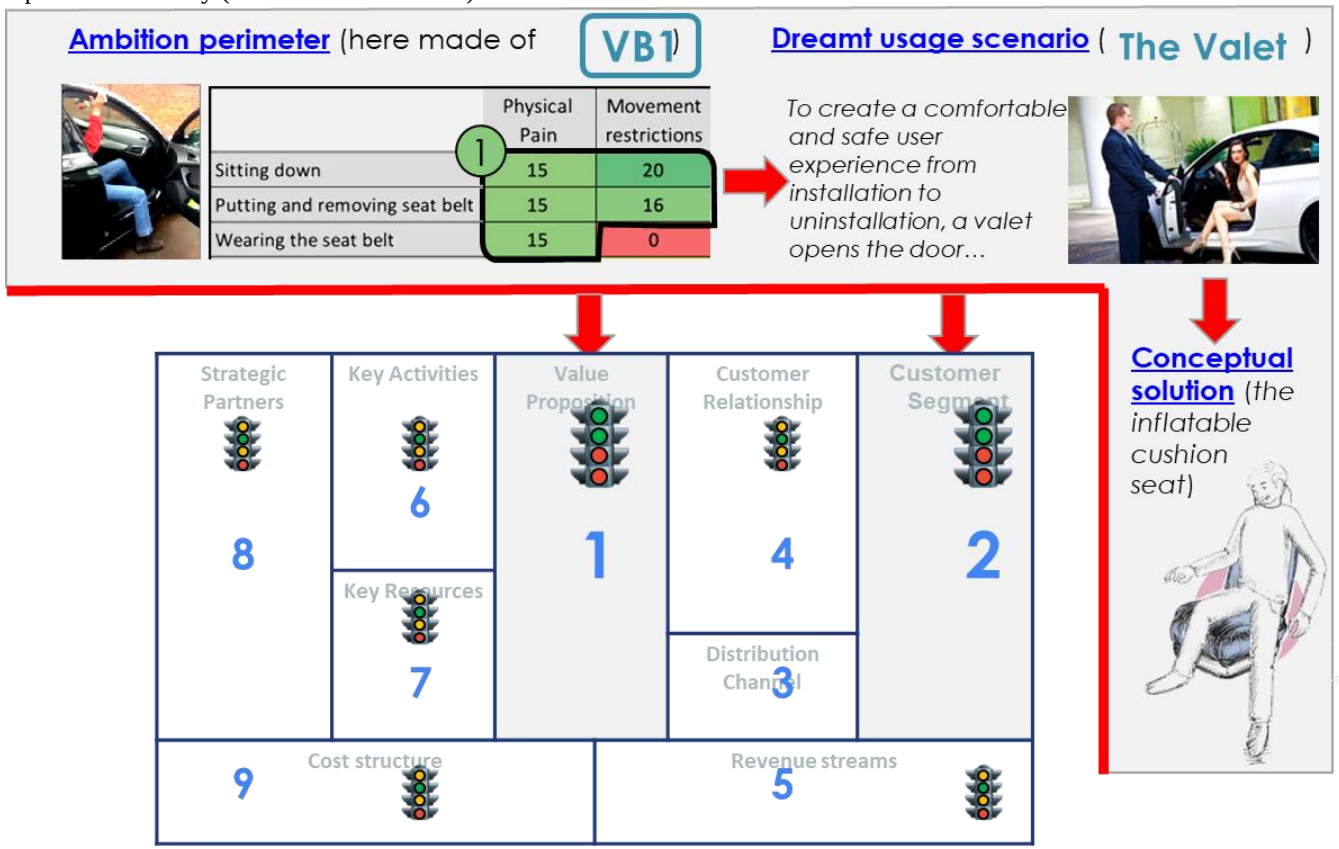

Figure 29: The BMC-RID method improved based on BMC

Tools

6.4 Tool: RID creativity tool

The RID creativity tool is a powerful ideation tool which achieves focused creativity from the value buckets of the ambition perimeter. It is used during scenario creativity at the very beginning of the solution design sub-process and allows you to explore new scenarios' space intensively.

Types of shift

Attributes of an MVB		IS (painful situation)	IS NOT (similar painless situation)	Distinction contrast	Disctinction cause	Dreamt usage scenario	Conceptual solution
User	User						
Problem	Nature (failure mode)						
	Cause						
	Consequence						
	Importance						
	Period						
	Timing						
	Conditions						
	Location						
Nowadays	Emergence						
Usage situation	Nature						
	Size						
No other satisfactory solutions	Solutions						

Principles

Comparing the defective and painful **existing situation, the "IS" situation**, to **other similar but trouble-free situations, the *"IS NOT"***

Each attribute of the MVB is shifted to imagine the "IS NOT" situations. Four questions lead to express the distinction between IS and IS NOT situations :

1. **What** is different?
2. **Why** is it different?
3. Regarding the cause of distinction, imagine a **dreamt usage scenario**
4. Imagine a **conceptual solution**

Figure 30: Principles of the RID creativity tool

6.5 Tool: UNPC monitor tool

UNPC monitor is a tool for concurrently increasing the maturity of a subset of innovative ideas or projects and for finally selecting one of them for its value profile UNPC under uncertainty. It is used in the stages of (a) assessing the macro value buckets, (b) assessing the dreamt usage scenarios, and (c) assessing the conceptual solutions.

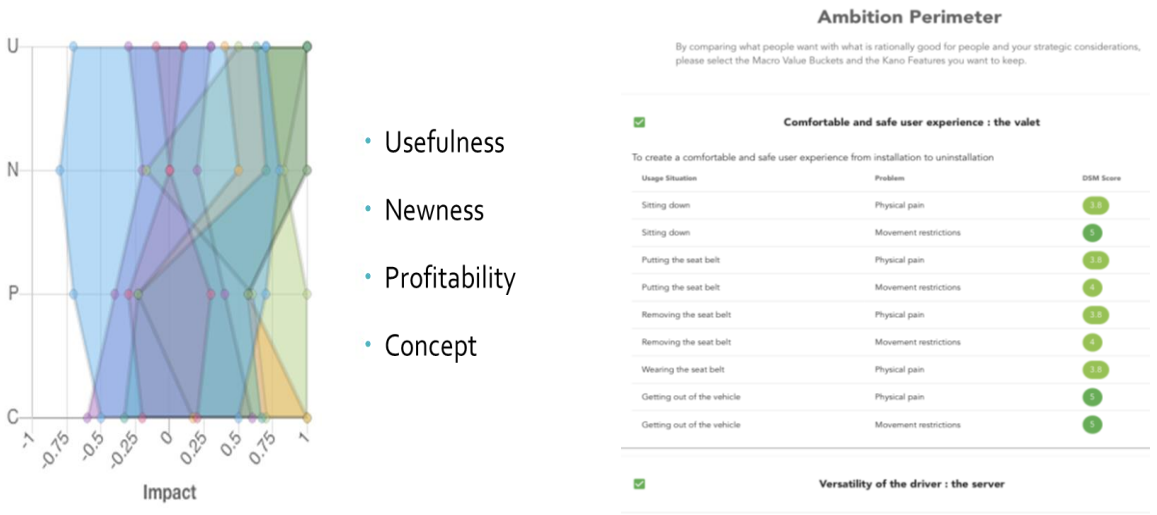

Figure 31: UNPC monitor tool

7. Proposal of a RID ontology

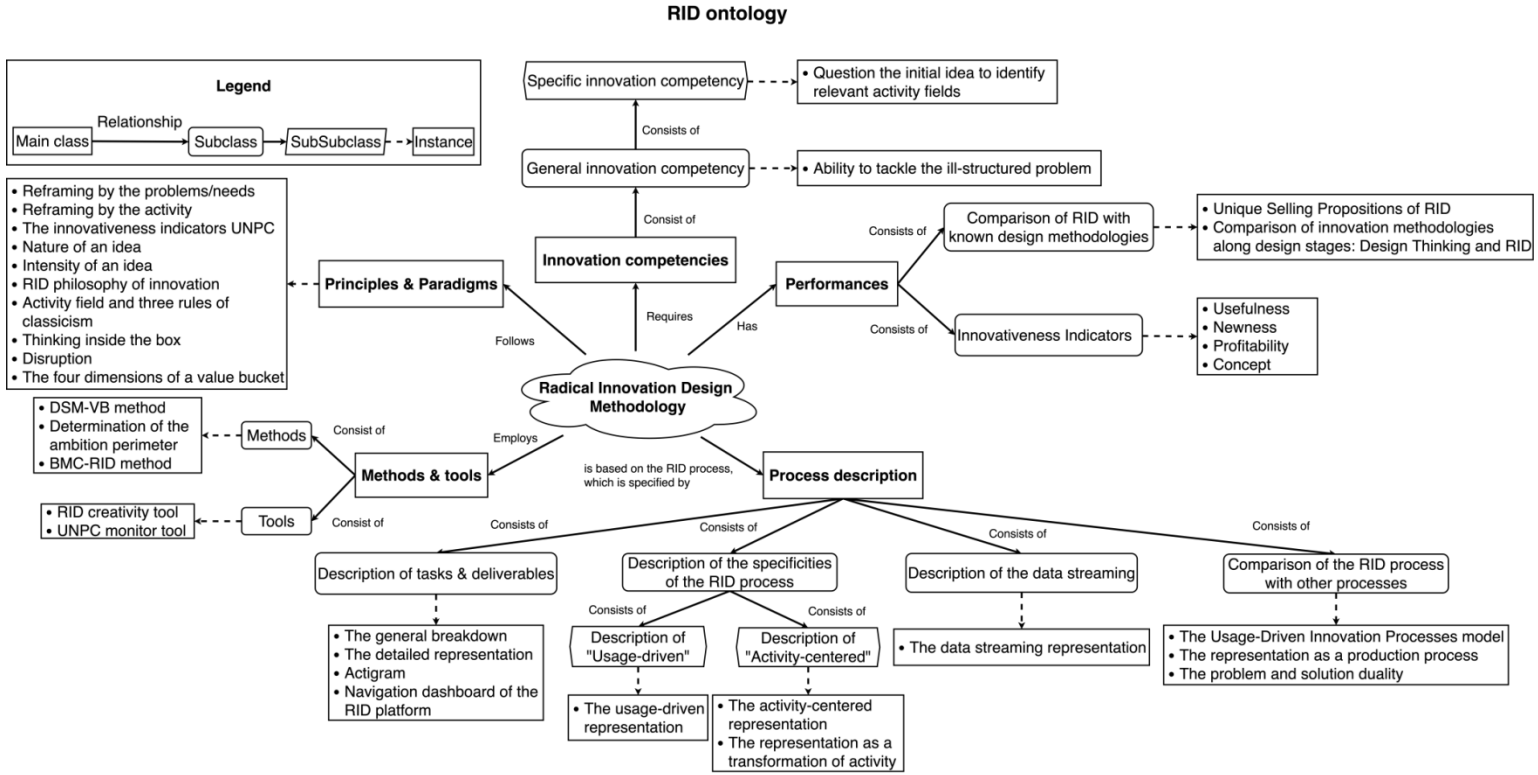

Figure 32: RID ontology

The above diagram presents an ontology for the RID methodology, which aims to better structure the content of this RID textbook. The RID ontology is constituted by six main classes: innovation competencies, process description, structuring concepts, performances, methods & tools, and principles & paradigms. Each of them corresponds to one part of the content in the textbook. One main class can be further categorized into several subclasses, and each subclass may link with related subsubclasses.

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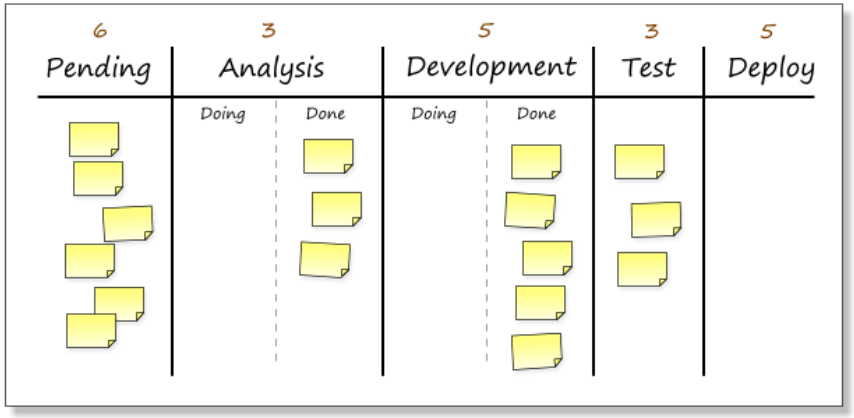
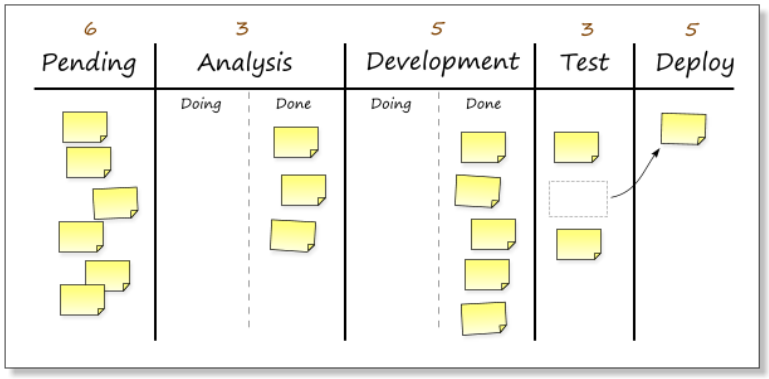
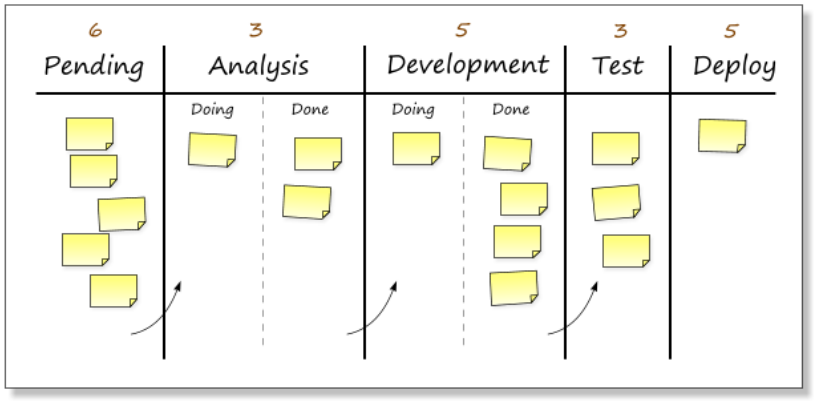
Appendix C: Description of industrial engineering methodologies

1. Description of Kanban by Expert F

Object category	Detailed object
Objective of the methodology	A lean method to manage and improve work across human systems, which aims to manage work by balancing demands with available capacity, and by improving the handling of system-level bottlenecks.
Process description	The board below shows a situation where the developers and analysts are being prevented from taking on any more work until the testers free up a slot and pull in the next work item. At this point the developers and analysts should be looking at ways they can help relieve the burden on the testers.  Notice that we've split some of the columns in two, to indicate items being worked on and those finished and ready to be pulled by the downstream process. There are several different ways to layout out the board. This is a fairly simple way. The limits at the top of the split columns cover both the "doing" and "done" columns. Once the testers have finished testing a feature, they move the card and free up a slot in the "Test" column.



Now the empty slot in the “Test” column can be filled by one of the cards in the development “done” column. That frees up a slot under “Development” and the next card can be pulled from the “Analysis” column and so on.



Performance	**Kanban Metrics** In the software, Kanban aims to accelerate the workflow in the value chain. For this purpose, process steps are determined, flow is visualized, operation rules are determined, flow is monitored, bottlenecks are determined and actions are taken to overcome them and improvements are made. To evaluate these improvements, we need to compare the values before and after the improvement. For this purpose, various metrics are used in Kanban. Commonly used ones are listed below. ***Lead Time*** It is the time from the moment a job is decided to be done and enter the backlog (to-do column) to the moment it is finished. When we consider the Task Board, we can say that it is the time from the moment a job enters the To-Do column to the moment it comes to the Finished column. That is the total time it takes for a job to go from the to-do column to analysis, from analysis to UX design, from UX design to coding, from coding to test, from test to live. ***Cycle Time*** It is the time from the moment a job starts to be done to the moment it is completed. In other words, it is the time interval from the time coding starts to the time it goes live. Average cycle time and lead time can be calculated for different job types. Thus, the average time for the delivery of such a job can be estimated. They are used for measuring how fast the work progresses in the current process and in which steps the process slows down. The speed of access to the market can be calculated using lead time. In addition, an evaluation can be made based on end dates according to the previous data. It can be observed if there is a delay by comparing the delivery times of similar previous jobs. By reviewing the times in different steps within the process, we can see whether this job waited longer, was blocked, whether different stages of the process were repeated and reprocessed, and the real working time. In general, the target is to reduce lead time and cycle time. Attention must be paid when using these two metrics; because the lead time of a job can be much longer than the cycle time. Therefore, an improvement of 50% in cycle time may not exceed 10% in overall lead time. So, it is important to be careful about where the actual improvement will take place. ***Throughput*** It shows how much work has been done for a certain time period. For example, it shows how many jobs have been completed in 1 week or 2 weeks. We can estimate the amount of work that can be done in the future by noting this number in a few time periods of the same length. Throughput may go down as the Lead Time declines. This may be because the Work In Progress limit is not selected carefully and kept too low.

Number of problematic and blocked jobs

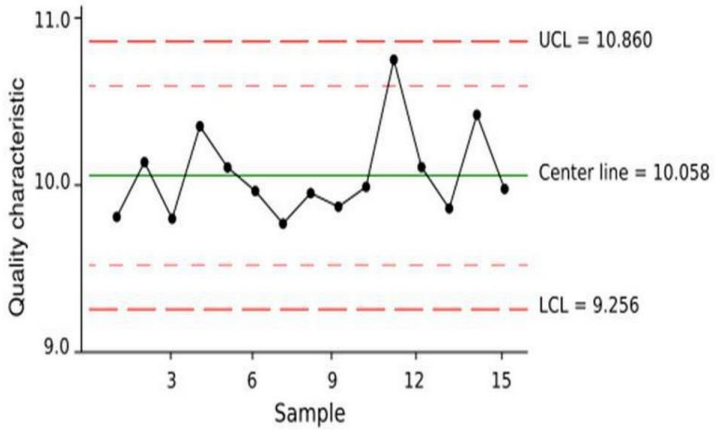
Problematic jobs are an indication that the throughput fails to deliver the desired quality. Blocked jobs indicate that the flow is not smooth. A decline in the Lead Time is a good thing, but a decline in quality shows that the alarm bells are ringing. The period of one step waiting for a job from another step in the process can be measured and determining an increase in this period provides realistic feedback. We can keep the record of the number of problematic and blocked jobs for a certain period of time. These numbers are compared for the following same time periods.

End Date Performance

According to the promised dates, we can keep the record if a job has been completed or not. Thus, the reliability and credibility of the team can be revealed. This metric is calculated very easily by comparing the end date of the job with the promised date.

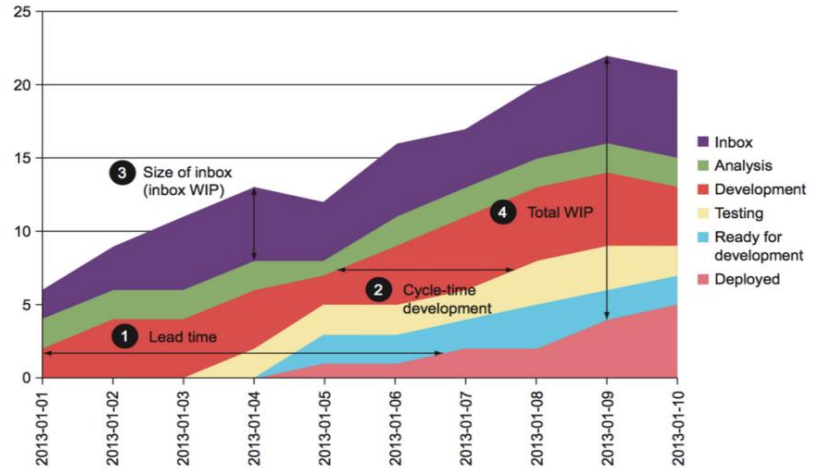
Statistical Process Control Diagram

Visualizing the lead times of all finished jobs by placing them on a chart makes it easier to determine the progress and jobs that are above expectation. In this graph, the vertical axis represents the lead time and the horizontal axis represents the time at which the job went live. The causes of deviations are investigated. Improvement measures are identified for these problems. Leaving the extreme lead times (outliers) apart, different interpretations can be made based on the average lead time, upper control limit, and lower control limit. For example, the small gap between the upper and lower control limits indicates a highly accurate lead time estimate. The downward trend of lead time shows that the improvements are working.



Cumulative flow diagram (CFD)

In order to draw the Cumulative Flow Diagram, the number of jobs in each column on the board should be posted daily and every day should be added to the previous day. A separate color is used for each column when drawing the CFD.



The following metrics can be calculated from this diagram:
Lead Time
Cycle Time
Work in Progress
Backlog Size

Comparative Study within Scrum, Kanban, XP (Saleh et al., 2019)

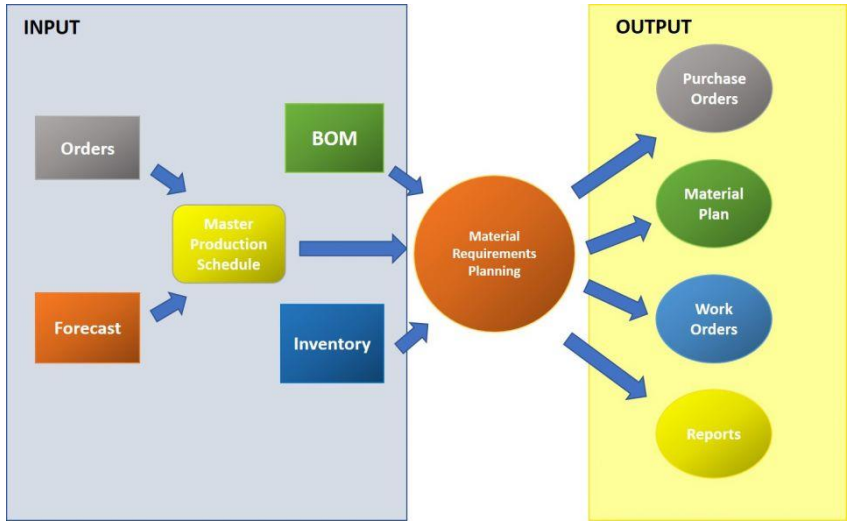
TABLE IV. SCRUM, KANBAN, XP REHEARSES EXPLANATIONS

ANSWERS	RQ2 → MAIN FEATURES OF THE CHOSEN FACTORS		
RQ1	Scrum	Kanban	XP
Jobs & Duties	Predefined jobs and duties regarding each colleague, including Product Owner, Scrum Master, and others [19, 5, 51, 17, 44]	No predefined jobs and duties [4, 5, 51, 17, 44]	Predefined jobs and duties including customer, programmer, coach, and others [54, 55]
Acceptance time	Snags facing major change might be expert [7]. In any case, the majority of the links receive Scrum before Kanban [11]	Less hard change [7], mainly when groups that keep up and leaders need to move from [11]	Effect possibly littler if the group effectively received with SCRUM [58].
Team Measurement	With consideration of Scrum Master and Product Owner, a team contains 5-11 members [19, 36]. On the off chance that the group is wide, it will be difficult to offer some benefit to all Agile coworkers [36]. So, for huge groups, Kanban is superior to Scrum [53]	Kanban has greater adaptability when contrasted with Scrum [53], in that group can have under 5 colleagues [52], or it very well may be more than 11 (up to 14 colleague) [53]	Team size should be 5 or less people [57], XP groups exist tiny. Some of the time they are even single individual group. Be that as it may, they can play out the hardest software industry actions [54].
WIP Size	Substantial clump measure (short of what multi-month Sprint) is thought to be enormous particularly when managing consistent changes [5, 11]. The group should focus on conveying runs on time [5, 51, 17]	It must have little groups with little measure of WIP [4, 7, 11, 51]. This shows day by day/hourly carriage of vital kits should be possible [5]. Duty isn't obligatory [5, 51, 17]	Small batch size (less than two weeks sprint) is considered, normally one week [56]
Requirements plan	The requisites require listing based on the length of the run, each two, three or a month [5, 44]	The listing of basics is done always, which can be every day/hourly [5, 44]	The listing of prerequisites is done always [26, 49]
Features size	It is portrayed by little component measure [7, 11]	It can be classified into little pieces, which can show helpful when the expert group needs quicker criticism [7, 11]	Acmes to be created are organized by the client. Much the same as Scrum, XP centers around business esteem [57]
Principal time	Scrum abstains from cutting principal time dissimilar to Kanban [21]	Kanban cuts principal time by avoiding performing various tasks and restricting the WIP highlights [11, 13, 22, 17]	XP is an approach that was calm mostly to bear the major trials of group inside the most partial events of time [54].
Technical preparation	There has no adept drills in Scrum [24, 44]	There has no specialized uses in Kanban [25, 44]	XP has specialized practices [55, 56]
Budget	Not at all like Kanban, Scrum keeps away from cost sparing yet it focuses more on info, skill and basic control in light of what is known [11]	Spotlights on slicing cost when contrasted with Scrum [11], particularly for activities [11]	XP always follow the ease way to amended the cost in a reasonable way [57]
Software Quality	The Sprint evaluation gathering represents the main technique for quality improvement in the Scrum framework [26]	When we want to compare with Scrum, it fixates mostly on performance improvement in Kanban [11, 21]	The more test, the more be adept and viable in their accent tasks [57]

Competencies	• Visualize (the work, workflow and business risks) • Limit WIP • Manage Flow • Make Process Explicit • Implement Feedback Loops • Improve Collaboratively, Evolve Experimentally (using models & the scientific method)
Principles	Toyota has formulated six rules for the application of Kanban (Ohno, 1988):

	• Each process issues requests to its suppliers when it consumes its supplies. • Each process produces according to the quantity and sequence of incoming requests. • No items are made or transported without a request. • The request associated with an item is always attached to it. • Processes must not send out defective items, to ensure that the finished products will be defect-free. • Limiting the number of pending requests makes the process more sensitive and reveals inefficiencies.
Concepts	Kanban system, Kanban board, Kanban card, Swimlane, WIP, WIP limits, Kanban Cadence, Throughput, Cycle Time, Lead Time, CFD - Cumulative Flow Diagram, Little's Law.
Methods & Tools	Methods: Team Kanban method and Portfolio Kanban method. Tools: nTask Board, Trello, Kanbanize, Monday.com, Hygger, Jira, Asana, etc.

2. Description of Material Requirements Planning (MRP) by Expert F

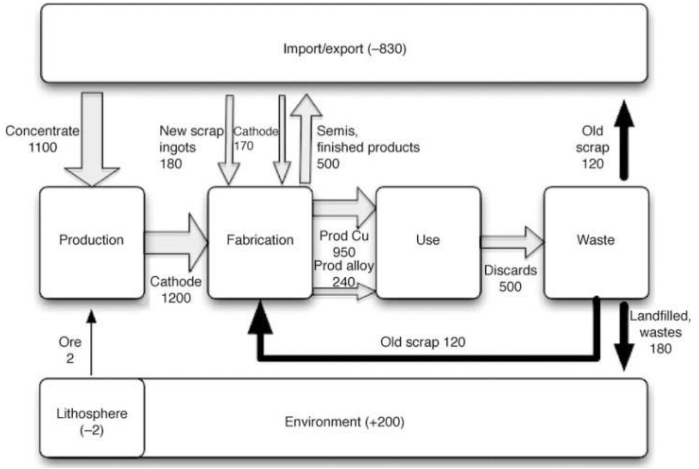
Object category	Detailed object
Objective of the methodology	MRP is a methodology used to calculate the components and the materials, which will be needed for the sake of making a product.
Process description	 The MRP process can be broken down into four major steps: • Identifying requirements to meet demand The first step of the MRP process is identifying customer demand and the requirements needed to meet it, which starts with inputting customer orders and sales forecasts. Using the bill of materials required for production, MRP then disassembles demand into the individual components and raw materials needed to complete the build while accounting for any required sub-assemblies. • Checking inventory and allocating resources Utilizing the MRP to check demand against inventory and allocating resources accordingly, people can see both what items they have in stock and where they are—this is especially important if they have inventory across several locations. This also lets them

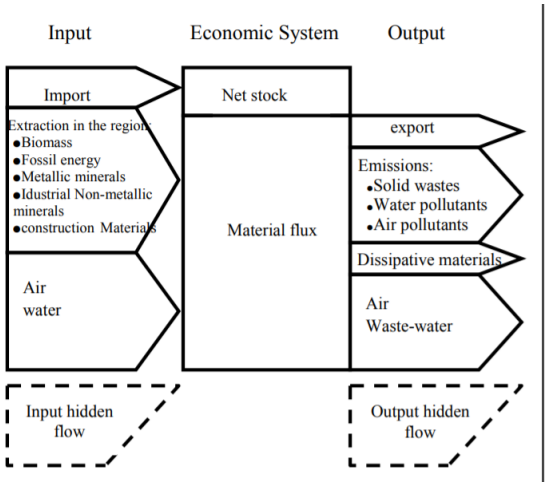
	see the status of items, which gives visibility into items that are already allocated to another build, as well as items not yet physically in the warehouse that are in transit, or on order. The MRP then moves inventory into the proper locations and prompts reorder recommendations. • Scheduling production Using the master production schedule the system determines how much time and labor are required to complete each step of each build and when they need to happen so that the production can occur without delay. The production schedule also identifies what machinery and workstations are needed for each step and generates the appropriate work orders, purchase orders, and transfer orders. If the build requires subassemblies, the system considers how much time each subassembly takes and schedules them accordingly. • Identifying issues and making recommendations Finally, because the MRP links raw materials to work orders and customer orders, it can automatically alert the team when items are delayed and make recommendations for existing orders: automatically moving production in or out, performing what-if analyses and generating exception plans to complete the required builds.
Performance	**MRP's performance** MRP systems allow to plan and schedule production efficiently; making sure materials move through the work order quickly and helping businesses fulfill customer orders on time. An MRP system that is integrated across an organization eliminates manual processes, such as pulling historical sales and existing inventory. People spend less time building Gantt charts and production flows to understand when and where they need product available, which frees up time and removes a layer of complexity. When builds are complex and require multiple sub-assemblies within the work order, it's easy to miscalculate timing. An MRP helps understand all of the components that go into each sub-assembly and how long it takes to complete each step, preventing delays in the production cycle and increasing production yield. MRP has drawbacks, including: • Increased inventory costs: While MRP is designed to ensure adequate inventory levels at the required times, companies can be tempted to hold more inventory than is necessary, thereby driving up inventory costs. An MRP system anticipates shortages sooner, which can lead to overestimating inventory lot sizes and lead times, especially in the early days of deployment before users gain the experience to know the actual amounts needed. • Lack of flexibility: MRP is also somewhat rigid and simplistic in how it accounts for lead times or details that affect the master production schedule, such as the efficiency of factory workers or issues that can delay delivery of materials. • Data integrity requirements: MRP is highly dependent on having accurate information about key inputs, especially demand, inventory and production. If one or two inputs are inaccurate, errors can be magnified at later stages. Data integrity and data

	management are thus essential to effective use of MRP systems.
Competencies	The training of MRP can develop the skills: • Understand the MRP Planning process • Understand key material master settings that affect MRP • Learn to create demand using forecast • Learn to create supply by running MRP to generate planned orders • Run MRP for a single material and for all materials plant-wide. • Learn to evaluate the MRP results • Learn to convert planned orders to purchase requisitions • Resolve exception messages
Principles	An MRP system is intended to simultaneously meet three objectives: • Ensure raw materials are available for production and products are available for delivery to customers. • Maintain the lowest possible material and product levels in store. • Plan manufacturing activities, delivery schedules and purchasing activities.
Concepts	**MRP Inputs** • Demand – Including sales forecasts and customer orders. When working with predicted demand, a system that is integrated with an enterprise-wide ERP system allows forecasting using historical sales vs. just sales forecasts. • Bill of materials (BOM) – Keeping a single updated version of the bill of materials is essential for accurate supply forecasting and planning. A system that's integrated into the enterprise-wide inventory management system avoids version control issues and building against outdated bills, which result in reworks and increased waste. • Inventory - It's essential to have a real-time view of inventory across the organization to understand what items the people have on hand and which are en route or have purchase orders issued, where that inventory is and what the inventory's status is. • Master production schedule – The master production schedule takes all build requirements and plans machinery usage, labor and workstations to account for all outstanding work orders to be completed. **MRP Outputs** There are two outputs and a variety of messages/reports: • Output 1 is the "Recommended Production Schedule." This lays out a detailed schedule of the required minimum start and completion dates, with quantities, for each step of the Routing and Bill Of Material required to satisfy the demand from the master production schedule (MPS). • Output 2 is the "Recommended Purchasing Schedule." This lays out both the dates on which the purchased items should be

	received into the facility and the dates on which the purchase orders or blanket order release should occur in order to match the production schedules. Messages and reports: • Purchase orders. An order to a supplier to provide materials. • Reschedule notices. These recommend cancelling, increasing, delaying or speeding up existing orders. Inventory control, Bill of material processing, Elementary scheduling, Dependent demand, and independent demand.
Methods & Tools	Fishbowl Inventory, NetSuite, IQMS, GMDH Streamline, Downfalls, etc.

3. Description of Material Flow Analysis (MFA) by Expert C

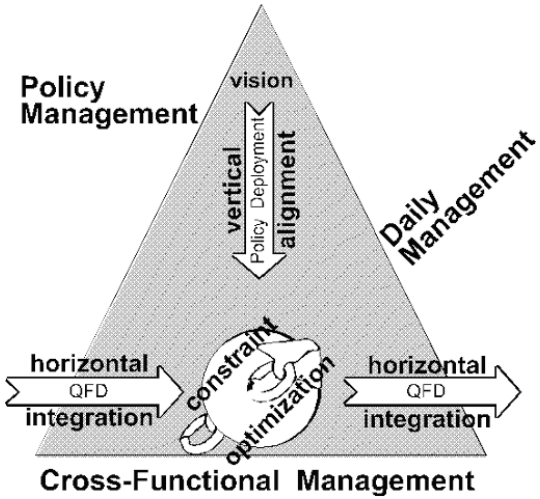
Object category	Detailed object
Objective of the methodology	Material Flow Analysis (MFA) is the quantification and assessment of matter (water, food, excreta, wastewater...) and substances (nitrogen, phosphorus, carbon...) mass flows and processes, in a system (city, country, etc.) during a defined period.
Process description	 Material flow analysis contains the following main steps: • Identification of the key (material flow related) issues. • System analysis (selection of the relevant matter, processes, indicator substances (elements), and system boundaries). • Quantification of mass flows of matter and indicator substances. • Identification of weak points in the system. • Development and evaluation of scenarios and schematic representation, interpretation of the results.
Performance	**Advantages** • MFA allows having a critical view of sanitation/water management current status in a city. • MFA helps to evaluate the environmental soundness of sanitation options. • MFA can be used as a decision tool to choose sustainable sanitation technology. • MFA is an ideal technical basis for planning and decision making, especially in developing and emerging countries with limited technical and financial resources.

	• In developing countries, MFA has been proven to be a suitable tool for early detection of environmental problems and development of appropriate solutions. **Disadvantages** • Needs a lot of data to be implemented; there are only limited, reliable data available for developing countries. • There is a need to deal with uncertainties. MFA can be used to systematically measure and analyze the material flux and distribution in a specific time and space scale, and to study the laws of material metabolism through the analysis of the relationship among material flows, resource consumption and socio-economic development. MFA can not only measure the direct use of the economic system functioning, but also can measure the amount of environmental substances indirectly affected, which makes the results more significant in the coordination of economy and environment. 
Competencies	The learning outcomes of a training on MFA: **Knowledge** • The main challenges and strategies for the socio-economic metabolism related to the basic human activities (to nourish, to clean, to transport and communicate, to reside and work); • The theory of the socio-economic metabolism and its examination in space and time through material flow analysis (MFA).

	Skills • To explain the role of key substances and materials in today's societal metabolism and their potential interactions with the environment; • To define MFA systems, and to describe a system as a mathematical model in order to test the impact of data uncertainties and to develop simple scenarios(forecasting, backcasting, analyzing implications of interventions); • To point out and reflect on strengths, limitations, and specific areas of application of different MFAs (including other industrial ecology tools that build on them), and to interpret the results in terms of their policy implications(e.g., judge the effectiveness of different interventions). **General competence** • Familiarize with the use of system approaches for solving complex problems; • Become aware of the similarities and differences between MFA and other industrial ecology tools, the types of questions they can address, and their limitations; • Learn to effectively communicate complex information with practitioners (including visual representation).
Principles	MFA is based on two fundamental and well-established scientific principles, the systems approach and mass balance. The system definition is the starting point of every MFA study.
Concepts	Material flow analysis, Materials, Raw materials, Elements, Compounds, Input mass, Output mass, Storage, Eco-balances, Flow, Waste, Emissions, Weak points, Balance scope, Balance period, Flowcharts, etc.
Methods & Tools	The complete MFA is a system combined of the **methods** from each step. As can be seen from the process of methodology development, MFA is heading in the direction which for the comprehensive and precise results, and directly relevance to the macro-control of the environment-economic systems. **Establishment of MFA framework** • Substance Flow Analysis (SFA) • Stock and Flow (STFA) • Combination of EW-MFA and SFA • Regional Dynamic Model • Input-Output Table • Three dimensional input-output table **Collection of information** • Top-down model • Bottom-up model • Tracking model and fixed-point model

	Data processing • Total amount model • Material use intensity model Tools: Online Material Flow Analysis Tool (OMAT), stan2web, STAN, etc.

4. Description of Total Quality Management (TQM) by Expert F

Object category	Detailed object
Objective of the methodology	Total Quality Management (TQM) is a management technique based on the idea that all "employees continuously improve their ability to provide on-demand products and services that customers will find of particular value.
Process description	 The major process components of TQM are policy management, daily management and cross functional management. Some companies include Vendor quality also in this process since their quality depends upon Vendor's products and services. **Process #1. Policy Management** It can also be referred to as policy deployment, management by policy, etc. Policy management is a systematic process used to direct corporate resources towards solving problems and making improvements in selecting high priority areas. Policy management is essential for executing corporate strategy. There should be a total commitment from top management and other employees for policy management.

	Process #2. Daily Management Daily management process is to ensure that overall operations are improved and the things done as per planning. Daily management is a means both to control and to improve day to day operations. Day to day management problems are solved by daily management process. Top management ensures that processes for satisfying customer needs are in place. The managers and supervisors are responsible for actual execution and checking of TQM system. **Process #3. Cross Functional Management (CFM)** CFM is essential to achieve organizational goals and helping in quality improvement. The team characteristics may differ depending on the type and nature of problem to be solved. A work atmosphere must be developed where managers and workers listen to and respect each other's ideas. This type of atmosphere can be developed only when there is a commitment to achieve objectives. The team approach is a better way of building trust and respect.
Performance	**Total quality management benefits and advantages**: • Strengthened competitive position • Adaptability to changing or emerging market conditions and to environmental and other government regulations • Higher productivity • Enhanced market image • Elimination of defects and waste • Reduced costs and better cost management • Higher profitability • Improved customer focus and satisfaction • Increased customer loyalty and retention • Increased job security • Improved employee morale • Enhanced shareholder and stakeholder value • Improved and innovative processes
Competencies	The competencies required by TQM • Problem-solving • Applying quality tools • Selecting quality models and systems • Using Lean and Six Sigma applications • Change management • Understanding ISO systems • Benchmarking
Principles	• Is customer-focused. Everything a company does—from training employees to buying new tools—is done with the customer

	in mind. • Involves all employees. Employees must be empowered to work toward common goals and allowed to operate in a workplace free from fear. • Is process-centric. By enacting processes that take inputs and turn them into outputs, you can consistently create high-quality products regardless of the people involved. • Is integrated. All developed processes must be integrated into one larger process, and everyone must be on the same page, buying into the company's vision, mission, and guiding principles. • Has a strategic and systematic focus. Companies must formulate strategic plans that include quality integration as a fundamental component. • Is constantly improved upon. Empowered managers and employees must continually look for new ways to increase product competitiveness and efficacy. • Involves fact-based decision-making. You must gather data on performance in order to know how well you're doing. You also need to analyze this data to constantly improve and refine how you do things. • Facilitates seamless communication. Managers, employees, and owners need to communicate routinely and effectively to help maintain morale and boost motivation.
Concepts	**Customer-focused:** The customer ultimately determines the level of quality. No matter what an organization does to foster quality improvement—training employees, integrating quality into the design process, or upgrading computers or software—the customer determines whether the efforts were worthwhile. **Total employee involvement:** All employees participate in working toward common goals. Total employee commitment can only be obtained after fear has been driven from the workplace, when empowerment has occurred, and when management has provided the proper environment. High-performance work systems integrate continuous improvement efforts with normal business operations. Self-managed work teams are one form of empowerment. **Process-centered:** A fundamental part of TQM is a focus on process thinking. A process is a series of steps that take inputs from suppliers (internal or external) and transforms them into outputs that are delivered to customers (internal or external). The steps required to carry out the process are defined, and performance measures are continuously monitored in order to detect unexpected variation. **Integrated system:** Although an organization may consist of many different functional specialties often organized into vertically structured departments, it is the horizontal processes interconnecting these functions that are the focus of TQM. Micro-processes add up to larger processes, and all processes aggregate into the business processes required for defining and implementing strategy. Everyone must understand the vision, mission, and guiding principles as well as the quality policies, objectives, and critical processes of the organization. Business performance must be monitored and communicated continuously. An integrated

	business system may be modeled after the Baldrige Award criteria and/or incorporate the ISO 9000 standards. Every organization has a unique work culture, and it is virtually impossible to achieve excellence in its products and services unless a good quality culture has been fostered. Thus, an integrated system connects business improvement elements in an attempt to continually improve and exceed the expectations of customers, employees, and other stakeholders. **Strategic and systematic approach:** A critical part of the management of quality is the strategic and systematic approach to achieving an organization's vision, mission, and goals. This process, called strategic planning or strategic management, includes the formulation of a strategic plan that integrates quality as a core component. **Continual improvement:** A large aspect of TQM is continual process improvement. Continual improvement drives an organization to be both analytical and creative in finding ways to become more competitive and more effective at meeting stakeholder expectations. **Fact-based decision making:** In order to know how well an organization is performing, data on performance measures are necessary. TQM requires that an organization continually collect and analyze data in order to improve decision making accuracy, achieve consensus, and allow prediction based on past history. **Communications:** During times of organizational change, as well as part of day-to-day operation, effective communications plays a large part in maintaining morale and in motivating employees at all levels. Communications involve strategies, method, and timeliness.
Methods & Tools	**Tools** • Pareto Principle. • Scatter Plots. • Control Charts. • Flow Charts. • Cause and Effect, Fishbone, Ishikawa Diagram. • Histogram or Bar Graph. • Check Lists. • Check Sheets.

5. Description of Program Evaluation Review Technique (PERT) by Expert E

Object category	Detailed object
Objective of the methodology	PERT aims at planning the project in terms of cost and time estimation and task network representation.
Process description	PERT has a set series of steps in mapping out a complex project, which include: • List all the tasks and milestones (a.k.a. events) required for completion of the project • Determine the required sequence of tasks • Design a chart to visually display all the steps • Estimate the time required for each task • Identify the critical path – the longest series of tasks in the project • Adjust the chart to reflect progress made once the project starts
Performance	PERT creators argued that, considering uncertainty in cost and time estimates would allow for being more reliable at a global project level, even if individual tasks did not behave as planned. Several tasks would get their optimistic or pessimistic estimate, and most of the tasks will get their most likely value. However, in reality, it was not so simple, because of the assignment of resources and actors to tasks. This means that, if a task is late, then its successor is supposed to start a bit later, except if the resource is not available anymore. This will involve an additional delay, until the resource becomes available once again.
Competencies	Task estimation, uncertainty in estimation, graph modelling,
Principles	PERT is a combination of a visual tool and a mathematical formalism used in project planning. Using the technique helps project planners identify start and end dates, as well as interim required tasks and timelines. First, the PERT network uses numbered circles or rectangles to represent milestones and straight lines with arrows at the end to represent tasks to be completed. The direction of the arrows, and the numbers, indicate the required sequence. PERT network is also often used with tasks as nodes and sequence relationships as edges. Second, the PERT is also a way to propose a duration or cost estimate for each task. Knowing its optimistic, pessimistic and most likely values, the PERT estimate is given as follows: 1/6*(Optimistic + 4 * Most Likely + Pessimistic). The third principle is to choose whether PERT network and PERT estimates are combined or not. In the first case, the PERT estimates are included in the PERT network. There is also the possibility to simulate project-level time or cost distribution by using detailed optimistic, most likely and pessimistic values (for instance in Monte-Carlo simulations). In the second case, each task is estimated using an ad hoc method, either based on expertise or experience.
Concepts	PERT estimate PERT network
Methods & Tools	Graph modeling tools, table-based tools (like Excel), all classical project management tools include a PERT-related function.

6. Description of SCRUM by Expert E

Object category	Detailed object
Objective of the methodology	Scrum aims at assisting project teams to deliver complex products with better time, quality and cost results, while improving the well-being of project members.
Process description	Scrum is based on the repetition of sprints, each sprint intending to deliver an iteratively improved product: • Project initiation: project objectives and constraints, initial version of Product Backlog, user stories and so on. • Sprint planning, around 2-4 weeks and a selection of some items of the global Product Backlog • Sprint execution, with the emblematic (daily) scrum meeting • Sprint closing, with two meetings, respectively Sprint Review and Sprint Retrospective. • Project closing step: administrative closure, people reassignment, contract closure, and so on.
Performance	Scrum has emerged in software development projects, and has initially improved desired parameters, meaning lower cost, lower duration and higher level of delivered functionalities. Teams were about 8 to 12 members. The impact on human well-being is indirectly measured by the adherence of people to this methodology, and the fact that they generally don't want to go back to classical project management. Scrum is an easy-to-understand method, albeit it is sometimes hard to apply (because of the cultural difference with classical hierarchy- and planning and control-based management). The will to spread agile principles to other parts of the organizations or other types of organizations involved some successes and failures, for several reasons: • The cultural change, depending on the way the organization was managed, and on the type (and complexity) of system that was developed. • The interface with the rest of the organization, since when a team managed with agile principles is in interface with its management or other teams differently managed, this could involve numerous issues. • The size of the team was initially small, which allowed for working even if some principles were not present or precise in scrum methodology. This has not been the case anymore in bigger teams.
Competencies	Collective expression like voting on backlog priorities or user stories priorities, non-hierarchical team management, Product Owner (customer relationship, delivery orientation), Scrum Master (process and team orientation)
Principles	• Breaking down the project into smaller and iterative sprints (instead of bigger and sequential phases) • Reducing the controlling effort, by initial and final sprint meetings (around 1 to 2 h) combined to a short daily scrum meeting (15' max) • Giving the opportunity to the team to continuously progress by the original Sprint Retrospective (which is not deliverable-oriented, but team performance and team improvement for next sprint) • Giving more autonomy to project members, both for task prioritization during meetings and task execution during

	intervals between meetings.
	• Adherence to agile values:
	  o Interaction between people is better than Processes
	  o Communication with the client is better than Negotiation of the Contract
	  o (Putting effort in) Delivery is better than Documentation
	  o Adaptation to reality is better than Strict follow-up of the initial plan

Concepts	Sprint, Product / Sprint Backlog, Scrum meeting, Burn-down Chart, User story, Epic (combination of coherent Product backlog items), Backlog prioritization using team-based opinions
Methods & Tools	Trello, Jira, Miro

7. Description of Design Thinking (DT) by Expert G

Object category	Detailed object
Objective of the methodology	Design thinking is at the same time an innovation management method for conducting an innovation project, and a state of mind. It has been developed at Stanford University in the 1980s by Rolf Faste. It was popularized in the 2000s by IDEO under the aegis of Tim Brown. The first school to teach (practice) design thinking is the school of Stanford University at the initiative of David Kelley, the founder of IDEO. Since the 2000s, the DT has democratized design in companies. Design Thinking is a synthesis between analytical and intuitive thinking. It is part of a global approach called collaborative design and is it a balanced way to implement user-centered design. It is largely based on a co-creativity process involving feedback from the end user. Unlike analytical thinking, design thinking is a set of interlocking spaces rather than a linear process with a beginning and an end.
Process description	Design thinking is primarily defined as a simple multi-step process whose number varies depending on the authors: Initially made up of seven steps according to Rolf Faste (en), professor of design at Stanford University: *define*, *research*, *imagine*, *prototype*, *select*, *implement*, *learn*. It has been further reduced to five by Jeremy Gutsche of the Trend hunter site: *define*, *imagine*, *synthesize*, *prototype*, *test*, and even to three by Tim Brown, the boss of the IDEO company: *inspiration*, *imagination*, *implementation*. The most popular representation of the DT process is the Stanford University d.school's which defines five steps (see Figure 1) that are logically linked but should not be taken as a linear process: one can and should go through several cycles, return to *empathize* or *define* while *prototyping*, for instance. These five steps are: • **Empathize** (or understand your clients). This step consists of interviewing the interested client to empathize with him/her. It is about establishing what users do, think, feel and say. The objective is to obtain a sentence such as: "The interested person" needs "something" because of "something else". • **Define** (the problem). This step aims to establish a "good point of view": o framework of the problem o inspiration for the team; o reference frame for evaluating the relevance of ideas; o parallelization of the team's decision making; o establishment of the "How could we...". • **Ideate** (or Finding the solution). This phase is the production of ideas, using techniques such as brainstorming. • **Prototype** (your solution). As a key step, prototyping allows: o to gain empathy by identification with the user; o to explore options; o to carry out tests;

- to inspire other team members.

- **Test** (your solution). This phase allows for user feedback and refinement of the "right point of view".

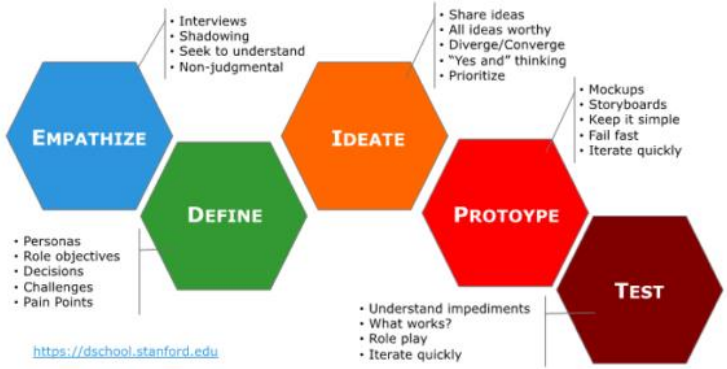


Figure 1: *The Stanford d.school Design Thinking process*

In practice, Design Thinking is practiced in adapted places where it is possible to innovate in a relax attitude, as well as prototype, also showcasing with clients. These places are called innovation labs, but also Design labs / maker spaces / Fab labs (see Figure 2).

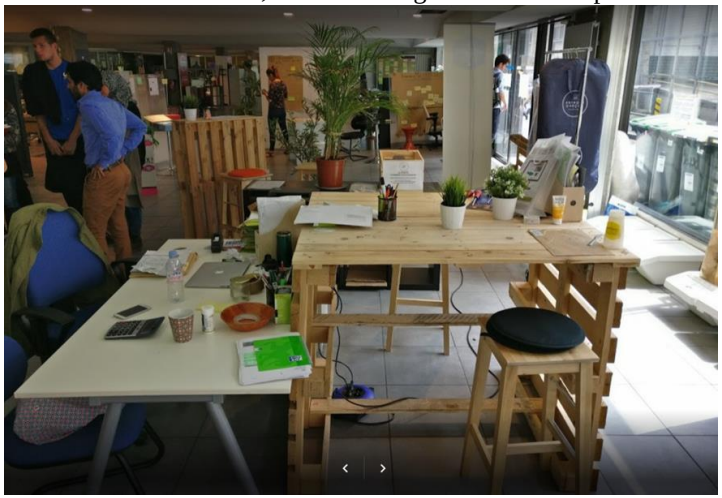


Figure 2: *The "Le Square" Innovation Lab of Renault company*

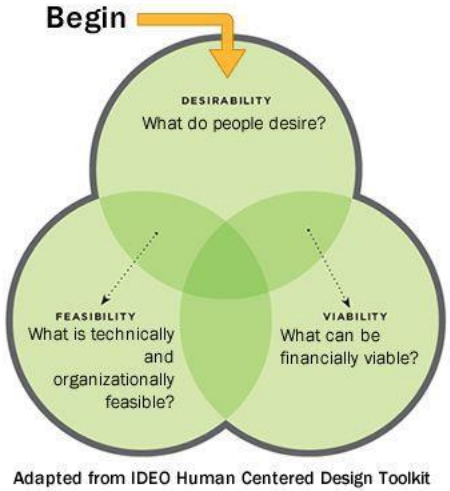
<table>
<tr><td>Performance</td><td>In Design Thinking, the ultimate value to be developed is desirability for the consumer, followed by feasibility and viability (see Figure 3). Desirability is associated to the “wow effect” expected from the users/clients.
 

Figure 3: The performance set of indicators of an innovative project outcome for IDEO</td></tr>
<tr><td>Competencies</td><td>From the competencies framework in innovation management proposed by [Moubdi et al., 2018], the competencies linked to Design Thinking are:
In Empathize and Define stages: ability to tackle ill structured problem, empathy skills, Curiosity, Perseverance, communication Skills, and openness
In Ideate stage: Creativity, collective knowledge sharing, Networking, and synthesizing skills
In Prototype and Test stages: experimenting and prototyping skills, problem-solution pairing, idea association skills, collective learning, and collective intelligence</td></tr>
<tr><td>Principles</td><td>The main principles of Design Thinking:
User-centered innovation: The users are at the center of the design.
Empathy: putting oneself in the shoes of the users and non-users is crucial. For instance, the designers are incented to simulate themselves the disabilities of disable people.
Field study: ethnographic observations must be performed; several techniques can be found in designingwithpeople.org website.
UX design (User Experience) is complementary to Design Thinking
Iterations, feedback loops: Proceed with as much iteration as necessary.
Fail fast. It is an important rule to respect: if you can prove your design track is wrong, do it as soon as possible to switch to another trail.
Co-design and collective intelligence. The attitude of co-designing aims at developing a collective intelligence.</td></tr>
</table>

Concepts	We can mention the concept of: • **Desirability / viability / feasability**
Methods & Tools	Design Thinking recommends the use of appropriate tools and methods at each step of the process. Numerous websites have consequently classified hundreds of tools and methods along the five DT process stages. Such tools, toolkits and guides may be found hereafter: • Designing with people website by the Helen Hamlyn Centre for Design at the Royal College of Art • 20 Best Online Tools for Design Thinking • The Most Complete Design Thinking Tools & Resource Collections • Stanford d.School Resources & Tools • frog design’s 43 page Collective Action Toolkit • SessionLab Brainstorming Facilitation Tools • 45 Design Thinking Resources for Educators • IDEO.org Field Guide to Human Centered Design • Design Thinking for Educators Toolkit co-developed by IDEO • Google Design Sprint Kit • IBM Design Thinking Field Guide • Alexandar Cowan Venture Design (great tools/templates for Empathy, Ideation, & Agile)

Among these tools, two are worthy to be mentioned. **The personas method** is a fictional user model (see Figure 4) is used in design teams [Cooper, 1999] and serves as a shared basis for communication [Grudin & Pruitt, 2002]. It is used as well in the *Empathize* stage to represent archetypal users, as during the *Ideate* and test stages to design and test from the data of personas.

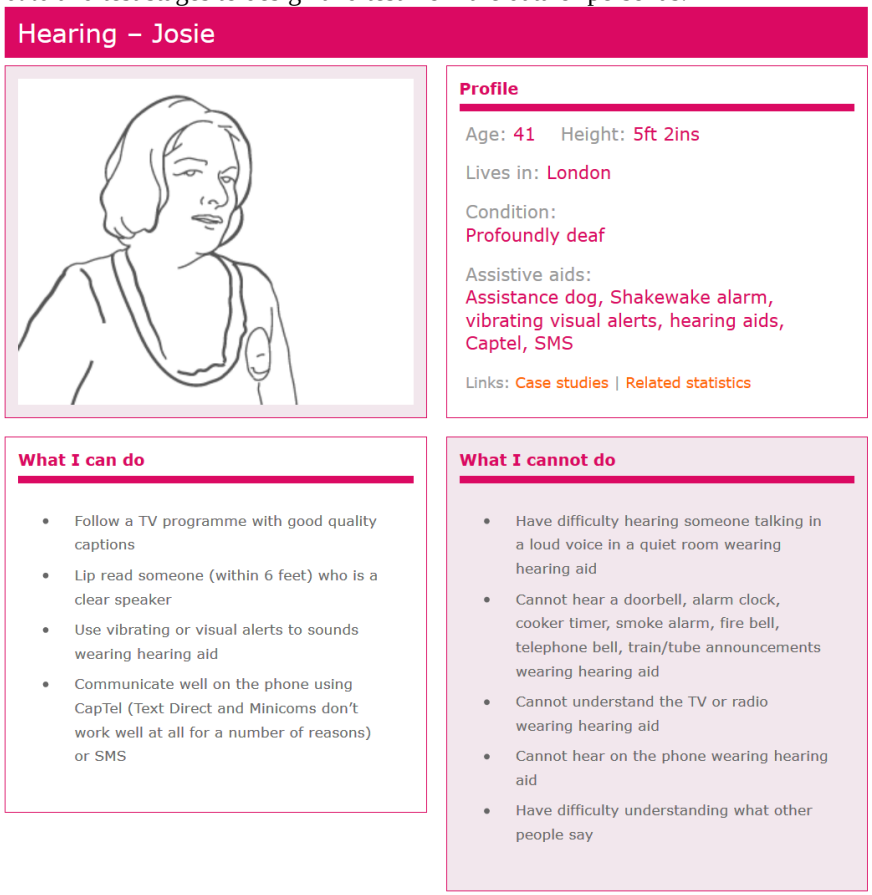


Figure 4: *A persona Id from the designwithpeople.org website*

The **Customer Journey Map** enables to describe the user experience of a persona (see Figure 5) during a period of time, and uncover the interactions experienced by the user.

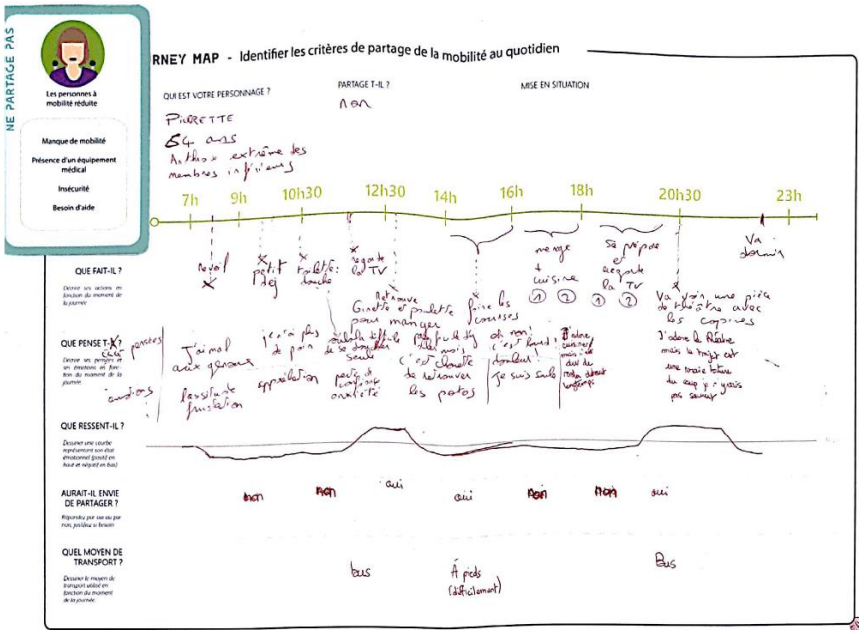


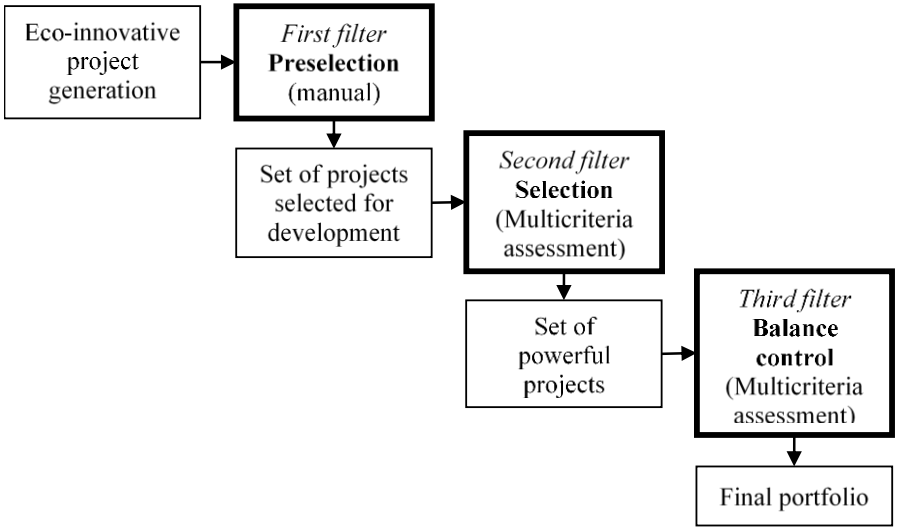
Figure 5: *A Customer Journey Map imagined for a given persona living a shared mobility experience (Courtesy Flore Vallet)*

8. Description of the methodology Eco-innovation of R&D projects portfolio for complex industrial systems by expert D

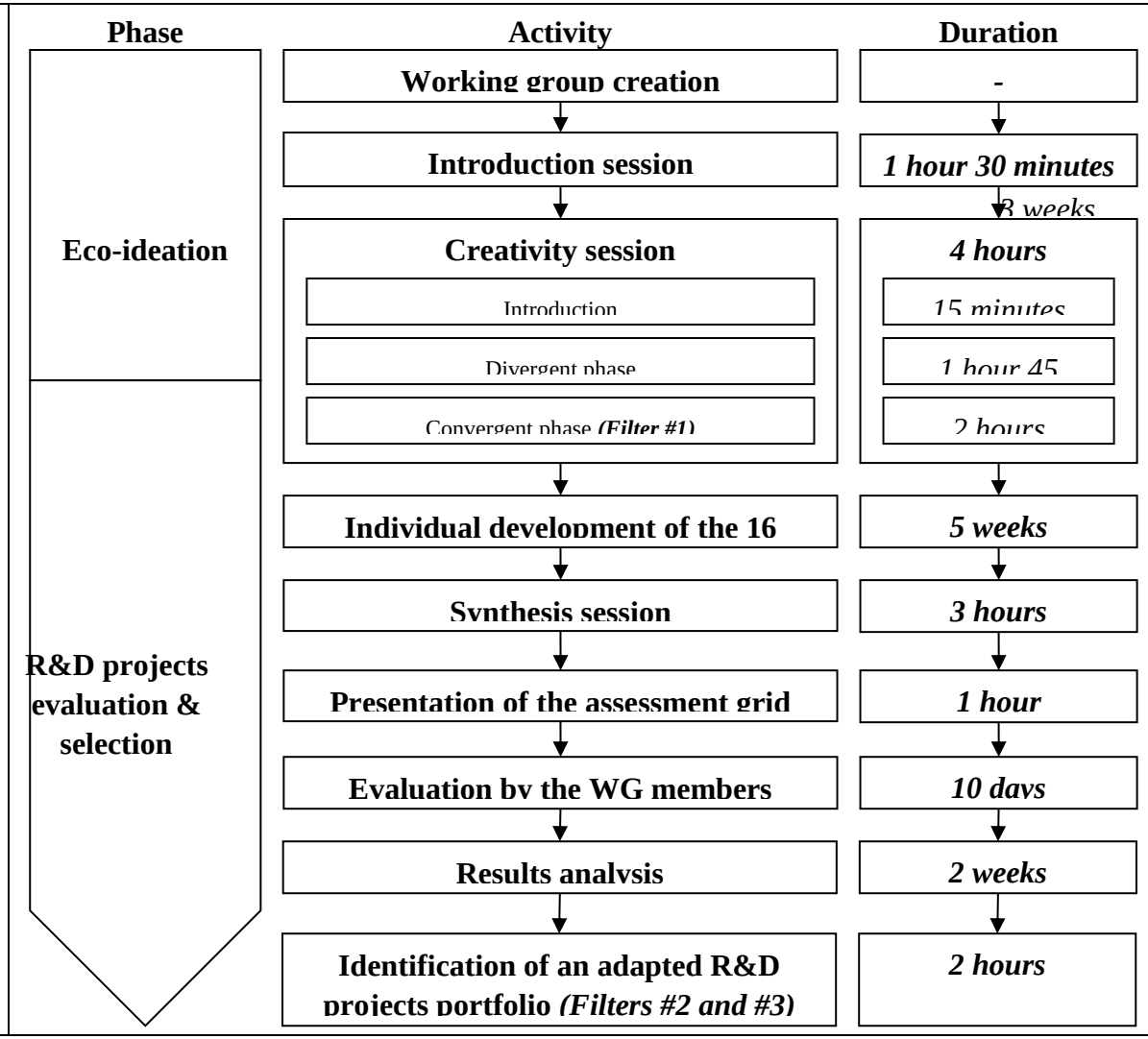
Based on the publication (Cluzel et al., 2016)

Object category	Detailed object
Objectives of the methodology	We define a complex industrial system in the eco-design vein as: • A large-scale system in terms of sub-systems and components, mass and resource usage; • A system whose life cycle is unpredictable at the design level in the long-term, in particular with regard to its lifetime, upgrades, maintenance and end-of-life; • A system whose sub-systems may have different life cycles and different obsolescence times; • A system which is in close interaction with its environment (e.g. super system, geographic site); • A system which is supervised by human decisions and management. Concerning eco-innovation, the main problem of such systems is that the customers' specifications or the regulations and standards severely limit the ability to radically innovate, as only long-term proven technologies are used. **Thus, the challenge associated with an eco-innovation approach is how to identify a set of reliable incremental eco-innovative projects, and/or to be able to make radical eco-innovations possible which are acceptable to customers.** We propose that an adapted and effective eco-innovation methodology for complex industrial systems should: • Consider the different system levels (components, subsystems, system, etc.), as incremental innovations that are constantly made at a component or subsystem level, while radical innovations are more likely to appear at a system level (new unexpected architecture), • Be very simple, as multidisciplinary knowledge is required to consider all the aspects of such a large-scale system, i.e. the process mainly involves non-environmental experts, • Be flexible, implantable within a short time-frame with limited resources, and easily accepted by the management and the experts involved, • Be very efficient, reaching the best possible ratio between resources used and results, • Build a strong basis for future eco-design work, both to maximize the learning potential of the process and to maximize the success rate of the identified R&D projects, • Take into account multi-criteria aspects, by considering technical, economic and marketing dimensions, to be easily accepted, • Provide strong proof in terms of feasibility and interest for the customers, so as to be successful on the markets.
Process description	The eco-innovation process for complex industrial systems presented is this paper is part of a larger methodology described in (Cluzel et al., 2012) and built on the following hypotheses: • Eco-innovation is deployed in a company providing complex industrial systems, but with no specific knowledge in eco-

	design/eco-innovation; • The approach is supported by at least one eco-design expert; • An environmental evaluation (Life Cycle Assessment or simplified LCA) has identified high impacting elements (materials, components, subsystems, life cycle phases) of the complete system life cycle. Moreover, as expressed widely in research, one major success factor is the support of the management of the company (McAloone, 1998; O'Hare, 2010). This ensures in particular the ability to build a multidisciplinary working group, if department managers give their acceptance to include their experts in the working group. The choice of a collaborative approach as opposed to an individual one is justified by the fact that the global vision of a complex industrial system is necessarily shared by several persons with different knowledge (product, life cycle, technical aspects, design process, customers etc.). That is why the main departments of the company need to be represented: R&D, engineering, commercial & marketing, sourcing…. 6 to 10 participants is generally perceived as the optimal number for an efficient creativity process. The eco-design expert required to support the approach is the leader of the creativity sessions. The objective of the eco-innovation process is to identify a set of pertinent environmental improvement projects (incremental or radical eco-innovations) ready to be assessed by the decision-makers. This portfolio needs to be composed of powerful individual projects, but also to have global coherence. This is also a way to prepare the company for the future and further extended eco-design work, as the members of the working group will be able to act as eco-design 'ambassadors' in their respective departments.



Once the working group has been defined, the eco-innovation consists of two main steps: eco-ideation, and eco-innovation R&D projects evaluation and selection. The building of an adapted portfolio of eco-innovative projects is performed through three successive filters that cover these two steps. This process is described in Figure 2 and also mentioned in Figure 7 to clearly position them in the whole process, and it is detailed below. The three filters are detailed in the paper. The figure below describes an application of the methodology.

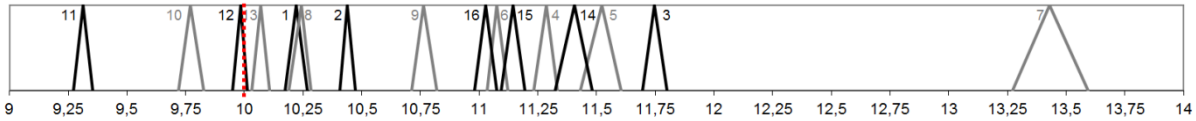

Phase
Activity
Duration
Eco-ideation
R&D projects evaluation & selection
Working group creation
-
Introduction session
1 hour 30 minutes
3 weeks
Creativity session
4 hours
Introduction
15 minutes
Divergent phase
1 hour 45
Convergent phase (Filter #1)
2 hours
Individual development of the 16
5 weeks
Synthesis session
3 hours
Presentation of the assessment grid
1 hour
Evaluation by the WG members
10 days
Results analysis
2 weeks
Identification of an adapted R&D projects portfolio (Filters #2 and #3)
2 hours

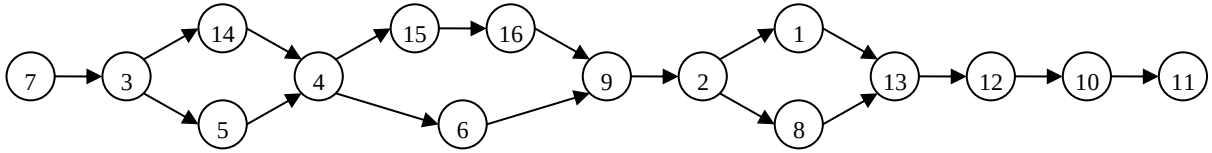
Performances	The performance of the methodology is assessed in terms of quantity, variety, quality and novelty of the ideas produced. The methodology encompasses criteria and indicators to assess the quality of projects. The projects are examined dimension by dimension in the following order: 1. Feasibility, as it is unfruitful to consider unfeasible projects for longer, 2. Customers' value, as it is useless to consider a project that deteriorates these values for longer, 3. Environmental benefits: the global score is first considered, but also the detail of each Brezet wheel's axis. Indeed a project may have for instance excellent benefits on end-of-life aspects and at the same time not bring benefits to the other axes, resulting in a poor global environmental score.
Competencies	Competencies needed for using this methodology are eco-design and innovation competencies. By using this methodology, people will develop competencies in R&D project portfolio management in an eco-design perspective for complex industrial systems. However these competencies have not been developed so far.
Principles	We propose that an adapted and effective eco-innovation methodology for complex industrial systems should: • Consider the different system levels (components, subsystems, system, etc.), as incremental innovations that are constantly made at a component or subsystem level, while radical innovations are more likely to appear at a system level (new unexpected architecture), • Be very simple, as multidisciplinary knowledge is required to consider all the aspects of such a large-scale system, i.e. the process mainly involves non-environmental experts, • Be flexible, implantable within a short time-frame with limited resources, and easily accepted by the management and the experts involved, • Be very efficient, reaching the best possible ratio between resources used and results, • Build a strong basis for future eco-design work, both to maximize the learning potential of the process and to maximize the success rate of the identified R&D projects, • Take into account multi-criteria aspects, by considering technical, economic and marketing dimensions, to be easily accepted, • Provide strong proof in terms of feasibility and interest for the customers, so as to be successful on the markets
Concepts	Concepts are mentioned all along the paper and this table. To cite few of them: eco-innovation, R&D project portfolio, complex industrial system, eco-ideation, eco-selection, potential environmental benefits, feasibility, customers' value, time horizon, project perimeter, project nature, expertise…
Methods & Tools	The methodology includes or uses several methods and tools; • The eco-design strategy wheel (Brezet wheel) • An expertise level indicator based on a pairwise comparison approach and fuzzy logics. These indicators are used to weight the assessments of evaluators by their expertise level. They also allow to measure an uncertainty grade associated with each assessment.

- Qualitative scales to measure the benefits on criteria. For example:

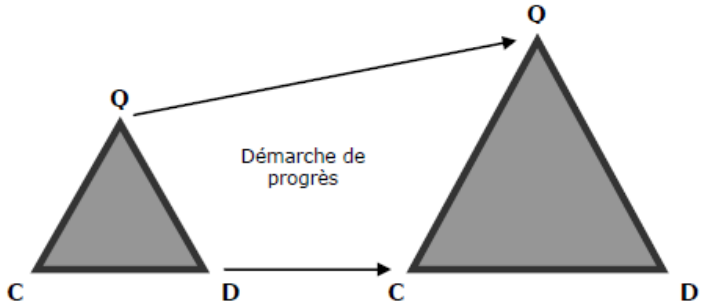
Score	Description
0	The project highly deteriorates the environmental performance of the current solution.
1	The project significantly deteriorates the environmental performance of the current solution.
2	The project does not bring any benefit or damage compared to the current solution.
3	The benefits brought by the project are minimal.
4	The benefits brought by the project are significant.
5	The benefits brought by the project are very important.

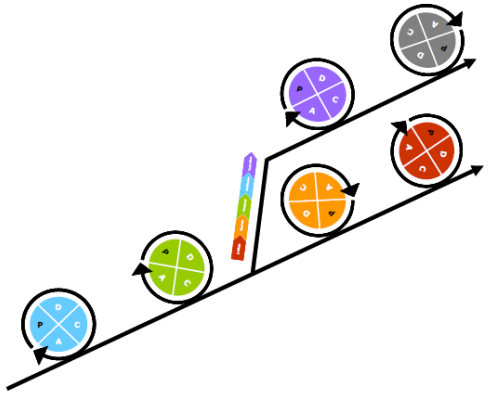
- Graphs showing uncertainty grades and outranking diagrams as decision-aiding tools to represent the results. For example:





9. Description of Lean Six Sigma by expert D

Object category	Detailed object
Objectives of the methodology	Lean 6 Sigma is a continuous improvement approach. L6S aims at creating a competitive advantage from the client's point of view and maximizing value creation. Historically one dimension of the paradigm QCD (Quality, Cost, and Time (D for Délai in French in the Figure below)) was improved only to the detriment of the others. With the L6S paradigm all dimensions progress together.  The two historical ways for continuous improvement are Lean Manufacturing and Six Sigma, merged in Lean 6 Sigma. The performance of a company may be represented by the following formula: P = L6S * A * PC where P is Performance, L6S Lean 6 Sigma, recognized today as the synthesis of the best practices of operational performance, A the animation of the team and PC continuous progress.
Process description	L6S is based on two main tools that are in fact processes: PDCA and DMAIC. PDCA (Plan, Do, Check, Act) aims at monitoring continuous progress on a daily basis. It is a step by step approach with 4 stages: • Plan : define perimeter, gather data, formulate hypotheses, elaborate the test program • Do: implement, train, inform • Check: verify results, obtain solutions, identify root causes • Act: prevent repetitions, define standards, communication, identify new improvements

	 DMAIC (Define, Measure, Analyze, Improve, and Control) aims at monitoring a progress project and at reaching a punctual and superior performance improvement, as described below.  
Performances	The measure of performance in L6S is mainly based on Key Performance Indicators (KPI). KPIs are mainly formulated in terms of Cost, Quality and Time, but may concern other domains in larger approaches (for example Environment in Green & Lean approaches, that are an extension of L6S).

<table>
<tr>
<td>Competencies</td>
<td>There are three levels of competency for Lean and Six Sigma described in the ISO-18404 standard: Lean Practitioner, Leader, and Expert; and Six Sigma Green, Black, and Master Black Belt. “Lean & Six Sigma” is simply a combination of the competencies of the equivalent Lean and Six Sigma levels, and follows the same belt structure as Six Sigma. For each level, the standard lists competencies, performance criteria, and suggested evidence of understanding, applying, managing, and training the competency.
There are 18 competencies described for Lean Practitioner, Leader, and Expert. The focus of the Lean Practitioner level is on understanding and applying the Lean Principles, change at individual and organizational level, workplace optimization (see 5S), and analysis and measurement of data and process improvement. At Lead Leader and Expert level there is additional focus on stakeholder management, team engagement, and reporting skills, as well as a shift towards management and teaching of the competencies. The expectations of the three levels are summarized in the table below:
<table>
<tr><th>Level</th><th>Expectations</th></tr>
<tr><td>Lean Practitioner</td><td>1. Work to implement improvements in the local area
2. Use workplace layout techniques to improve process flow
3. Be required to lead improvement activities and quantify benefits delivered
4. Coach team members on process improvement methods and activities
5. Run training sessions on Lean techniques</td></tr>
<tr><td>Lean Leader</td><td>1. Work with the local ‘line management’ to identify and drive improvement within the local environment
2. Use tact times and cycle times to identify appropriate resource requirements
3. Be required to lead improvement activities and quantify benefits delivered
4. Coach Lean practitioners on process improvement methods and activities
5. Run training sessions on Lean techniques</td></tr>
<tr><td>Lean Expert</td><td>1. Lead improvement initiatives as required
2. Determine if any training activities are appropriate and effective
3. Provide training in Lean approaches to Lean leaders as required
4. Assist in the identification of suitable areas for Lean implementation
5. Assist in periodic reviews of the implementation
6. Provide internal consultancy in Lean
7. Provide support so that improvements identified are realized and maintained
8. Coach and mentor the Lean leaders in the implementation of Lean principles and the selection and use of the techniques required
9. Work regularly with senior management to build Lean awareness, Lean skills and support for implementation</td></tr>
</table>
</td>
</tr>
</table>

	10. Perform Lean audits at site level and use the results to identify future Lean events 11. Benchmarking 12. Instigate/coordinate reward and recognition as appropriate

There are 23 competencies for Six Sigma in ISO 18404, which are consistent across all the levels. As with Lean, as one progresses to the higher belts there is more attention to specific techniques and to managing and teaching the competencies. We're not Six Sigma experts so we can't comment on the appropriateness of the standard in this area, however, the approach and tools and techniques in ISO 18404 have been drawn from ISO 13053-1 and -2.

Source: https://www.lean6sigmatraining.co.uk/lean-and-six-sigma-competencies-as-defined-by-iso-18404/

Principles	Lean 6 Sigma is based on the principles of Lean Manufacturing and 6 Sigma. Principles of Lean Manufacturing are: (https://www.manufacturing.net/home/article/13193437/the-principles-of-lean-manufacturing) • Identify value • Map the value stream • Create flow • Establish pull • Seek perfection Principles of Six Sigma are: (https://www.process.st/six-sigma-principles/) • Always focus on the customer • Understand how work really happens • Make your processes flow smoothly • Reduce waste and concentrate on value • Stop defects through removing variation • Get buy-in from the team through collaboration • Make your efforts systematic and scientific

Concepts	Numerous concepts exist in L6S, which are already mentioned in this document for a few of them. To go further, Lean 6 Sigma dictionaries exist, see for example: https://www.isixsigma.com/dictionary/
Methods & Tools	Here we focus only on the DMAIC process. There exist several tools that are used at the different steps of the DMAIC process. Here are some of them: • Voice of the Customer • Project charter • SIPOC (Supplier Input Process Output Customer) • Ishikawa diagram • Value Stream Map

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Saleh, S. M., Huq, S. M., & Rahman, M. A. (2019, February). Comparative study within Scrum, Kanban, XP focused on their practices. In 2019 International Conference on Electrical, Computer and Communication Engineering (ECCE) (pp. 1-6). IEEE.

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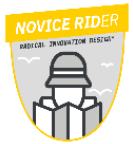
Appendix D: Definition of the expertise levels of RID experts

RID certification level	Acquired skills
	Level 0 • Know the main principles and types of innovations (need seeker, market reader, technology driver) • Know the principles, the process and the main RID deliverables • Understand user-driven innovation and its interest in business
	Level 1 + • Develop a state of mind and behavior conducive to innovation • Implement the key RID deliverables (investigation, problem reframing, observation, causality, value buckets and ambition perimeter) • Take a step back and question an idea of innovation
	Level 2 + • Implement a complete RID process in a simplified context (limited duration and team) • Sizing a RID project
	Level 3 + • Sizing, initiating and piloting a RID project in real conditions with a multidisciplinary team • Training employees/customers in the RID methodology (level 1 and 2 certifications) • Support RID projects (level 2 and 3 certifications)
	Level 4 + • Develop the RID methodology (RIDcore) • Guarantee the validity of the RID projects carried out by the certified • Train and certify employees/customers in the RID methodology (all levels) • Support RID projects (all levels)

Appendix E: User personas of the RID serious game

1. Introduction

Personas are "fictitious, specific, concrete representations of target users [1]," which are a commonly used tool in product and service design. The benefits of personas have been widely described in the literature [2,3,4], such as "empathy creation," "audience focus," "problem scope definition" and "challenge assumption" [5]. We employed this tool in the RID serious game design process to understand and characterize SG users' archetypes. In doing so, we could better identify users' needs to define the scope of the problem, that is, the RID game's design purposes.

2. Research method and related results

In order to create personas of the RID serious game, we followed three steps:

1) Identify potential users of the RID serious game. Our ambition is that the game will be used for higher education and vocational training. Based on the past experience, students who participated in the RID training generally come from three types of educational institutions: engineering school, business school, and design school. We also proposed three professional personas. First, we believe that user experience[1] (UX) designers are natural clients that should/could adopt RID methodology. RID goes beyond a shallow user experience in being based on the concept of activity and considering that innovative design is made in the context of providing a solution to augment an activity [6]. Second, people who intensively use the Business Model Canvas [7] should also be concerned. As it is shown in [8,9] that the use of BMC would gain in robustness in initiating the creative process with selected RID value buckets within "Value Proposition" and "Customer Segmentation" blocks. Finally, Bekhradi et al. show in [9,10] through a survey with 60 technological startups that these startuppers can plan the maturation of their technology by using RID several times so as to find value buckets in the markets potentially linked to the technology.

Here are the six resulting user personas:
① A student who studies at an engineering school;
② A student who studies at a business school;
③ A student who studies at a design school;
④ A professional who works as a user experience (UX) designer;
⑤ A professional who works as a business consultant;
⑥ A professional who founds a startup.[14]

2) Create the persona template. The second step is to determine what information could be relevant for describing the above user profiles. Based on the literature review about personas [12,13,14], we

[14] User experience: a person's perceptions and responses that result from the use or anticipated use of a product, system or service [11].

identified two common elements: personal information and educational background. Considering students and professionals have different expectations for the RID serious game, we decided to create a template for each group. Then we organized a session to brainstorming about additional elements to constitute two templates. According to Kiili [15], a serious game's user experience consists of educational experience and gaming experience. Thus, the brainstorming was oriented by the balance of gaming and educational aspects of the serious game experiences. On each template, we established a "gaming section" and an "education section" corresponding to these two aspects.

For the template of students (Figure 1), we further identified three elements. The first element, "gaming background," and the second element, "prior experience about innovation training," are generic for the serious games of teaching different innovation methodologies. The third element, "possible interests to learn RID using the serious game," is specific to the RID game. If we intend to design an eco-innovation game, this element should be "possible interests to learn eco-innovation with the serious game."

Gaming section

① Gaming background. This element aims to describe the frequency of playing games, game taste, and prior experiences about serious games. According to Statista (a German company specializing in market and consumer data), there will be three billion video gamers worldwide by 2023. We think that lots of students play games as games are extremely popular with young adults. Their game tastes may be different. However, there are still a considerable number of students who are not interested in playing games, so we took this into consideration when describing the personas.

Education section

② Prior experience about innovation training. It consists of three things: a story for learning innovation; prior knowledge about innovation methodologies; an evaluation of the persona's innovation competencies. The story for learning innovation was fed by the expertise of HyB'RID's (RID consulting company) founders. To model and quantify personas' innovation competencies, we organized an expert workshop. Three RID experts first selected eight core innovation competencies required by the RID methodology from the need seeker competency framework [16]. When the model was established, they evaluated each student's eight competencies based on previous teaching experiences.

③ Possible interests to learn RID using the serious game. This element describes the persona's expectations for the RID game. These expectations were derived from the first two elements.

Figure 1: Persona template of students

For the template of professionals (Figure 2), we further identified five elements, which were categorized into three sections: "profession section," "gaming section," and "education section."

Profession section

① Profession. This element is specific to professionals to explain how their daily work is linked with innovation activities. It describes a persona from three aspects: company; job title and responsibilities; employment history.

Gaming section

② Gaming background. This is the same element used in both templates.

Education section

③ Problems encountered in innovation activities and related expectations. For example, lack of guidance from known innovation methodologies. All these questions are extracted from the questionnaire, in which the professionals explained the difficulties they met in the innovation activities. Considering these difficulties, they also put forward some expectations.

④ Expertise in innovation. It describes a persona's prior knowledge about different innovation methodologies. Unlike the student's persona template, we used eight known innovation methodologies to model the professional's innovation expertise. The innovation expertise assessment of each persona took into account their seniority and specialized area.

⑤ Possible interests to learn RID using the serious game. It details why the persona is willing to experience the RID game. This element is deduced from the problems encountered in innovation activities and related expectations.

Figure 2: Persona template of professionals

The following table makes a comparison between the aforementioned two templates.

Table 1: Comparison between elements of two templates

Elements in the template of students	**Elements in the template of professionals**	**Differences**
Personal information	Personal information	Same
Educational background (university and major)	Educational background (higher education institution and major)	Student's current university; Higher or executive education institutions where professionals graduated
Gaming experience (game taste, frequency)	Gaming experience (game taste, frequency)	Same
Prior experiences about serious games	-	Only for students, as we consider that students have higher expectations for the gaming experience
A story for learning innovation	Problems encountered in innovation activities and related expectations	The former describes the problems encountered when learning innovation; The latter describes the problems encountered in innovation activities
Prior knowledge about innovation methodologies (question)	-	This question is just for students because we believe that only a small percentage of them have been trained in innovation methodologies (unnecessary).
Expertise in innovation (core innovation competencies)	Expertise in innovation (known innovation methodologies)	Eight innovation competencies are used to model students' innovation expertise; Eight innovation methodologies are used to model professionals' innovation expertise
Possible interests to learn RID using the serious game	Possible interests to learn RID using the serious game	Same

3) Develop personas for each identified user profile. Based on the above two templates, then we developed six personas (Figure 3~8).

① Persona #1: Maxime Quéré, a student at INSA Lyon.

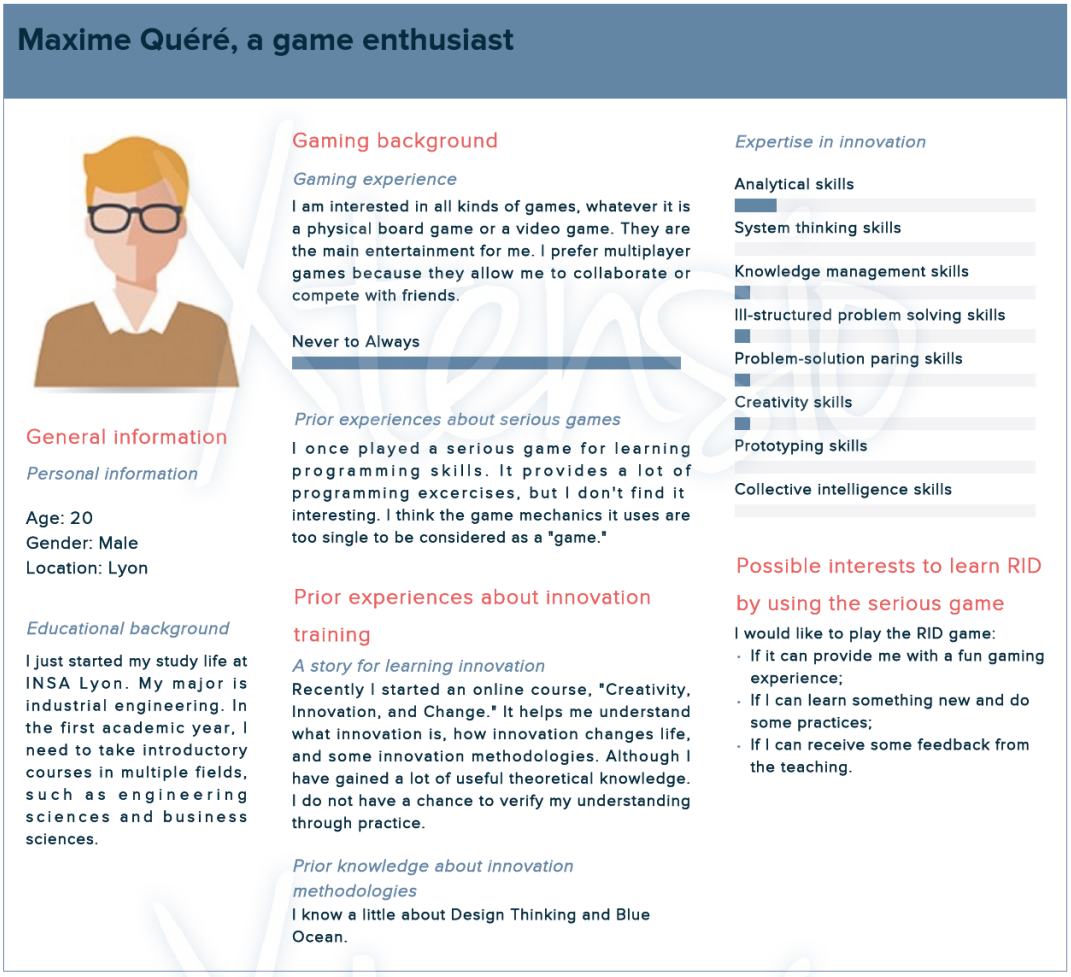


Figure 3: Persona – engineering school student

② Persona #2: Solène Hébert, a student at Montpellier Business School.

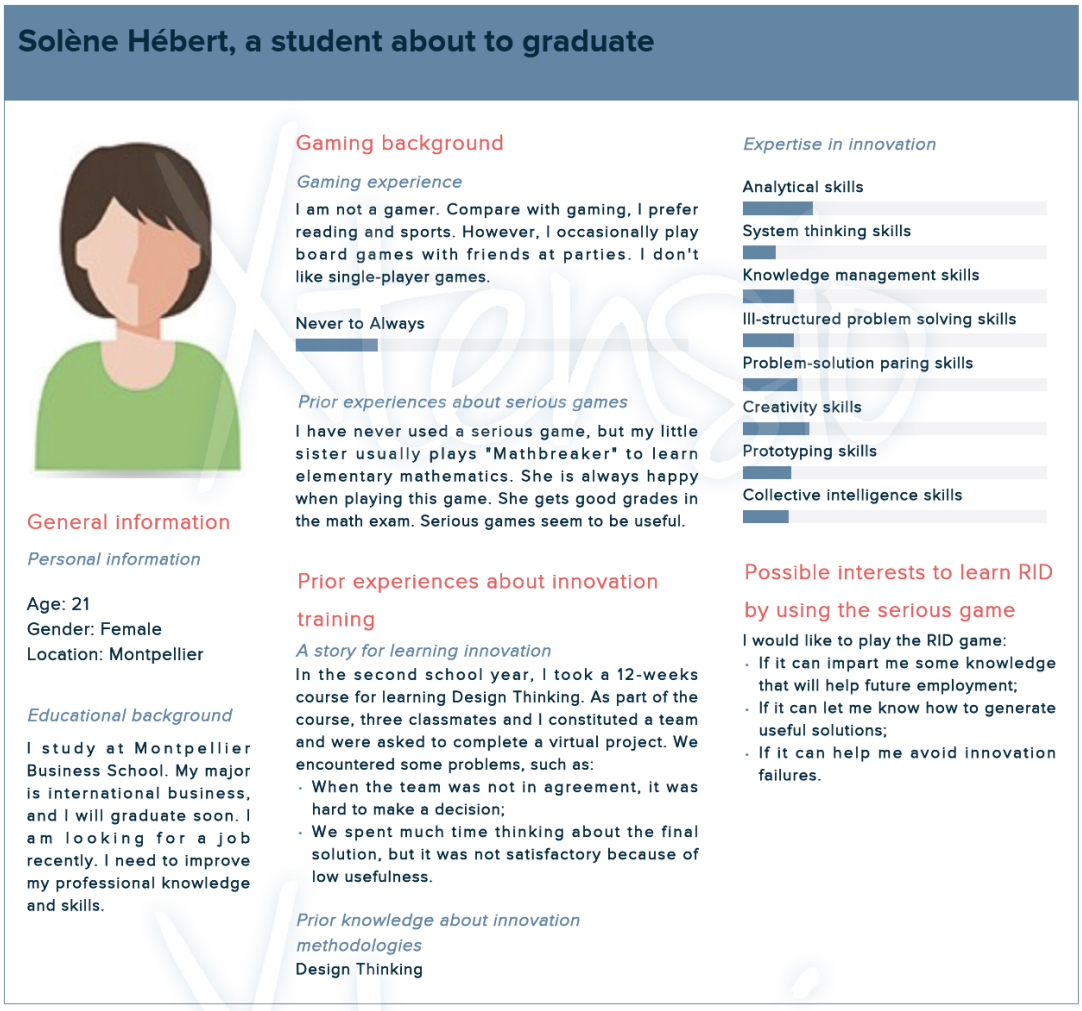


Figure 4: Persona – business school student

③ Persona #3: Antoine Pietri, a student at Montpellier Business School.

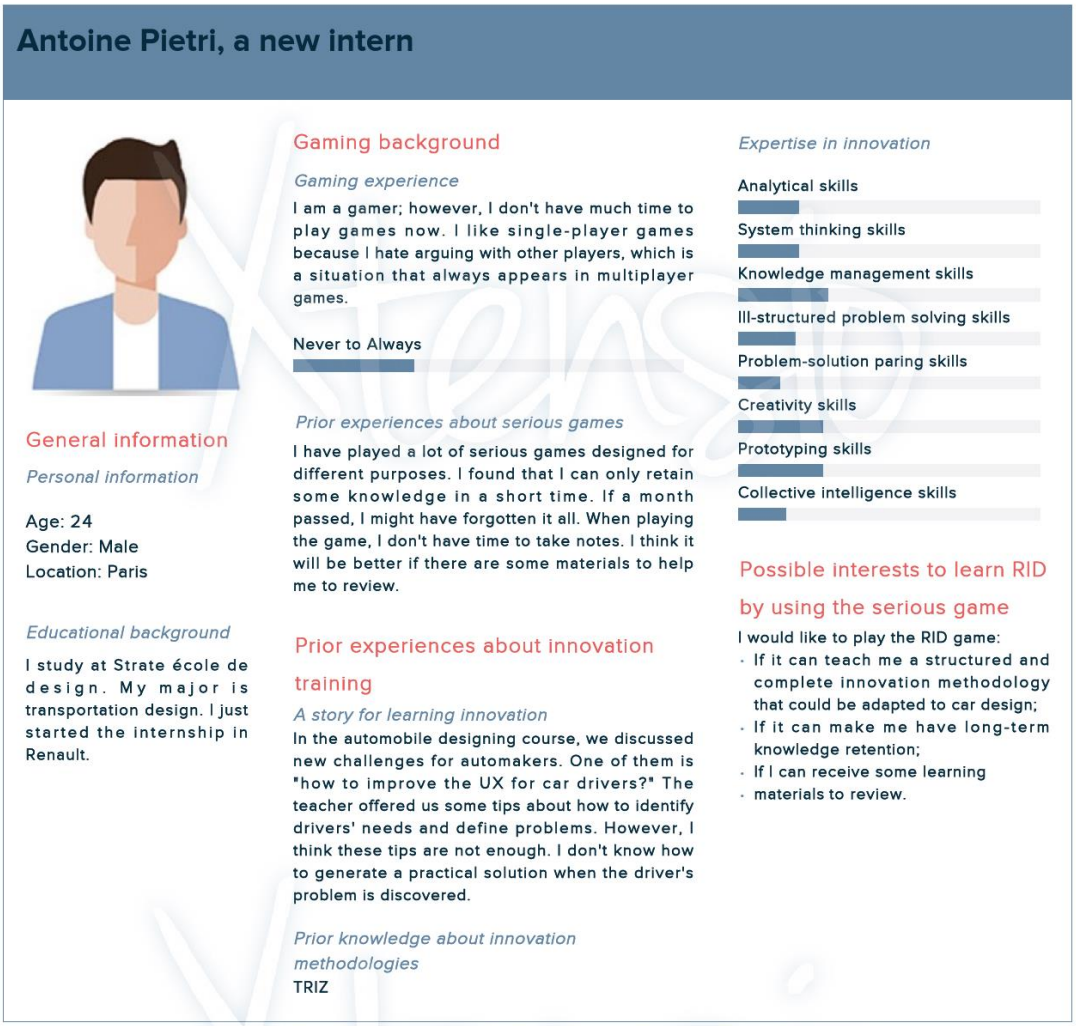


Figure 5: Persona – design school student

④ Charlotte Ferguson, an UX designer.

Figure 6: Persona – UX designer

⑤ Gabriel Boisante, a business consultant.

Figure 7: Persona – business consultant

⑥ Philip Ferrere, an founder of a startup.

Figure 8: Persona – entrepreneur

The above six personas were created to define the design purposes of the RID serious game. However, we consider it could also be beneficial to involve real users corresponding to these personas join the design process. On the one hand, they may generate exciting game ideas and help us make decisions during the game design phase; On the other hand, we can invite them to participate in game testing to validate whether the design purposes are achieved.

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Appendix F: Discussion results of the story frame

Synthesis of story elements

Element	Synthesis
Setting	In total, these seven stories contain 3 types of settings: ① Players are working in a consultant company and need to provide professional advice for the other companies. ② Players are participating in an innovation competition that is initiated by an institution (internal innovation competition or external innovation competition). ③ Players are working in an innovative company and need to work for an innovation project. Comments: • The first one and the third one are more suitable for a cooperative game. In these two settings, there seems to be no need for competition between each team. However, we can also think of a way to compare the performance (score system) of different teams to achieve competition. • The second type of setting contains the collaboration within a team and the competition between different teams. • Whether there is just one team of players or multiple teams, these three settings are applicable.
Characters	The commonality of all the characters in these stories is that the players are the performers of one innovation activity. Based on different story settings, the characters in the story are also different. In total, there are four types of characters: ① Business roles: Each player plays a different business role. These business roles come from different departments of the company. There may exist a special role from outside the company, "client". The client is the one who initiates the innovation project. ② Ordinary employees: Players play as employees working in innovative companies or consulting companies. There is no difference between player characters. ③ Ordinary employees with different roles at different game levels: Players are ordinary employees but need to complete various individual challenges at each step of the game. ④ Ordinary employees with different character traits: Each player's behavior during the game needs to be consistent with the traits he chooses. Comments: • Each type of character corresponds to one or more specific story settings. • The "client" as a specific role may or may not exist. If it exists, we need to further think about who will play this role. Here are three choices: ✧ Animators: RID experts can play as clients so as to publish tasks and evaluate results. ✧ Players: We can imagine that a player plays as the employee of the project initiator company. He/she needs to publish the project but at the same time work with the innovation team. He is the only one has access to the special information related to the project initiator (ex: the voice from the company). ✧ No one: A fictive client. The initial idea from the client only needs to be conveyed in some other ways (slides presentation, video).
Plot	What the plots in these stories have in common is that the players are all engaged in an innovation project and they need to complete the project by using the RID methodology. These story plots can be divided into three categories: ① Innovation contest: There exists collaboration within the team as well as the competition between teams. ② Innovation contest but the relationship between the different teams is collaboration: Combine the contributions of all teams to maximize value. ③ Innovation project: The initiator of the project can come from inside or outside the company. The relationship of members within the innovation team is collaboration. The competition between different teams can be realized if we use some methods to evaluate the performance of each innovation group, for example, the scoring system.

Conflict	There are four kinds of conflicts: ① The dilemma of the initiator of the innovation project. For example: gradually lose the market, inconsistency between the company's internal opinions and customer's ideas. ② Tricky innovation challenges need to be solved quickly and well: Players need to come up with solutions at the end of the game for this conflict. ③ Conflicts that occur when the innovation team doing the project: ✧ Unfamiliar with RID: The innovation team is attracted or required to use the RID methodology, however, it is the first time, so that the team needs to learn by doing. ✧ Limited time: The innovation team needs to complete all tasks within the stipulated time. ✧ Limited money: The innovation team is doing the project with budget constraints. ✧ Limited manpower: The innovation team needs to complete all tasks by themselves. ④ Production conflict: This is a conflict between players. Players may devote different levels of energy. This phenomenon will cause everyone's contribution to be unequal. Comments: • Limited money: This conflict can be realized by using game cards, for example, players need to use the limited virtual currency to buy "investigation strategies" cards. • Limited time: This conflict can be realized by using the game mechanic "Time control". Players need to complete each task within a limited time, which is controlled by the animator. • Limited manpower: This conflict seems to be more related to the story plot. It can bring players a sense of mission and responsibility. • Production conflict: This conflict seems concerning "how to make all players more immersed in the game". It may be effective to adopt the "mutual evaluation within the team". Players may, therefore, work harder to complete in-game challenges.
Solution	In total, there are two kinds of solutions: ① Adopt the RID methodology to complete tasks and generate solutions. ② The solution dedicated to the conflict "Limited time". Solving the time conflict can be done by co-validating the maturity/completeness of each task and deciding collectively of time reallocation of people on tasks." Comments: • For the story element "Solution", all stories are highly consistent. • The second solution could be useful if the players have already learned RID. However, if they are newbies, it will be hard for them to decide when to switch from one task to another.

Based on the similarities of these seven stories and consider each story's particularities, we generated three stories as following and these stories should inspire the design of the final story frame.

① You are members of the Global Design Agency (GDA). The famous GDA made of SUPER-designers, to save the world with the augmented innovation methodology --- Radical Innovation Design® methodology. Today, you are called together and form an innovation team to accomplish an extraordinary mission "XXX". Each of you will play different roles in the game, and different roles also mean different personal missions. Your team is expected to put forward effective solutions for "XXX" within a limited time and with a limited budget. (Collaboration within the team and no competition between teams)

② You are all consultants in innovation management and work at your consulting company headquarter. You have access to the different departments and resources of the company. You are asked to perform a mission for a company called “XXX”. “XXX” regularly loses market shares because the products are not attractive anymore, and a lot of competitors have appeared in this market. To get rid of this dilemma, “XXX” wants to develop new products that can do well to the world, with a focus on health and the environment. After the COVID-19 crisis, it is really time to reconsider our occidental way of producing and consuming! Your team will follow the Radical Innovation Design® methodology, to gather information, and to generate solutions for convincing your client! You must complete the project within a limited time and with a limited budget. Please note that you are not the only company “XXX” asks for help, your competitors are all around you. (Collaboration within the team and competition between teams)

③ You are members of different start-up companies who are joining the innovation contest organized by the incubator (CentraleSupélec) to develop an innovation on the topic “XXX”. The challenge is to develop an innovation on the topic “XXX” over one single day. The employees of each company will form an innovation team to conquer the challenge. You are expected to efficiently use the Radical Innovation Design® methodology to come up with innovative concepts. The incubator has gathered you to generate a set of relevant propositions. That is why you have to propose concepts that can be assembled like puzzle pieces to maximize the overall value. Your performance will be evaluated by the innovation expert. (Collaboration within the team; Competition and cooperation between teams)

Appendix G: Hidden data of the RID serious game

1. MarketVB-based scoring for usefulness

①Transportation workers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Increasing the tiredness	Lack of safety	Loss of public space	High maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	0	5	5	4	0	0	2	2	0
2	Commuting from work or education	0	5	5	4	0	0	2	2	0
3	Business travel	1	3	3	2	0	1	1	1	1
4	Leisure	0	0	0	0	0	0	0	0	0
5	Shopping	0	0	0	0	0	0	0	0	0
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	1	1	1	1	0	0	0	0	0
9	Carry heavy weight	1	3	3	3	0	0	0	0	0

②Non-transportation workers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Increasing the tiredness	Lack of safety	Loss of public space	High maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	3	2	3	2	0	1	3	2	0
2	Commuting from work or education	1	2	3	2	0	1	3	1	0
3	Business travel	1	0	2	0	1	1	0	0	1
4	Leisure	0	0	0	0	1	0	0	0	1
5	Shopping	5	1	2	4	1	1	0	2	0
6	Accompanying others	1	0	1	0	0	0	1	1	0
7	Emergency	4	0	2	1	0	0	1	1	1
8	Travel in a poorly-served area	0	1	1	1	0	0	0	0	1
9	Carry heavy weight	0	1	1	1	0	0	1	0	0

③Students

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Increasing the tiredness	Lack of safety	Loss of public space	High maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	3	0	0	0	0	0	5	3	0
2	Commuting from work or education	3	0	0	0	0	0	5	0	0
3	Business travel	0	0	0	0	0	0	0	0	0
4	Leisure	0	0	0	0	0	0	0	0	1
5	Shopping	4	0	2	0	1	0	0	2	0
6	Accompanying others	2	0	2	0	0	0	1	2	0
7	Emergency	5	0	2	0	0	0	0	0	0
8	Travel in a poorly-served area	0	0	2	3	0	0	0	0	0
9	Carry heavy weight	0	1	3	2	0	0	0	0	0

④Children and young travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Increasing the tiredness	Lack of safety	Loss of public space	High maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	0	3	0	5	0	1	4	2	0
2	Commuting from work or education	0	3	0	5	0	1	4	1	0
3	Business travel	0	0	0	0	0	0	0	0	0
4	Leisure	1	0	0	1	1	0	0	0	1
5	Shopping	1	1	1	1	1	1	1	1	1
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	1	2	1	2	0	0	0	0	1
9	Carry heavy weight	0	0	0	0	0	0	0	0	0

⑤Elderly travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Increasing the tiredness	Lack of safety	Loss of public space	High maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	0	0	0	0	0	0	0	0	0
2	Commuting from work or education	0	0	0	0	0	0	0	0	0
3	Business travel	0	0	0	0	0	0	0	0	0
4	Leisure	0	4	4	4	1	0	4	4	0
5	Shopping	2	5	5	5	3	2	5	5	0
6	Accompanying others	1	3	3	3	0	0	3	3	0
7	Emergency	2	0	3	1	0	0	1	1	0
8	Travel in a poorly-served area	0	0	0	0	0	0	0	0	0
9	Carry heavy weight	0	2	2	1	0	0	1	0	0

⑥Disabled travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Increasing the tiredness	Lack of safety	Loss of public space	High maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	0	2	3	0	0	1	3	1	0
2	Commuting from work or education	0	1	3	0	0	1	3	1	0
3	Business travel	0	0	1	0	0	1	0	0	0
4	Leisure	0	0	0	0	0	0	0	0	0
5	Shopping	1	4	4	4	2	1	5	1	1
6	Accompanying others	0	0	1	0	0	0	1	0	0
7	Emergency	1	5	5	5	0	0	5	1	0
8	Travel in a poorly-served area	0	0	0	0	0	0	0	0	0
9	Carry heavy weight	0	1	1	1	0	0	0	0	0

⑦Tourists

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Increasing the tiredness	Lack of safety	Loss of public space	High maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	0	0	0	0	0	0	0	0	0
2	Commuting from work or education	0	0	0	0	0	0	0	0	0
3	Business travel	0	0	2	3	1	0	0	0	1
4	Leisure	0	0	0	4	1	0	0	0	0
5	Shopping	2	0	2	5	3	0	0	1	0
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	0	0	0	0	0	0	0	0	0
9	Carry heavy weight	0	4	4	4	3	0	0	0	0

⑧Short-term visitors

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Increasing the tiredness	Lack of safety	Loss of public space	High maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	0	0	0	0	0	0	0	0	0
2	Commuting from work or education	0	0	0	0	0	0	0	0	0
3	Business travel	4	1	5	3	2	2	0	1	3
4	Leisure	3	1	4	2	1	1	0	1	2
5	Shopping	2	1	2	1	1	1	1	1	1
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	0	0	0	0	0	0	0	0	0
9	Carry heavy weight	1	2	4	2	0	0	1	0	0

⑨Passing travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Increasing the tiredness	Lack of safety	Loss of public space	High maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	0	0	0	0	0	0	0	0	0
2	Commuting from work or education	0	0	0	0	0	0	0	0	0
3	Business travel	0	0	2	4	1	1	0	0	2
4	Leisure	0	0	3	5	0	0	0	0	1
5	Shopping	1	0	1	0	0	0	0	1	0
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	0	0	0	0	0	0	0	0	0
9	Carry heavy weight	0	2	3	2	0	0	1	0	0

2. Scoring for opportunity - MOB&PARK

①Transportation workers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	1	1	2	2	1	1	1	1
2	Commuting from work or education	2	1	1	2	2	1	1	1	1
3	Business travel	5	2	2	5	5	2	2	2	2
4	Leisure	5	2	2	5	5	2	2	2	2
5	Shopping	5	2	2	5	5	2	2	2	2
6	Accompanying others	5	2	2	5	5	2	2	2	2
7	Emergency	2	1	1	2	2	1	1	1	1
8	Travel in a poorly-served area	2	1	1	2	2	1	1	1	1
9	Carry heavy weight	5	2	2	5	5	2	2	2	2

②Non-transportation workers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	1	1	2	2	1	1	1	1
2	Commuting from work or education	2	1	1	2	2	1	1	1	1
3	Business travel	5	2	2	5	5	2	2	2	2
4	Leisure	5	2	2	5	5	2	2	2	2
5	Shopping	5	2	2	5	5	2	2	2	2
6	Accompanying others	5	2	2	5	5	2	2	2	2
7	Emergency	2	1	1	2	2	1	1	1	1
8	Travel in a poorly-served area	2	1	1	2	2	1	1	1	1
9	Carry heavy weight	5	2	2	5	5	2	2	2	2

③Students

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	1	0	0	1	1	0	0	0	0
2	Commuting from work or education	1	0	0	1	1	0	0	0	0
3	Business travel	2	1	1	2	2	1	1	1	1
4	Leisure	2	1	1	2	2	1	1	1	1
5	Shopping	2	1	1	2	2	1	1	1	1
6	Accompanying others	2	1	1	2	2	1	1	1	1
7	Emergency	1	0	0	1	1	0	0	0	0
8	Travel in a poorly-served area	1	0	0	1	1	0	0	0	0
9	Carry heavy weight	2	1	1	2	2	1	1	1	1

④Children and young travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	1	0	0	1	1	0	0	0	0
2	Commuting from work or education	1	0	0	1	1	0	0	0	0
3	Business travel	2	1	1	2	2	1	1	1	1
4	Leisure	2	1	1	2	2	1	1	1	1
5	Shopping	2	1	1	2	2	1	1	1	1
6	Accompanying others	2	1	1	2	2	1	1	1	1
7	Emergency	1	0	0	1	1	0	0	0	0
8	Travel in a poorly-served area	1	0	0	1	1	0	0	0	0
9	Carry heavy weight	2	1	1	2	2	1	1	1	1

⑤Elderly travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	1	1	2	2	1	1	1	1
2	Commuting from work or education	2	1	1	2	2	1	1	1	1
3	Business travel	5	2	2	5	5	2	2	2	2
4	Leisure	5	2	2	5	5	2	2	2	2
5	Shopping	5	2	2	5	5	2	2	2	2
6	Accompanying others	5	2	2	5	5	2	2	2	2
7	Emergency	2	1	1	2	2	1	1	1	1
8	Travel in a poorly-served area	2	1	1	2	2	1	1	1	1
9	Carry heavy weight	5	2	2	5	5	2	2	2	2

⑥Disabled travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	1	1	2	2	1	1	1	1
2	Commuting from work or education	2	1	1	2	2	1	1	1	1
3	Business travel	5	2	2	5	5	2	2	2	2
4	Leisure	5	2	2	5	5	2	2	2	2
5	Shopping	5	2	2	5	5	2	2	2	2
6	Accompanying others	5	2	2	5	5	2	2	2	2
7	Emergency	2	1	1	2	2	1	1	1	1
8	Travel in a poorly-served area	2	1	1	2	2	1	1	1	1
9	Carry heavy weight	5	2	2	5	5	2	2	2	2

⑦Tourists

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	1	1	2	2	1	1	1	1
2	Commuting from work or education	2	1	1	2	2	1	1	1	1
3	Business travel	5	2	2	5	5	2	2	2	2
4	Leisure	5	2	2	5	5	2	2	2	2
5	Shopping	5	2	2	5	5	2	2	2	2
6	Accompanying others	5	2	2	5	5	2	2	2	2
7	Emergency	2	1	1	2	2	1	1	1	1
8	Travel in a poorly-served area	2	1	1	2	2	1	1	1	1
9	Carry heavy weight	5	2	2	5	5	2	2	2	2

⑧Short-term visitors

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	1	1	2	2	1	1	1	1
2	Commuting from work or education	2	1	1	2	2	1	1	1	1
3	Business travel	5	2	2	5	5	2	2	2	2
4	Leisure	5	2	2	5	5	2	2	2	2
5	Shopping	5	2	2	5	5	2	2	2	2
6	Accompanying others	5	2	2	5	5	2	2	2	2
7	Emergency	2	1	1	2	2	1	1	1	1
8	Travel in a poorly-served area	2	1	1	2	2	1	1	1	1
9	Carry heavy weight	5	2	2	5	5	2	2	2	2

⑨Passing travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	1	1	2	2	1	1	1	1
2	Commuting from work or education	2	1	1	2	2	1	1	1	1
3	Business travel	5	2	2	5	5	2	2	2	2
4	Leisure	5	2	2	5	5	2	2	2	2
5	Shopping	5	2	2	5	5	2	2	2	2
6	Accompanying others	5	2	2	5	5	2	2	2	2
7	Emergency	2	1	1	2	2	1	1	1	1
8	Travel in a poorly-served area	2	1	1	2	2	1	1	1	1
9	Carry heavy weight	5	2	2	5	5	2	2	2	2

3. Scoring for opportunity - MOBICOMPANION

①Transportation workers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	2	2	1	1	1	2	1	2
2	Commuting from work or education	2	2	2	1	1	1	2	1	2
3	Business travel	2	2	2	1	1	1	2	1	2
4	Leisure	2	2	2	1	1	1	2	1	2
5	Shopping	0	0	0	0	0	0	0	0	0
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	2	2	2	1	1	1	2	1	2
9	Carry heavy weight	0	0	0	0	0	0	0	0	0

②Non-transportation workers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	2	2	2	5	2	5
2	Commuting from work or education	5	5	5	2	2	2	5	2	5
3	Business travel	5	5	5	2	2	2	5	2	5
4	Leisure	5	5	5	2	2	2	5	2	5
5	Shopping	0	0	0	0	0	0	0	0	0
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	5	5	5	2	2	2	5	2	5
9	Carry heavy weight	0	0	0	0	0	0	0	0	0

③Students

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	2	2	2	5	2	5
2	Commuting from work or education	5	5	5	2	2	2	5	2	5
3	Business travel	5	5	5	2	2	2	5	2	5
4	Leisure	5	5	5	2	2	2	5	2	5
5	Shopping	0	0	0	0	0	0	0	0	0
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	5	5	5	2	2	2	5	2	5
9	Carry heavy weight	0	0	0	0	0	0	0	0	0

④Children and young travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	2	2	1	1	1	2	1	2
2	Commuting from work or education	2	2	2	1	1	1	2	1	2
3	Business travel	2	2	2	1	1	1	2	1	2
4	Leisure	2	2	2	1	1	1	2	1	2
5	Shopping	0	0	0	0	0	0	0	0	0
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	2	2	2	1	1	1	2	1	2
9	Carry heavy weight	0	0	0	0	0	0	0	0	0

⑤Elderly travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	2	2	2	5	2	5
2	Commuting from work or education	5	5	5	2	2	2	5	2	5
3	Business travel	5	5	5	2	2	2	5	2	5
4	Leisure	5	5	5	2	2	2	5	2	5
5	Shopping	0	0	0	0	0	0	0	0	0
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	5	5	5	2	2	2	5	2	5
9	Carry heavy weight	0	0	0	0	0	0	0	0	0

⑥Disabled travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	2	2	2	5	2	5
2	Commuting from work or education	5	5	5	2	2	2	5	2	5
3	Business travel	5	5	5	2	2	2	5	2	5
4	Leisure	5	5	5	2	2	2	5	2	5
5	Shopping	0	0	0	0	0	0	0	0	0
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	5	5	5	2	2	2	5	2	5
9	Carry heavy weight	0	0	0	0	0	0	0	0	0

⑦Tourists

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	2	2	2	5	2	5
2	Commuting from work or education	5	5	5	2	2	2	5	2	5
3	Business travel	5	5	5	2	2	2	5	2	5
4	Leisure	5	5	5	2	2	2	5	2	5
5	Shopping	0	0	0	0	0	0	0	0	0
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	5	5	5	2	2	2	5	2	5
9	Carry heavy weight	0	0	0	0	0	0	0	0	0

⑧Short-term visitors

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	2	2	2	5	2	5
2	Commuting from work or education	5	5	5	2	2	2	5	2	5
3	Business travel	5	5	5	2	2	2	5	2	5
4	Leisure	5	5	5	2	2	2	5	2	5
5	Shopping	0	0	0	0	0	0	0	0	0
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	5	5	5	2	2	2	5	2	5
9	Carry heavy weight	0	0	0	0	0	0	0	0	0

⑨Passing travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	2	2	2	5	2	5
2	Commuting from work or education	5	5	5	2	2	2	5	2	5
3	Business travel	5	5	5	2	2	2	5	2	5
4	Leisure	5	5	5	2	2	2	5	2	5
5	Shopping	0	0	0	0	0	0	0	0	0
6	Accompanying others	0	0	0	0	0	0	0	0	0
7	Emergency	0	0	0	0	0	0	0	0	0
8	Travel in a poorly-served area	5	5	5	2	2	2	5	2	5
9	Carry heavy weight	0	0	0	0	0	0	0	0	0

4. Scoring for opportunity – MOBINSURANCE

①Transportation workers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	2	2	5	2	2	5	5	5
2	Commuting from work or education	2	2	2	5	2	2	5	5	5
3	Business travel	2	2	2	5	2	2	5	5	5
4	Leisure	2	2	2	5	2	2	5	5	5
5	Shopping	2	2	2	5	2	2	5	5	5
6	Accompanying others	2	2	2	5	2	2	5	5	5
7	Emergency	2	2	2	5	2	2	5	5	5
8	Travel in a poorly-served area	1	1	1	2	1	1	2	2	2
9	Carry heavy weight	1	1	1	2	1	1	2	2	2

②Non-transportation workers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	2	2	5	2	2	5	5	5
2	Commuting from work or education	2	2	2	5	2	2	5	5	5
3	Business travel	2	2	2	5	2	2	5	5	5
4	Leisure	2	2	2	5	2	2	5	5	5
5	Shopping	2	2	2	5	2	2	5	5	5
6	Accompanying others	2	2	2	5	2	2	5	5	5
7	Emergency	2	2	2	5	2	2	5	5	5
8	Travel in a poorly-served area	1	1	1	2	1	1	2	2	2
9	Carry heavy weight	1	1	1	2	1	1	2	2	2

③Students

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	2	2	5	2	2	5	5	5
2	Commuting from work or education	2	2	2	5	2	2	5	5	5
3	Business travel	2	2	2	5	2	2	5	5	5
4	Leisure	2	2	2	5	2	2	5	5	5
5	Shopping	2	2	2	5	2	2	5	5	5
6	Accompanying others	2	2	2	5	2	2	5	5	5
7	Emergency	2	2	2	5	2	2	5	5	5
8	Travel in a poorly-served area	1	1	1	2	1	1	2	2	2
9	Carry heavy weight	1	1	1	2	1	1	2	2	2

④Children and young travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	2	2	5	2	2	5	5	5
2	Commuting from work or education	2	2	2	5	2	2	5	5	5
3	Business travel	2	2	2	5	2	2	5	5	5
4	Leisure	2	2	2	5	2	2	5	5	5
5	Shopping	2	2	2	5	2	2	5	5	5
6	Accompanying others	2	2	2	5	2	2	5	5	5
7	Emergency	2	2	2	5	2	2	5	5	5
8	Travel in a poorly-served area	1	1	1	2	1	1	2	2	2
9	Carry heavy weight	1	1	1	2	1	1	2	2	2

⑤Elderly travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	2	2	5	2	2	5	5	5
2	Commuting from work or education	2	2	2	5	2	2	5	5	5
3	Business travel	2	2	2	5	2	2	5	5	5
4	Leisure	2	2	2	5	2	2	5	5	5
5	Shopping	2	2	2	5	2	2	5	5	5
6	Accompanying others	2	2	2	5	2	2	5	5	5
7	Emergency	2	2	2	5	2	2	5	5	5
8	Travel in a poorly-served area	1	1	1	2	1	1	2	2	2
9	Carry heavy weight	1	1	1	2	1	1	2	2	2

⑥Disabled travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	2	2	5	2	2	5	5	5
2	Commuting from work or education	2	2	2	5	2	2	5	5	5
3	Business travel	2	2	2	5	2	2	5	5	5
4	Leisure	2	2	2	5	2	2	5	5	5
5	Shopping	2	2	2	5	2	2	5	5	5
6	Accompanying others	2	2	2	5	2	2	5	5	5
7	Emergency	2	2	2	5	2	2	5	5	5
8	Travel in a poorly-served area	1	1	1	2	1	1	2	2	2
9	Carry heavy weight	1	1	1	2	1	1	2	2	2

⑦Tourists

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	2	2	5	2	2	5	5	5
2	Commuting from work or education	2	2	2	5	2	2	5	5	5
3	Business travel	2	2	2	5	2	2	5	5	5
4	Leisure	2	2	2	5	2	2	5	5	5
5	Shopping	2	2	2	5	2	2	5	5	5
6	Accompanying others	2	2	2	5	2	2	5	5	5
7	Emergency	2	2	2	5	2	2	5	5	5
8	Travel in a poorly-served area	1	1	1	2	1	1	2	2	2
9	Carry heavy weight	1	1	1	2	1	1	2	2	2

⑧Short-term visitors

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	1	1	1	2	1	1	2	2	2
2	Commuting from work or education	1	1	1	2	1	1	2	2	2
3	Business travel	1	1	1	2	1	1	2	2	2
4	Leisure	1	1	1	2	1	1	2	2	2
5	Shopping	1	1	1	2	1	1	2	2	2
6	Accompanying others	1	1	1	2	1	1	2	2	2
7	Emergency	1	1	1	2	1	1	2	2	2
8	Travel in a poorly-served area	0	0	0	1	0	0	1	1	1
9	Carry heavy weight	0	0	0	1	0	0	1	1	1

⑨Passing travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	1	1	1	2	1	1	2	2	2
2	Commuting from work or education	1	1	1	2	1	1	2	2	2
3	Business travel	1	1	1	2	1	1	2	2	2
4	Leisure	1	1	1	2	1	1	2	2	2
5	Shopping	1	1	1	2	1	1	2	2	2
6	Accompanying others	1	1	1	2	1	1	2	2	2
7	Emergency	1	1	1	2	1	1	2	2	2
8	Travel in a poorly-served area	0	0	0	1	0	0	1	1	1
9	Carry heavy weight	0	0	0	1	0	0	1	1	1

5. Scoring for opportunity – MOBISHUTTLE

①Transportation workers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	2	2	2	1	1	2	2	2
2	Commuting from work or education	2	2	2	2	1	1	2	2	2
3	Business travel	2	2	2	2	1	1	2	2	2
4	Leisure	2	2	2	2	1	1	2	2	2
5	Shopping	2	2	2	2	1	1	2	2	2
6	Accompanying others	2	2	2	2	1	1	2	2	2
7	Emergency	1	1	1	1	0	0	1	1	1
8	Travel in a poorly-served area	1	1	1	1	0	0	1	1	1
9	Carry heavy weight	1	1	1	1	0	0	1	1	1

②Non-transportation workers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	5	2	2	5	5	5
2	Commuting from work or education	5	5	5	5	2	2	5	5	5
3	Business travel	5	5	5	5	2	2	5	5	5
4	Leisure	5	5	5	5	2	2	5	5	5
5	Shopping	5	5	5	5	2	2	5	5	5
6	Accompanying others	5	5	5	5	2	2	5	5	5
7	Emergency	2	2	2	2	1	1	2	2	2
8	Travel in a poorly-served area	2	2	2	2	1	1	2	2	2
9	Carry heavy weight	2	2	2	2	1	1	2	2	2

③Students

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	5	2	2	5	5	5
2	Commuting from work or education	5	5	5	5	2	2	5	5	5
3	Business travel	5	5	5	5	2	2	5	5	5
4	Leisure	5	5	5	5	2	2	5	5	5
5	Shopping	5	5	5	5	2	2	5	5	5
6	Accompanying others	5	5	5	5	2	2	5	5	5
7	Emergency	2	2	2	2	1	1	2	2	2
8	Travel in a poorly-served area	2	2	2	2	1	1	2	2	2
9	Carry heavy weight	2	2	2	2	1	1	2	2	2

④Children and young travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	5	2	2	5	5	5
2	Commuting from work or education	5	5	5	5	2	2	5	5	5
3	Business travel	5	5	5	5	2	2	5	5	5
4	Leisure	5	5	5	5	2	2	5	5	5
5	Shopping	5	5	5	5	2	2	5	5	5
6	Accompanying others	5	5	5	5	2	2	5	5	5
7	Emergency	2	2	2	2	1	1	2	2	2
8	Travel in a poorly-served area	2	2	2	2	1	1	2	2	2
9	Carry heavy weight	2	2	2	2	1	1	2	2	2

⑤Elderly travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	5	2	2	5	5	5
2	Commuting from work or education	5	5	5	5	2	2	5	5	5
3	Business travel	5	5	5	5	2	2	5	5	5
4	Leisure	5	5	5	5	2	2	5	5	5
5	Shopping	5	5	5	5	2	2	5	5	5
6	Accompanying others	5	5	5	5	2	2	5	5	5
7	Emergency	2	2	2	2	1	1	2	2	2
8	Travel in a poorly-served area	2	2	2	2	1	1	2	2	2
9	Carry heavy weight	2	2	2	2	1	1	2	2	2

⑥Disabled travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	5	2	2	5	5	5
2	Commuting from work or education	5	5	5	5	2	2	5	5	5
3	Business travel	5	5	5	5	2	2	5	5	5
4	Leisure	5	5	5	5	2	2	5	5	5
5	Shopping	5	5	5	5	2	2	5	5	5
6	Accompanying others	5	5	5	5	2	2	5	5	5
7	Emergency	2	2	2	2	1	1	2	2	2
8	Travel in a poorly-served area	2	2	2	2	1	1	2	2	2
9	Carry heavy weight	2	2	2	2	1	1	2	2	2

⑦Tourists

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	5	2	2	5	5	5
2	Commuting from work or education	5	5	5	5	2	2	5	5	5
3	Business travel	5	5	5	5	2	2	5	5	5
4	Leisure	5	5	5	5	2	2	5	5	5
5	Shopping	5	5	5	5	2	2	5	5	5
6	Accompanying others	5	5	5	5	2	2	5	5	5
7	Emergency	2	2	2	2	1	1	2	2	2
8	Travel in a poorly-served area	2	2	2	2	1	1	2	2	2
9	Carry heavy weight	2	2	2	2	1	1	2	2	2

⑧Short-term visitors

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	5	5	5	5	2	2	5	5	5
2	Commuting from work or education	5	5	5	5	2	2	5	5	5
3	Business travel	5	5	5	5	2	2	5	5	5
4	Leisure	5	5	5	5	2	2	5	5	5
5	Shopping	5	5	5	5	2	2	5	5	5
6	Accompanying others	5	5	5	5	2	2	5	5	5
7	Emergency	2	2	2	2	1	1	2	2	2
8	Travel in a poorly-served area	2	2	2	2	1	1	2	2	2
9	Carry heavy weight	2	2	2	2	1	1	2	2	2

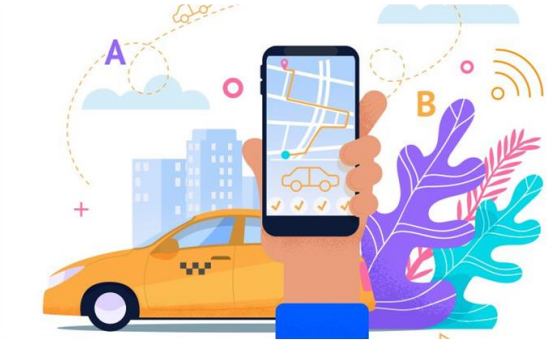
⑨Passing travelers

		1	2	3	4	5	6	7	8	9
		Waste of time	Lack of comfort	Risk of increasing the tiredness	Lack of safety	Loss of public space	High infrastructure maintenance costs	Bad air quality	Noise	CO2 emissions
1	Commuting to work or education	2	2	2	2	1	1	2	2	2
2	Commuting from work or education	2	2	2	2	1	1	2	2	2
3	Business travel	2	2	2	2	1	1	2	2	2
4	Leisure	2	2	2	2	1	1	2	2	2
5	Shopping	2	2	2	2	1	1	2	2	2
6	Accompanying others	2	2	2	2	1	1	2	2	2
7	Emergency	1	1	1	1	0	0	1	1	1
8	Travel in a poorly-served area	1	1	1	1	0	0	1	1	1
9	Carry heavy weight	1	1	1	1	0	0	1	1	1

Appendix H: Game props of the RID serious game

1. Company cards

MOBICOMPANION



You are developing user-friendly IT solutions to help people find the best mobility solutions to move in the city in all situations freely. You have knowledge in machine learning and data analytics and have access to citizens' aggregated mobility data (with respect to privacy). Because you are conscious of contemporary environmental issues, you wish to promote less impacting solutions and active modes as much as possible.

Initial budget 50

50

Initial knowledge & skills

IS 1 9

DK 20 25

MOB&PARK

You are convinced by the potential of the collaborative economy to help citizens solve their parking issues in every city at an affordable price. You are also concerned by the fact that many private parking spaces (hotels, residences, etc.) are underutilized most of the time. You are providing solutions to offer shared parking spaces in big cities.

Initial budget 50

50

Initial knowledge & skills

IS 4 6

DK 1 26

MOBISHUTTLE

You are a company that offers transportation services (for people and goods) based on the shuttles that navigate autonomously at sub-50 km/h speeds along predetermined, learned paths. You are committed to providing passengers with a comfortable and safe travel experience. Sustainable mobility is your business philosophy.

Initial budget 50

50

Initial knowledge & skills

IS 8 11

DK 5 21

MOBINSURANCE

You are concerned by road security but also with people's physical and psychological health, as well as social well-being. Dealing with the insurance of motorized modes (car, motorbikes, etc.) for your policyholders has revealed the urge to be involved in innovative mobility projects for urban citizens.

Initial budget 45

45

Initial knowledge & skills

IS 3 12

DK 18 29

2. Deep knowledge cards

Cars and parking spaces

1

The car is stationary 23 hours a day on average … this means every car uses an average of 8 parking spaces. This is not a sustainable way of using the city.

--- People A

Rewards

Up	1	Us	1	P	1

Problems encountered when taking buses

2

- If you are not a frequent user, if you don't know how to use a smartphone to have the transport app or if you are a tourist using only Wi-Fi, you won't be able to know where the bus goes or where is the best stop to get off and get your destination.
- Some buses have stairs to get the back part. It is dangerous for kids and aged people.
- Only the driver can open back doors and sometimes they forget, either because they are watching if people who get inside are paying or they don't listen to the bell.

--- People B

Rewards

Up	2	Us	1	P	1

Problems encountered when taking public transportation

3

As an environmentalist, I basically don't use cars in my daily life. Whether commuting to work or sending my children to school, I use public transportation. On weekends, I will ride my bike for shopping or entertainment. Although I am keen to use public transportation, sometimes I do encounter some annoying problems:

- At rush hour, the subway is too crowded, and there are not enough seats. This is a nightmare for me, who has just worked all day.
- Occasionally, there will be an unpleasant smell on the subway.
- When I take the bus, it will take a lot of time if I encounter a traffic jam.

--- People C

Rewards

Up	1	Us	2	P	2

Dream city in terms of mobility

4

It is a city accessible to every user, to every person: from the age of 8 to 80, someone who has mobility problems, someone who can move easily or someone who is laden with luggage.

--- People D

Rewards

Up	1	Us	1	P	1

Unpunctual bus

5

I needed to attend an important meeting this morning, but the bus did not arrive at my departure station following the stipulated time. I had to call a taxi in a hurry. Fortunately, I arrived at the company on time. It was the third time I have encountered the same problem this month.

--- People E

Rewards

Up	1	Us	1	P	1

Difficulties of a suburban resident

6

I live in the suburbs and work in the city center. Every morning I need to walk for 45 min to the nearest railway station and then take a suburban train for half an hour to reach the company. If there is a bus to the railway station near my house, I won't have to get up early and get tired before working.

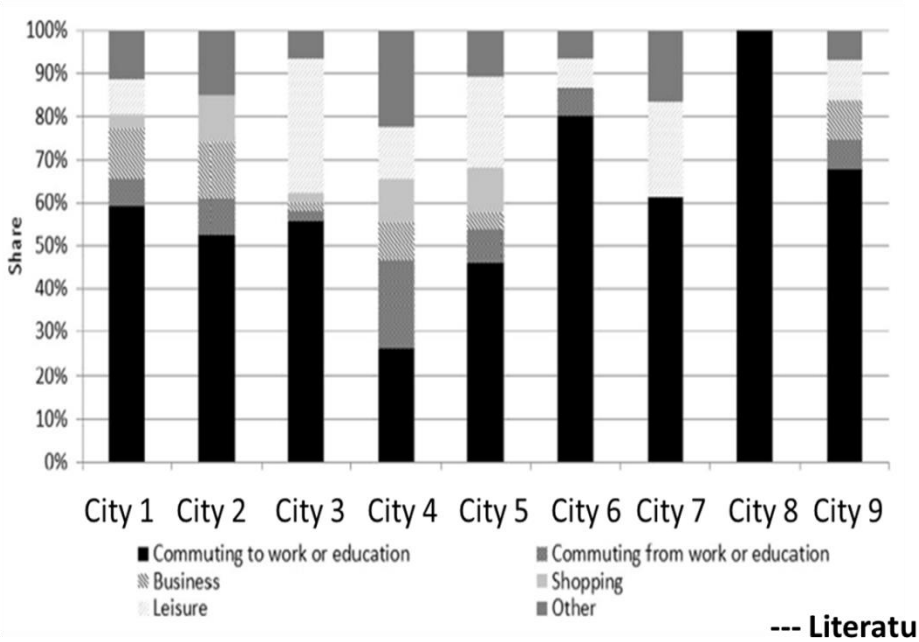
--- People F

Rewards

Up	1	Us	1	P	1

Trip purposes of people in big cities

7



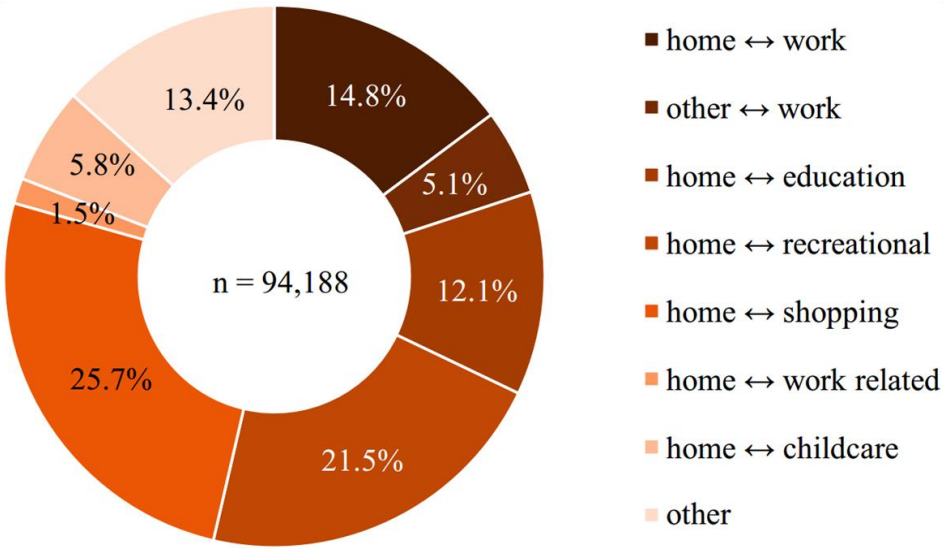
--- Literature C

Rewards

Up 0 Us 5 P 0

Trip purposes of local people

8



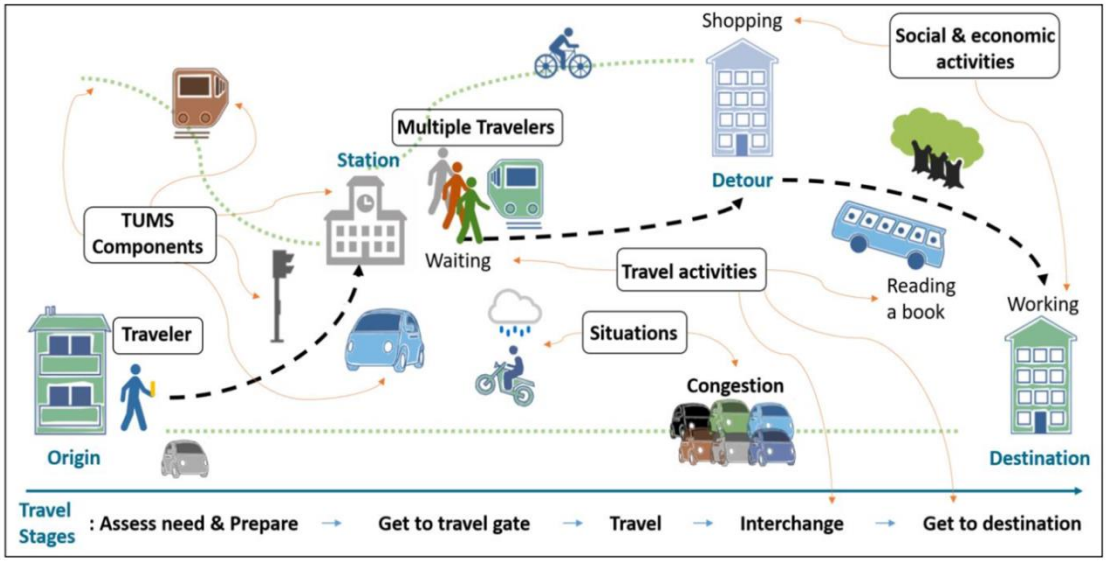
--- Literature E

Rewards

Up 1 Us 5 P 0

The door to door travel experience

9



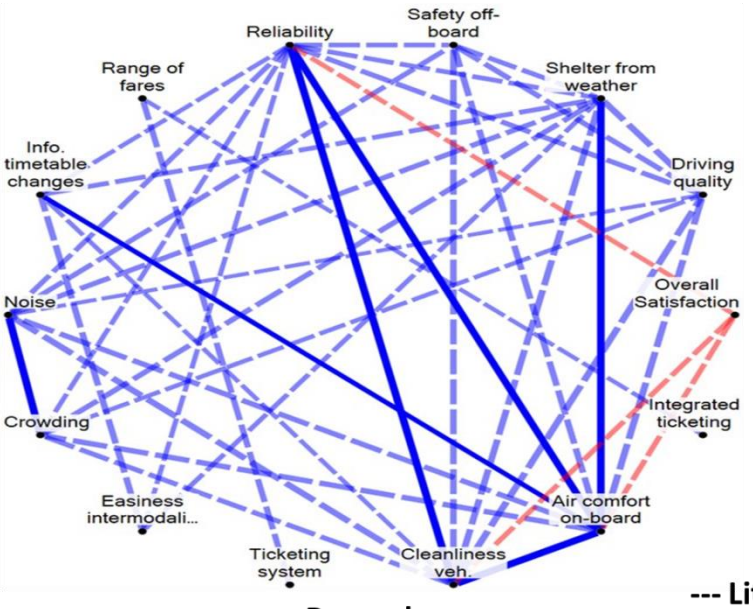
--- Literature B

Rewards

Up 2 Us 4 P 1

Cross-correlations among travel experience aspects and overall satisfaction (public transport)

10



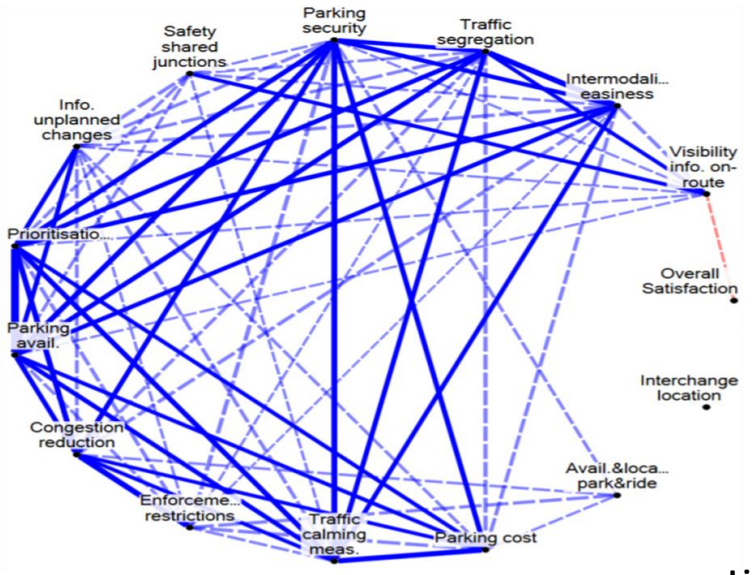
--- Literature C

Rewards

Up 0 Us 0 P 3

Cross-correlations among travel experience aspects and overall satisfaction (private car)

11



--- Literature C

Rewards

Up 0 Us 0 P 2

Summary of the salient characteristics of different traveler groups

12

Group	Special characteristics	Key factors
Full-time employed workers	Regularly incur more temporal constraints than monetary expenditure	Punctuality, reliability, cost
Female travelers	Travel shy, reassurance seeker and cautious planner. Complex scheduling of activities in terms of both time and space and is likely to bring additional bags.	Safe, reliable, affordable and comprehensive access
Parents with small children	More women than men, traveling with buggies and bags	Accessible vehicle and station, onboard space and supportive attitudes
Low income travelers	Tend to be captive to the cheapest mode alternative and spend a significant proportion of income on travel	Availability, adequacy, cost and safety
Children and young travelers	Smaller children highly dependent on their parents' decisions and preferences. For many young teens, travel represents a gateway to adulthood, enabling independence, socialization and a recognition of maturity	Practicalities (such as cost and speed of journey), flexibility and safety
Elderly travelers	Tend to have more limited ability and strength to move. The feeling of being able to travel independently is closely linked with a sense of self-worth. They have increased difficulty in identifying signs, in reading timetables, listening to loudspeakers and responding	Physical and emotional barriers, affordability, flexibility, reliability and support facilities
Disabled travelers	Have physical or mental impairment which has a substantial and long-term adverse effect on their ability to travel. Lack confidence when traveling, experience a lack of flexibility in their travel choices and difficult to be spontaneous	Physical accessibility and availability, support facilities (including information availability), cost, certainty and security and supportive attitudes
Tourists and unfamiliar travelers	Suffer lost-in-translation problem. Have high mobility needs, but limited spatial and linguistic knowledge	A simpler system, more information provision and more helpful and tolerant staff

--- Literature C

Rewards

Up 5 Us 0 P 2

Travel experience determinants of satisfaction

13

Variables	Women	Youth (−24)	Disabled	Low income or unemployed	All travelers
Public transport					
Station environment		+++	NA	+++	(+)
Waiting safety	+++				
Ease of transfer					+++
Frequency	+++	+++			
Onboard comfort					(+)
Travel time reliability	+++	+++		+++	
Number of Trip Stages					(+)
Main trip stage					(+)
Car					
Reliability	(+)	NA	NA	NA	
Relative time					+++
Safety	+++				+++
Parking price	+++				
Bicycle					
Prioritized on the street		+++	NA		
Absence of hindrances					+++
Ride quality	+++			+++	
Information					+++
Walking					
Proper design		+++		(+)	
Absence of hindrances	+++	(+)		+++	+++
Smoothness		(+)		+++	

(+) Marginally significant at the 90–95% level.
+++ Significant at the 99% level.
NA – not applicable due to a low number of observations.

--- Literature C

Rewards

Up **4** Us **0** P **1**

Traveler centered urban mobility performance system

14

Value	Description
Travel time	Reducing travel time (includes service and vehicle speed)
Travel price	Reducing price, fair price
Physical comfort	Enhancing the comfort of the body
Sensorial comfort	Enhancing the comfort of the senses
Cognitive comfort	Improving psychological comfort (ease of use, travelers interactions, information)
Temporal availability	Increasing frequency of the travel mean and make it available out of peak hours
Spatial availability	Improving access to underserved regions
Safety/security	Reducing the risk of injuries (caused either by material of people)
Improvement of travel activities	Enhancing travel activities

--- Literature B

Rewards

Up **0** Us **0** P **3**

Potential sources of travel problems

15

Sources	Categories	Sub-categories	Code	Instances
Technical	Physical	Essential	TPE	Few seats in the bus, shaky railroad, no shelter at the bus stop, non-adjustable car seat, hilly city
		Accidental	TPA	Frozen and slippery ground, broken/cold seats, wagon overheated, door blocked
	Functional	Essential	TFE	20-min gap between two trains
		Accidental	TFA	Train late/cancelled, screen shows wrong information, train terminates before destination, portico out of order
Personal	State	Physical	PSP	Sick, with huge luggage, tired, in a wheelchair, pregnant, blind, deaf
		Emotional	PSE	Stressed, angry, surprised, disgusted
		Cognitive	PSC	Lost, confused, unable to read
	(Re)action		PA	Wait, find alternative, inform colleagues, get slowed down, slip/fall, hit pedestrians, sweat
Contextual	Weather		CW	Rain, cold, wind, sun, hot
	Behaviour of fellow travellers or the system's agents		CUB	Smoking, not respecting the queue, brusque movement in a shared lane, drivers shouting, disagreeable agent
Activity-related	Simultaneous use		CSU	Crowds, queues, no parking places left, congestion, cycling with pedestrians
	Condition		AC	Arrival time obligations (meeting), need to arrive in good condition, no parking spaces, no showers
	Effect		AE	Arrive late, miss flight, stressed at work, delay/cancel tasks

--- Literature B

Rewards

Up **2** Us **3** P **3**

Placing transport workers on the agenda

16

Transport workers are conspicuously absent from both mobilities and urban studies literature. First, transport workers, primarily drivers, are disregarded mainly in mobilities and urban transport research. Second, the literature we find on transport workers remains outside recent and ongoing debates in critical urban transport studies.

--- Literature A

Rewards

Up **2** Us **0** P **1**

Limitations on mobility provision set by taxi drivers

17

Taxi drivers and operators set two types of limitations on mobility provision. First, they "cream-skim": offering services primarily in peak hours and limiting services at off-peak times and, more importantly, on low demand routes. Second, taxi drivers tend to avoid taking passengers eligible for reduced fares, such as pensioners or students, leading to continuous negotiation and conflict.

--- Literature A

Rewards

Up	3	Us	2	P	1

Vehicle noise

18

Noise pollution has been recognized as one of the significant hazards that impact the quality of life worldwide. Because of the rapid increase in technology, industrialization, urbanization, and other communication and transport systems, noise pollution has reached a disturbing level over the years, which needs to be studied and controlled to avoid different health effects like high blood pressure, sleeplessness, nausea, heart attack, depression, dizziness, headache, and induced hearing loss.

--- Literature D

Rewards

Up	0	Us	0	P	1

Attitudes of citizens towards urban mobility

19

• Half of citizens use a car everyday (50%) which is more than the proportion who cycle (12%) or use public transport (16%) combined.

• Around four in ten citizens encounter problems when travelling within cities (38%).

• A substantial majority of citizens believe that air pollution (81%), road congestion (76%), travelling costs (74%), accidents (73%) and noise pollution (72%) are important problems within cities.

--- Literature F

Rewards

Up	0	Us	1	P	2

Surge in tourism

20

Because of the Olympic Games, the city is expected to welcome 1.5 million international tourists this summer. The local government needs to increase the quality and capacity of the public transportation system to meet tourists' needs.

--- Website A

Rewards

Up	2	Us	0	P	1

Phase-out of fossil fuel vehicles

21

Halve the use of “conventionally-fuelled” cars in urban transport by 2030; phase them out in cities by 2050; achieve essentially CO2-free city logistics in major urban centers by 2030.

--- Website B

Rewards

Up	0	Us	0	P	1

Maintenance of public transport infrastructure

22

Urban transport infrastructure requires regular maintenance, which requires a lot of money. Delayed maintenance is relatively common since it conveys the benefit of keeping current costs low, but at the expense of higher future costs and, on some occasions, the risk of infrastructure failure. The more extensive the road and highway network, the higher the maintenance cost and its financial burden.

--- Website C

Rewards

Up	0	Us	0	P	1

Air pollution caused by cars

23

For many people, their biggest exposure to daily air pollution comes while they are driving their car. Air quality inside a car can be significantly affected by heavy stop and start traffic and over the course of a long drive, a car can accumulate levels of particulate matter (PM2.5 and NO2) that are unhealthy to breathe.

--- Website D

Rewards

Up	0	Us	0	P	1

Car Emissions & Global Warming

24

Car pollution is one of the major causes of global warming. Cars and trucks emit carbon dioxide and other greenhouse gases, contributing one-fifth of the world's total global warming pollution. Greenhouse gases trap heat in the atmosphere, which causes worldwide temperatures to rise.

--- Website E

Rewards

Up	0	Us	0	P	1

25

Photo taken at the central subway station at 8 am on a normal weekday

Rewards

Up	1	Us	1	P	1

26

Photo taken at an urban arterial road at 9 am on a normal weekday

Rewards

Up	0	Us	1	P	1

Travel with heavy luggage

27

Rewards

Up 1 Us 1 P 1

Crime rates rise during peak travel times

28

Rewards

Up 1 Us 1 P 1

29

An ambulance was involved in an accident while transporting emergency patients

Rewards

Up 1 Us 1 P 1

30

E-scooters are a new type of transportation that office workers like

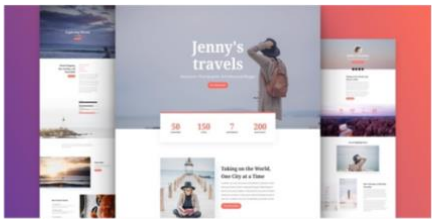
Rewards

Up 1 Us 1 P 1

3. Investigation strategy cards

Visit blogs

1



To visit online journals or informational websites (suburb trains, metro lines, cyclers...) that tell stories of travelers.

Cost 5
10

Access to DK

Retrieve outcomes of national surveys

2

Urban Mobility Plans
National Approaches and Local Practice

To read the surveys on transport and mobility issues (household travel survey, global transport survey, etc.) conducted by institutions and extract useful information.

Cost 10
20

Access to DK

Retrieve focused report

3

To search and read dedicated reports on urban mobility issues, e.g., accidentology, gender studies, and mobility preferences.

Cost 15
15

Access to DK

Collect videos and photos

4

To collect videos and pictures that record people moving in the city to observe their interactions with different transportation modes indirectly.

Cost 5
5

Access to DK

Launch an online survey

5

A set of survey questions is sent out to a target sample, and the members of this sample can respond to the questions over the world wide web.

Cost 20
10

Access to DK

Observe people on the move for 3 days

6

Over three days, directly observe a specific group of people to understand how they naturally interact with transportation modes and the problems they encounter.

Cost 5
10

Access to DK

Interview people on the pavement

7

To interview pedestrians randomly with the help of prepared questions to obtain information about their mobility preferences, problems they encountered, and so on.

Cost 5
5

Access to DK

Interview people around you

8

To interview familiar people (relatives, neighbors, colleagues) to understand their travel stories.

Cost 0
5

Access to DK

Conduct in-depth interview with users

9

A type of qualitative research involving an unstructured personal interview with a single respondent, which usually lasts a long time and aims to understand one's travel experiences fully.

Cost 5
10

Access to DK

Benchmark competing products & services

10

To compare your company's products and services against a number of competitors in the urban mobility ecosystem using a set collection of metrics.

Cost 10
10

Access to DK

Visit professional exhibitions

11

To visit professional exhibitions on urban mobility can be related to these topics: shared mobility, smart city, e-mobility, etc.

Cost 10
5

Access to DK

Interview with experts

12

To interview senior practitioners or researchers in the urban mobility field to obtain more credible and comprehensive data.

Cost 10
10

Access to DK

Interview with associations of users

13

To interview the leaders of various urban mobility (cyclers, seniors, foot passengers) associations to understand the typical problems encountered by different users.

Cost 5

10

Access to DK

Conduct literature review

14

To collect information about how people move in the city and their problems by reading relevant scientific papers.

Cost 20

20

Access to DK

4. User profile cards

Transportation workers 1

Transportation workers have varied duties, from operating buses, car, trucks, trains, planes and boats to coordinating traffic and providing customer service. They may also transport material and products on roads, rails and waterways. They may encounter unique problems, e.g., conflict with passengers.

Unlocking cost Up **5**

Unlocking questions asked by the trainer

Non-transportation workers 2

Non-transportation workers refer to people who are not in the transportation industry. They demand punctual, low-cost, and efficient transportation.

Unlocking cost Up **5**

Unlocking questions asked by the trainer

Students 3

Students are people enrolled in schools or other educational institutions and under learning to acquire knowledge, develop professions, and achieve easy employment in a particular field. Students tend to move in groups, and their travel choices are flexible.

Unlocking cost Up **5**

Unlocking questions asked by the trainer

Children and young travelers 4

Smaller children (primary school students) are highly dependent on their parents' decisions and preferences. For teenagers, walking is the most common travel mode, followed by public transport and private cars.

Unlocking cost Up **5**

Unlocking questions asked by the trainer

Elderly travelers 5

Elderly travelers tend to have more limited ability and strength to move. The feeling of being able to travel independently is closely linked with a sense of self-worth. They have increased difficulty in identifying signs, in reading timetables, listening to loudspeakers and responding. They may use any kind of transportation. The elderly may encounter problems when using transportation means, which require mobile apps. For example, do not know how to unlock a self-service scooter.

Unlocking cost Up **5**

Unlocking questions asked by the trainer

Disabled travelers 6

Disabled people have a physical or mental impairment that has a substantial and long-term adverse effect on their travel ability. Lack of confidence when traveling, experience a lack of flexibility in their travel choices, and difficult to be spontaneous. People with physical impairment concern with the availability of facilities to assist their platform-crossing and boarding/alighting needs when choosing the mode of transport.

Unlocking cost Up **5**

Unlocking questions asked by the trainer

Tourists 7

Tourists' destinations are mainly scenic spots, they usually use public transportation.

Unlocking cost Up **5**

Unlocking questions asked by the trainer

Short-term visitors 8

Short-term visitors have business travel in a city for a few days. They may use public or private transportation.

Unlocking cost Up **5**

Unlocking questions asked by the trainer

Passing travelers 9

Passing travelers visit a city to participate in a particular event (e.g., concerts and exhibitions) and leave immediately after the event. They pay more attention to the punctuality and practicality of transportation.

Unlocking cost Up 5
Unlocking questions asked by the trainer

5. Usage situation cards

Commuting to work or education 1

Go to school/company from home or other places.

Unlocking cost Us 5
Unlocking questions asked by the trainer

Commuting from work or education 2

Return home from company or school.

Unlocking cost Us 5
Unlocking questions asked by the trainer

Business travel 3

Business travel happens occasionally. Workers travel from home to a temporary work place..

Unlocking cost Us 5
Unlocking questions asked by the trainer

Leisure 4

“Leisure travel” is travel in which the primary motivation is to take a vacation from everyday life. It is often a long-distance trip that usually happens on holidays.

Unlocking cost Us 5
Unlocking questions asked by the trainer

Shopping 5

The aim of “Shopping travel” is to buy products or services. It is often a short trip.

Unlocking cost Us 5
Unlocking questions asked by the trainer

Accompanying others 6

“Accompanying others” refers to transporting children to school and taking patients to the hospital. In this usage situation, the needs of the accompanying person will affect the choice of travel mode.

Unlocking cost Us 5
Unlocking questions asked by the trainer

Emergency 7

For some reasons, people need to move to a certain location in a short time. For example, being late soon. In this situation, people value the speed of travel very much.

Unlocking cost Us 5
Unlocking questions asked by the trainer

Travel in a poorly-served area 8

Travel in suburbs where there is little public transportation. People need to walk a long way to get to bus or subway stations.

Unlocking cost Us 5
Unlocking questions asked by the trainer

Carry heavy weight 9

Carry heavy cargo or luggage while moving. When taking the subway, pulling the suitcase all the time will increase passenger fatigue.

Unlocking cost Us 5
Unlocking questions asked by the trainer

6. Problem cards

Waste of time 1

Waste of time due to delay, traffic congestion; get in the wrong bus/subway, unable to buy tickets because of language barrier.

Unlocking cost P 5

Unlocking questions asked by the trainer

Lack of comfort 2

Crowded public transportation, broken/cold seats, foul smell, the temperature is too high or too low in the cabin, non-adjustable seats; poor driving skills will make users uncomfortable.

Unlocking cost P 5

Unlocking questions asked by the trainer

Increasing the tiredness 3

Few seats on the bus, long time to transfer, carry heavy objects, long waiting time will increase the tiredness.

Unlocking cost P 5

Unlocking questions asked by the trainer

Lack of safety 4

The congestion can generate drivers' violent behaviors (as social elements of a social-technical system). These bad behaviors may cause traffic accidents.

Unlocking cost P 5
Unlocking questions asked by the trainer

Loss of public space 5

Most roads are publicly owned and free of access. Increased traffic has adverse impacts on public activities, which once crowded the streets such as markets, agoras, parades and processions, games, and community interactions. These have gradually disappeared to be replaced by automobiles.

Unlocking cost P 5
Unlocking questions asked by the trainer

High infrastructure maintenance costs 6

Cities facing the aging of their transport infrastructure have to assume growing maintenance costs as well as pressures to upgrade to more modern infrastructure.

Unlocking cost P 5
Unlocking questions asked by the trainer

Bad air quality 7

A car's exhaust emits hydrocarbons, which causes air pollution: NOx, small particles and other pollutants which are harmful to human health.

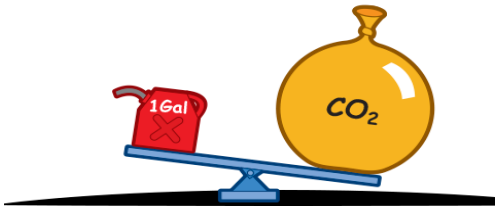
Unlocking cost P 5
Unlocking questions asked by the trainer

Noise 8

Transportation is one of the primary sources of noise pollution. High noise levels can contribute to cardiovascular effects in humans and an increased incidence of coronary artery disease.

Unlocking cost P 5
Unlocking questions asked by the trainer

CO2 emissions 9



Energy consumption and its related CO2 emissions by urban transportation have dramatically increased, and so the dependency on petroleum. Transport is estimated to be responsible for nearly a quarter of global energy-related CO2.

Unlocking cost P 5
Unlocking questions asked by the trainer

7. Existing solution cards

Subway 1

"Subway" refers to the underground rapid transit rail system. It makes the travel fast, secure and hassle-free.

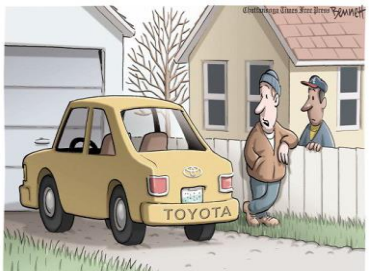
Bus 2

"Bus" consists of general buses and night buses. Traveling by bus is cheaper than owning and operating a car. It can also reduce air pollution and road congestion.

Suburban express train 3

A suburban express train connects the city and the suburbs. It is the most dependable mode of transport as it is the least affected by weather conditions such as rains, fog, etc.

Private car 4

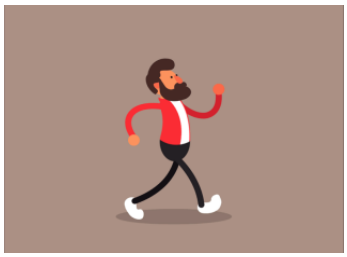


Private cars mean cars owned by individuals. The main advantage of owning a car is it gives freedom and comfort to travel.

Private bicycles 5

Bicycles improve health, ease congestion, save money, use less space, and provide efficient transportation with zero fuel consumption and zero carbon emissions.

Walk 6



Walking is the most environmentally friendly way of travel and does not cost money. However, it is only suitable for short-distance travel without heavy objects and it takes more time.

Electric car 7

An electric car is a car which is propelled by one or more electric motors, using energy stored in rechargeable batteries. Electric cars have several benefits over ICE cars, including a significant reduction of local air pollution.

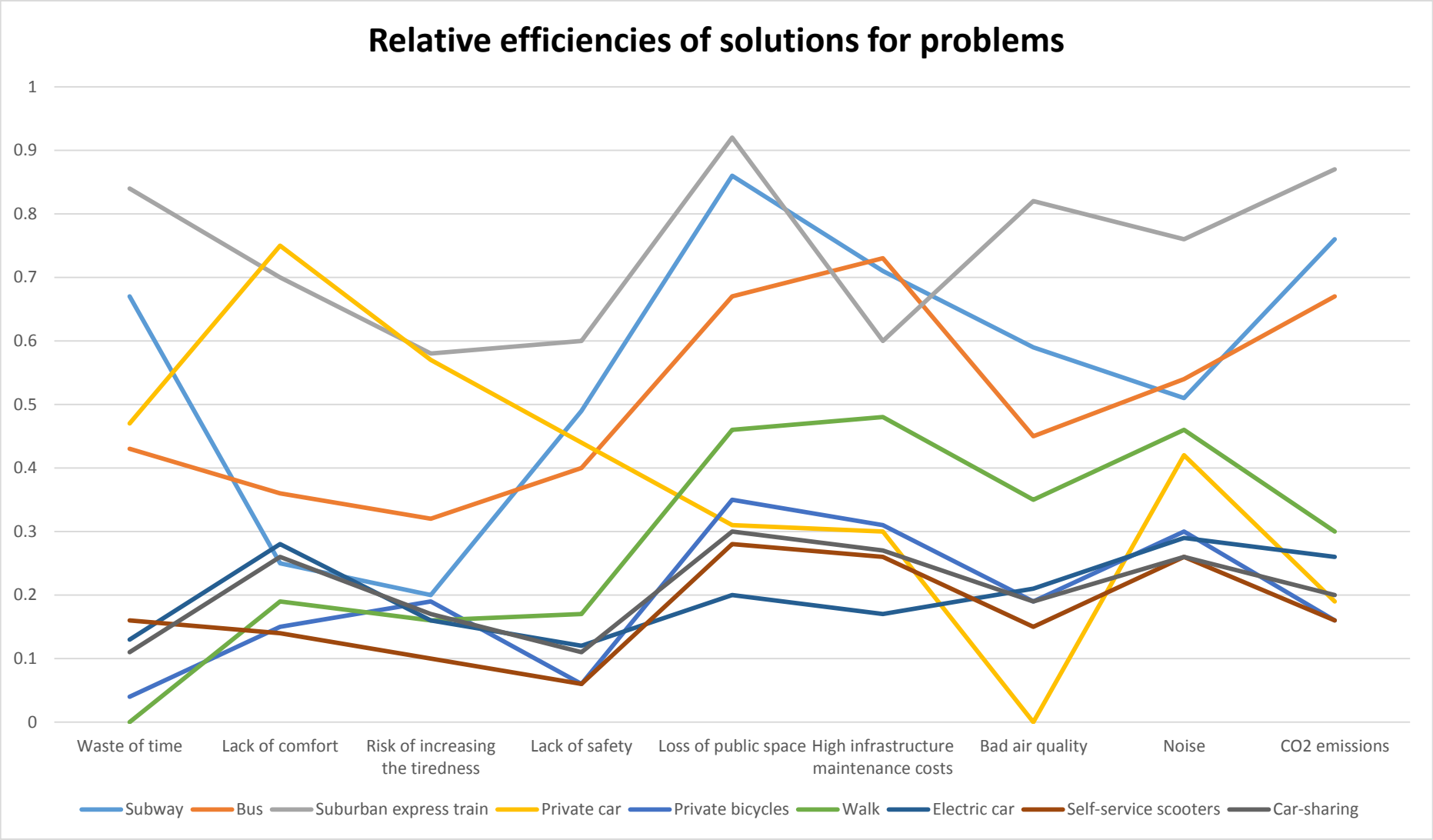
Self-service scooters 8

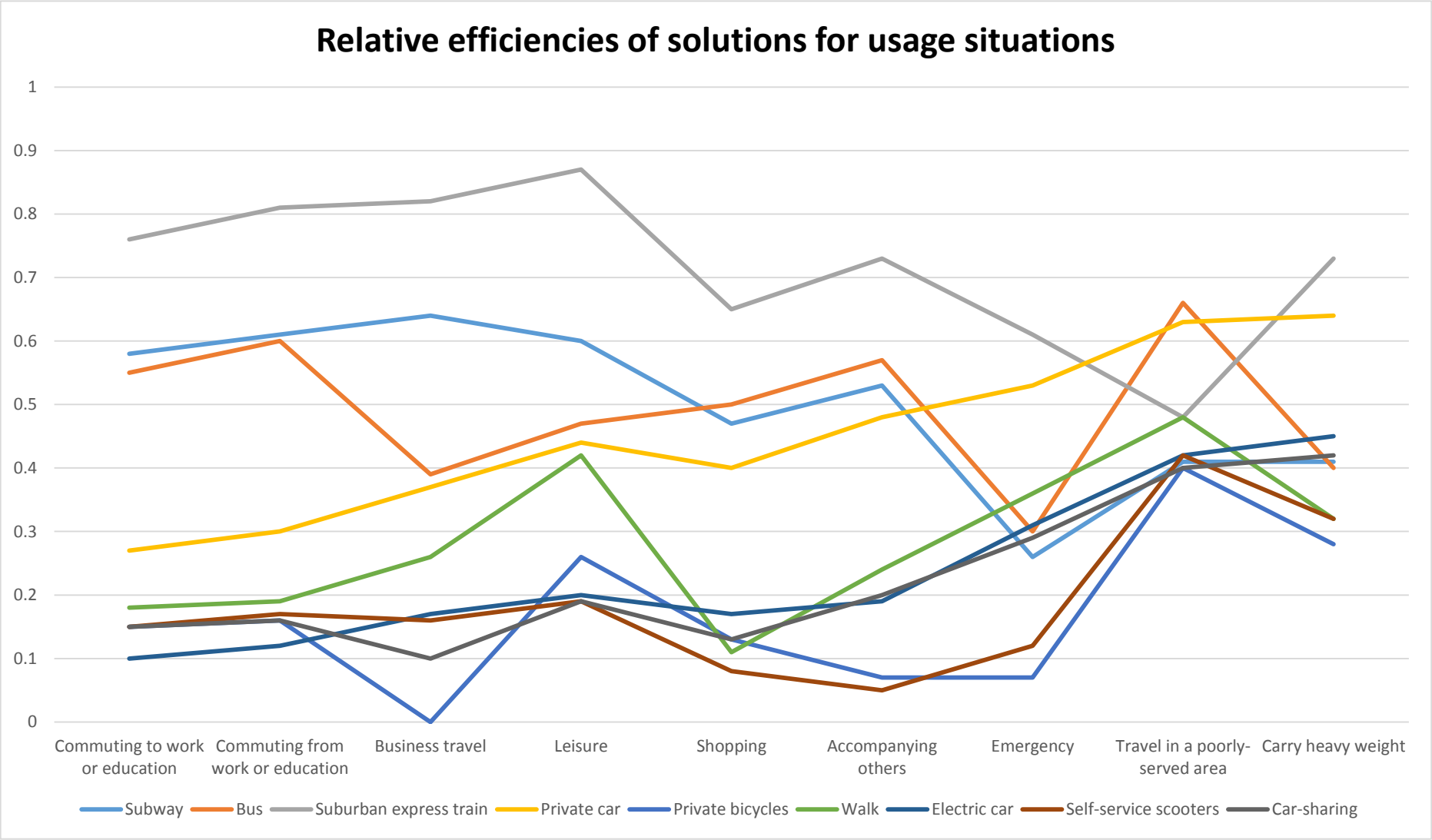
A Self-service scooter is a form of shared mobility and suitable for short-distance travel, at a low rental cost.

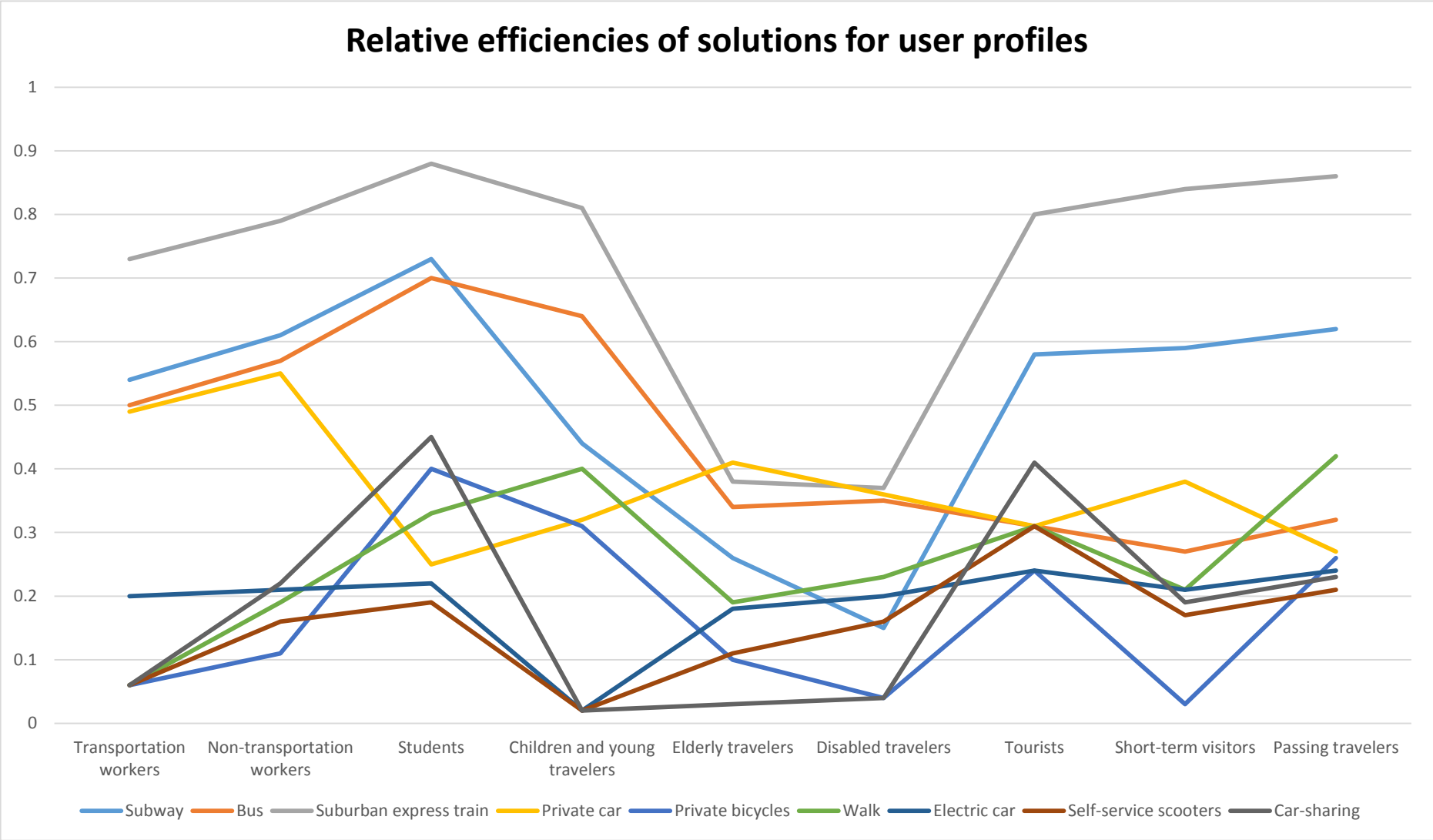
Car-sharing 9

“Car-sharing” allows a person to reserve a vehicle at any time, often for a short trip, without going via a third party. It enables users to benefit from a vehicle according to their needs, without paying the overall costs.

8. Efficiency profiles for the existing solutions




Relative efficiencies of solutions for usage situations
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Commuting to work or education
Commuting from work or education
Business travel
Leisure
Shopping
Accompanying others
Emergency
Travel in a poorly-served area
Carry heavy weight
Subway
Bus
Suburban express train
Private car
Private bicycles
Walk
Electric car
Self-service scooters
Car-sharing


Relative efficiencies of solutions for user profiles
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Transportation workers
Non-transportation workers
Students
Children and young travelers
Elderly travelers
Disabled travelers
Tourists
Short-term visitors
Passing travelers
Subway
Bus
Suburban express train
Private car
Private bicycles
Walk
Electric car
Self-service scooters
Car-sharing

9. Unlocking questions for the problems

P	DK	Q&A
① Waste of time	12, 13, 9, 14, 15, 10, 19, 3, 5	Q1: What can be the causes of this problem? (Congestion; Unpunctuality of public transportation) Q2: According to literature F, how many citizens think traffic congestion is an important issue? (76%)
② Lack of comfort	12, 13, 14, 15, 10, 3, 25	Q1: What can be the causes of this problem? (bad behaviors of other travelers or the system's agents; crowded; bad smell) Q2: Do the vast majority of travelers value onboard comfort when using public transportation? (Yes)
③ Risk of increasing the tiredness	12, 13, 15, 10, 3, 6, 27	Q1: What can be the causes of this problem? (Long walking distance to get the bus station; No seats; Waiting time to long; Travel with heavy luggage) Q2: Why are residents living in poorly-served areas more likely to have such a problem? (Long walking distance to get the bus/subway station)
④ Lack of safety	12, 13, 14, 15, 10, 11, 19, 2, 28, 29	Q1: According to literature C, which types of travelers concern more about safety? (Female travelers; Children) Q2: For children and the elderly, what are the potential safety hazards in buses? (Driver's poor driving skills; Stairs to get the back part; Broken seats)
⑤ Loss of public space	13, 1, 30	Q1: What can be the causes of this problem? (Randomly parked cars, electric scooters)
⑥ High infrastructure maintenance costs	22	Q1: What are the hidden dangers caused by delayed maintenance? (Expense of higher future costs and, on some occasions, the risk of infrastructure failure)
⑦ Bad air quality	23, 19	Q1: According to literature F, how many citizens think air pollution is an important issue? (81%) Q2: When are people most likely to be exposed to air pollution? Why? (Driving the car; NO2 and PM 2.5)
⑧ Noise	18, 19	Q1: According to literature F, how many citizens think noise pollution is an important issue? (72%) Q2: What are the health effects caused by noise pollution? (high blood pressure, sleeplessness, nausea, heart attack, depression, dizziness, headache, and induced hearing loss)
⑨ CO2 emissions	24	Q1: What are the effects of greenhouse gases produced by cars on global warming? (One-fifth of the world's total global warming pollution)

10. Unlocking questions for the user profiles

Up	DK	Q&A
① Transportation workers	16, 17	Q1: Based on the knowledge you have acquired, are transport workers valued in urban mobility research? (No) Q2: What kinds of limitations on mobility provision could be caused by transport workers? (Avoid taking passengers eligible for reduced fares; Limiting services at off-peak times)
② Non-transportation workers	12	Q1: What are the unique characteristics of non-transportation workers when traveling? (Regularly incur more temporal constraints than monetary expenditure) Q2: What are the key factors they concern when choosing a transport mode? (Punctuality, Reliability, Cost)
③ Students	7, 8	Q1: For students, is commuting to and from school the main purpose of travel? (Yes) Q2: According to the survey on travel purpose for locals, what percentage does "education" occupy? (12.1%)
④ Children and young travelers	12, 13, 2	Q1: What are the unique characteristics of children and young travelers? (Smaller children highly dependent on their parent' decisions and preferences) Q2: What are the key factors they concern when choosing a transport mode? (Practicalities, such as cost and speed of journey; flexibility; safety)
⑤ Elderly travelers	2, 12	Q1: What are the unique characteristics of elderly travelers? (Tend to have more limited ability and strength to move. They have increased difficulty in identifying signs, in reading timetables, etc.) Q2: What are the key factors they concern when choosing a transport mode? (Physical and emotional barriers, affordability, flexibility, reliability, and support facilities)
⑥ Disabled travelers	12, 13, 2	Q1: What are the unique characteristics of disabled travelers? (Have physical or mental impairment which has a long-term adverse effect on their ability to travel; Lack of flexibility in their travel choices) Q2: What are the key factors they concern when choosing a transport mode? (Physical accessibility and availability, support facilities, supportive attitudes, cost, and security)
⑦ Tourists	12, 13, 20	Q1: Compared with other travelers, what problem are tourists more likely to encounter? (Suffer lost-in-translation problem) Q2: According to website A's estimation, how many tourists will come to the city to watch Olympic Games? (1.5 million)
⑧ Short-term visitors	2, 12	Q1: How to relieve the difficulties encountered by short-term visitors when traveling? (A simpler system, more information provision, and more helpful and tolerant staff)
⑨ Passing travelers	2, 12	Q1: What difficulties might passing travelers encounter when taking the bus? (Won't be able to know where the bus goes or where is the best stop to get off and get your destination)

11. Unlocking questions for the usage situations

Us	DK	Q&A
① Commuting to work or education	7, 8, 15, 3, 25, 30	Q1: According to the survey on travel purpose for locals, what percentage does "work" occupy? (19.9%) Q2: For big cities, does "commuting to work or education" occupy a dominant position compared with other travel purposes? (Yes)
② Commuting from work or education	7, 8, 15, 3, 25, 30	Q1: After working all day, what problems might people encounter when riding the subway? (Increasing the tiredness; Time loss; Lack of comfort; Noise, Bad air quality)
③ Business travel	7, 8	Q1: According to the survey on travel purpose for locals, what percentage does "work related" occupy? (1.5%) Q2: According to literature C, are people in City 3 more likely to travel for business than for shopping? (No)
④ Leisure	7, 8, 15, 3, 28	Q1: According to the survey on travel purpose for locals, what percentage does "leisure" occupy? (21.5%) Q2: According to literature C, are people in City 4 more likely to travel for leisure than for business? (Yes)
⑤ Shopping	7, 8, 15	Q1: According to literature C, are people in City 1 more likely to travel for shopping than for leisure? (No) Q2: According to the survey on travel purpose for locals, what percentage does "shopping" occupy? (25.7%)
⑥ Accompanying others	7, 8, 15	Q1: According to the survey on travel purpose for locals, what percentage does "children care" occupy? (5.8%)
⑦ Emergency	7, 8, 29	Q1: What factors do people pay attention to when choosing transportation in an emergency? (Speed of the journey; Punctuality) Q2: Which situations can be considered emergency travel? (About to be late for work; Severely ill need to go to hospital)
⑧ Travel in a poorly-served area	6, 7, 8, 17	Q1: What problems are residents living in poorly-served areas more likely to have? (Risk of increasing the tiredness; Waste of time)
⑨ Carry heavy weight	7, 8, 15, 27	Q1: What problems might be encountered by travelers in this situation? (Risk of increasing the tiredness; Lack of safety)

Appendix I: Questionnaires results for the validation of the RID serious game

Pre-questionnaire for the experienced people

Pre-questionnaire for the validation of the RID serious game (Experienced people)

4 responses

Publish analytics

Could you please briefly describe your current work position or educational background?

4 responses

My last responsibilities were to manage the development of partnerships and the service offer of an association. I also advised entrepreneurs.

PhD Student at LGI

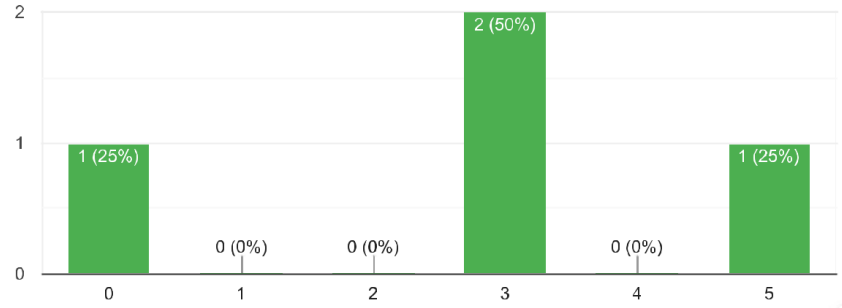
innovation consulting, ex Student OGI Centrale

Junior Researcher

How do you evaluate your expertise in the following methodologies (from 0 to 5)?

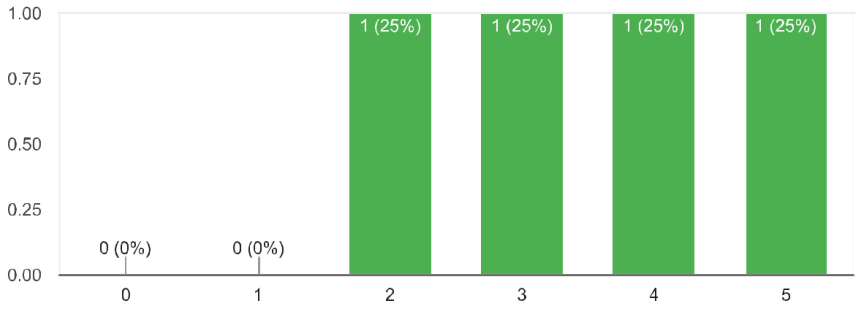
How do you evaluate your expertise in Design Thinking?

4 responses



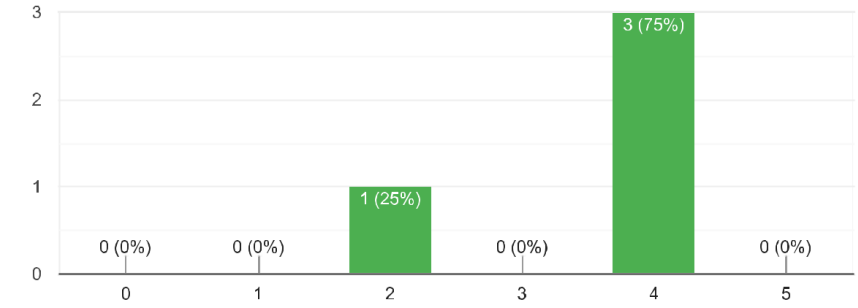
How do you evaluate your expertise in Creativity?

4 responses



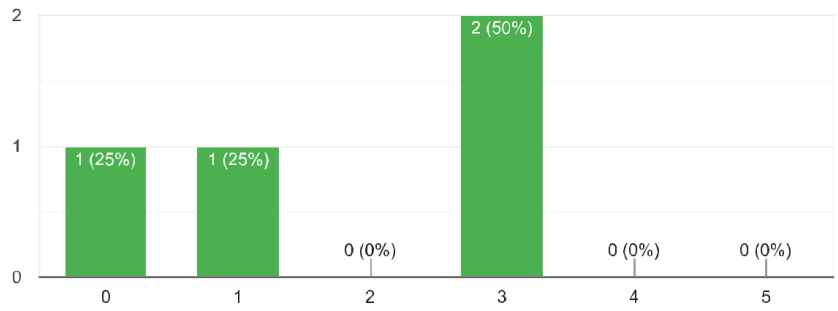
How do you evaluate your expertise in Project Management?

4 responses



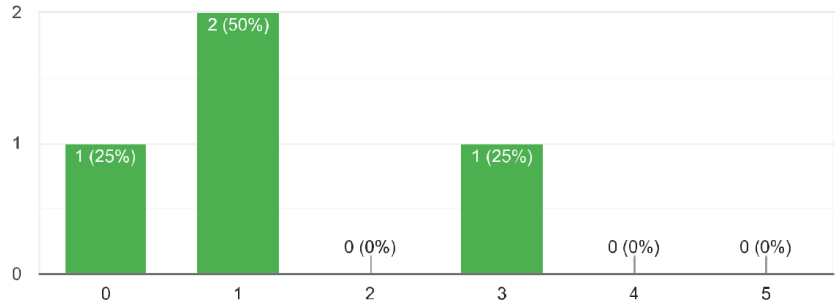
How do you evaluate your expertise in the C-K theory?

4 responses



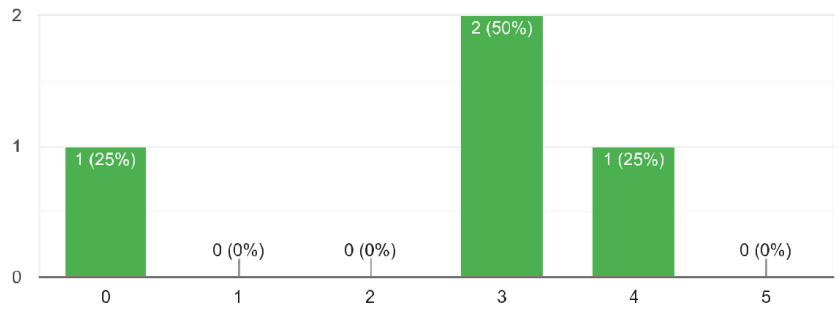
How do you evaluate your expertise in TRIZ?

4 responses



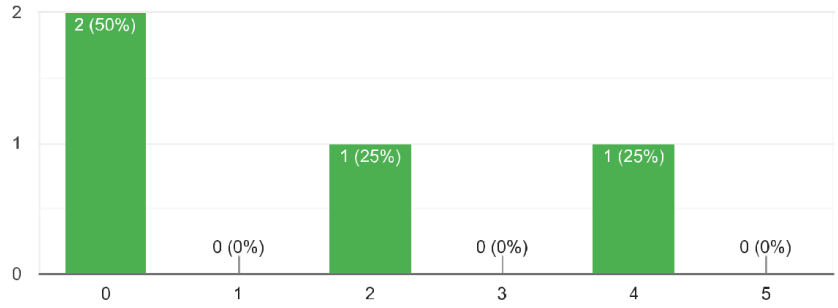
How do you evaluate your expertise in Blue Ocean Strategy?

4 responses



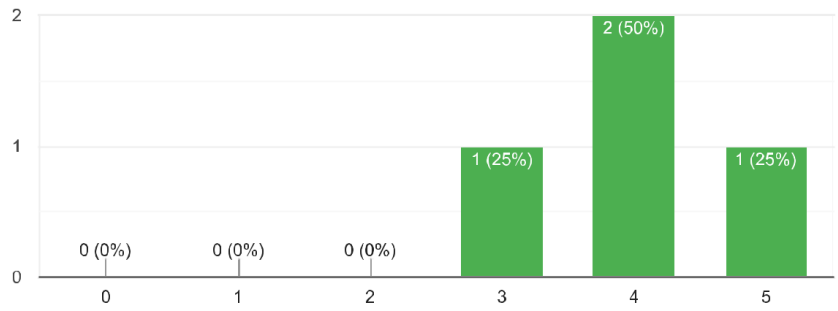
How do you evaluate your expertise in Lean Startup?

4 responses



How do you evaluate your expertise in Radical Innovation Design?

4 responses



When you think of RID, what are relevant words come to your mind? Please list them.

4 responses

Tool box / Process / Search / Uses / Differentiation / Capitalization

user-oriented, activity, usage, structuration of problems, opportunities for innovation

problem framing, pain points, usage situation, value bucket, frugality

Activity, PSO, innovation process, value bucket, ambition perimeter, utility, profitability, experimentation design, knowledge design

Have you participated in any innovation projects? If so, how many?

4 responses

I don't know... maybe between 100 and 150...

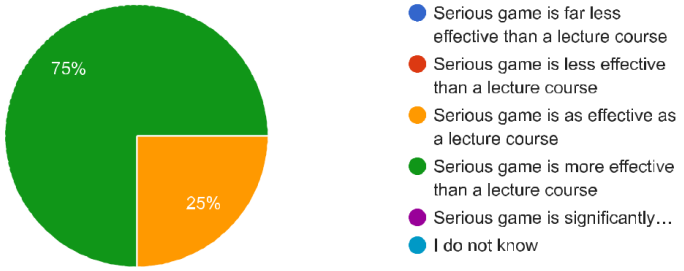
No

1

Yes, about approximately ten projects with varying size and importance.

Imagine if you are a beginner at RID, what are your perceptions of the effectiveness of two approaches for learning RID: a serious game and a lecture course?

4 responses



Can you justify your answer?

4 responses

Learning through serious play would be more involving than through a lecture course because I would be in action and in direct application.
But a lecture course is also interesting because it allows you to discover the concepts of the methodology and to understand the tools used.
Another important point is the trend of "serious game", some people think "It's a serious game, it's funny, it's for playing", although this game is called "serious game", sometimes it is not considered as a serious learning tool.

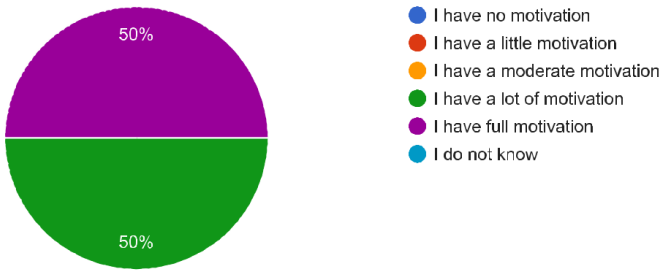
Depends on the profil of the person who learns RID but serious game is a relevant way of learning as you have a clear example of how it will work.

Participants are more involve in a serious game than a lecture course because it is more concrete

I think that the question is too simplistic. Comparing serious game and lecture course presentation cannot be decoupled from the targeted pedagogical scenario, the quality of both of them, the learning outcomes... However, learning through game can be more effective than a lecture course because it allows the learner to live an experience that makes him or her an actor in the learning process. The quality of

Imagine if you are a beginner of RID, how do you evaluate your motivation to learn it by playing the RID serious game?

4 responses



Do you have any comments or questions?

1 response

I don't know RID through a serious game, so I'm curious to discover it ! :)

Post-questionnaire for the experienced people

Post-questionnaire for the validation of the RID serious game (Experienced people)

4 responses

Publish analytics

Compared with your previous knowledge of RID, did you discover some new RID notions or gain some new insights during the game?

4 responses

I found the different RID notions that I knew. But thanks to the game, I discovered an important gain, it's to "manipulate" and "visualize" the different notions. It was very useful, it improves the understanding of the RID's mindset.

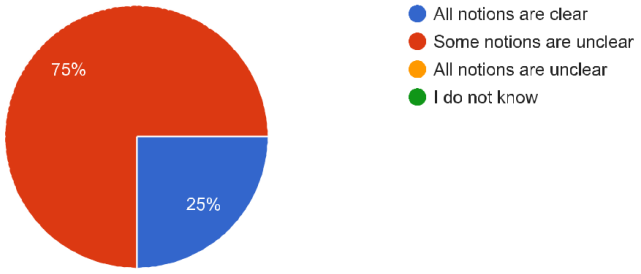
it was a good remember of the different steps of progression of RID methodology

Yes, about the usefulness and opportunity score

The game was an opportunity to practice the RID methodology in a more user-friendly way.

Do you think some RID notions (e.g., user profile, problem, usage situation, value bucket, etc.) in the game are difficult to understand for beginners?

4 responses



If you think some RID notions are unclear in the game, please list them and justify your answer.

4 responses

Beginners need more examples in their sector or usual issues to have more concrete understanding. "User profile", "User situation", etc. is very conceptual for beginners in innovation.

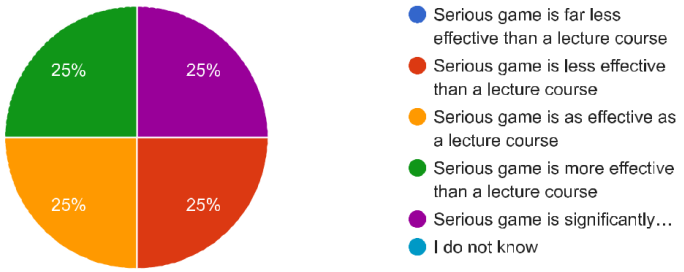
Maybe give a simple definition by Oral even if its alredy written on a paper

The notion of value bucket could be more explicit before entering the game as the objective of the first part of RID serious game

The presentation done just before the game by Bernard was sufficiently clear.

Imagine if you are a beginner at RID, what are your perceptions of the effectiveness of two approaches for learning RID: a serious game and a lecture course?

4 responses



Can you justify your answer?

4 responses

Serious game allows them to use and apply thanks to a use case, it isn't just learn a lecture course without participating. This give an active role, that's why it was more educational.

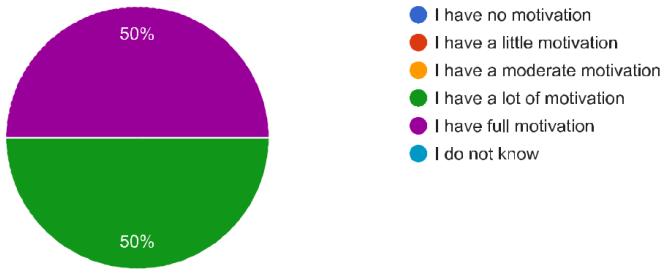
by practicing, you can easely imagine how to use it in reel conditions

I think they are borh complementary to each other, the course for the theory and the serious game for practice

RID introduces a number of concepts and a vision that is different from some methods of innovation. I'm not sure that a beginner is able to capture the spirit of the method through the serious game only.

What is your motivation when playing the RID serious game?

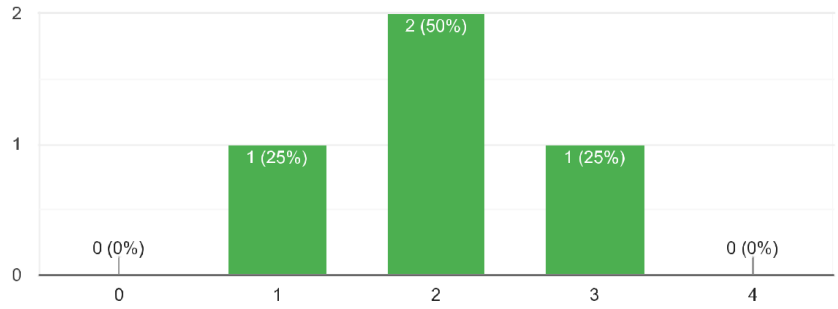
4 responses



Please indicate how you felt while playing the game for each of the items, on the following scale:

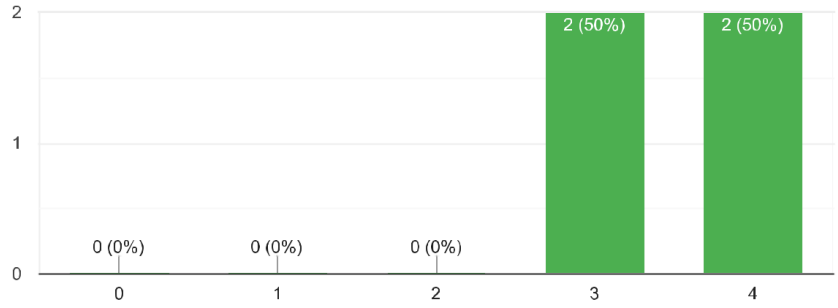
I felt skillful

4 responses



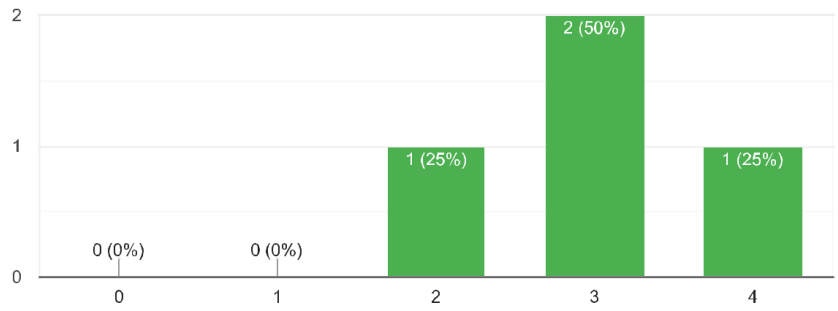
I was interested in the game's story

4 responses



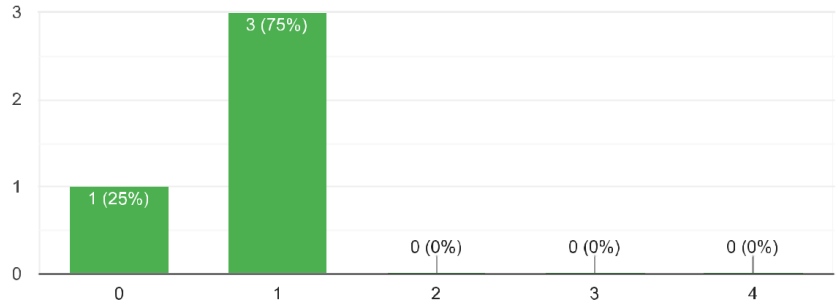
I thought it was fun

4 responses



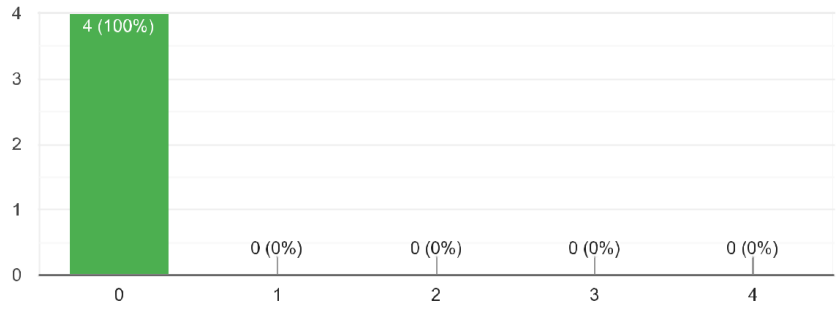
I thought about other things

4 responses



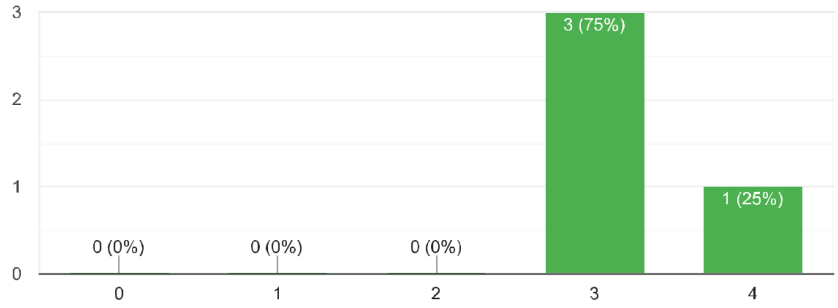
I felt bored

4 responses



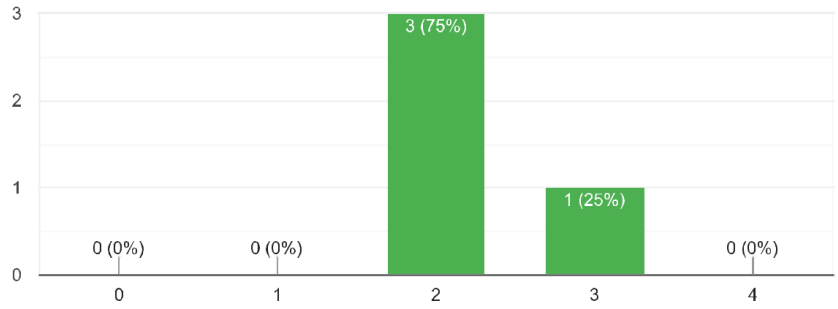
I enjoyed it

4 responses



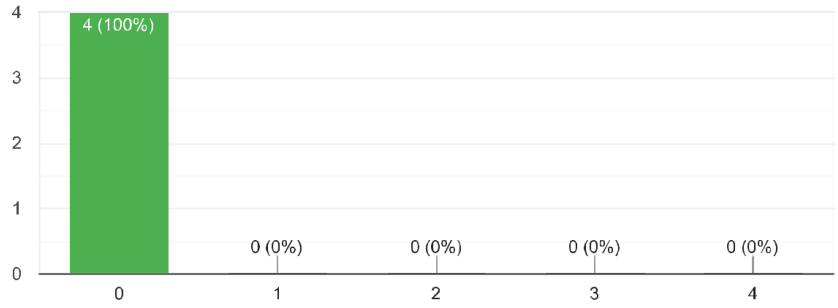
I was fast at reaching the game's targets

4 responses



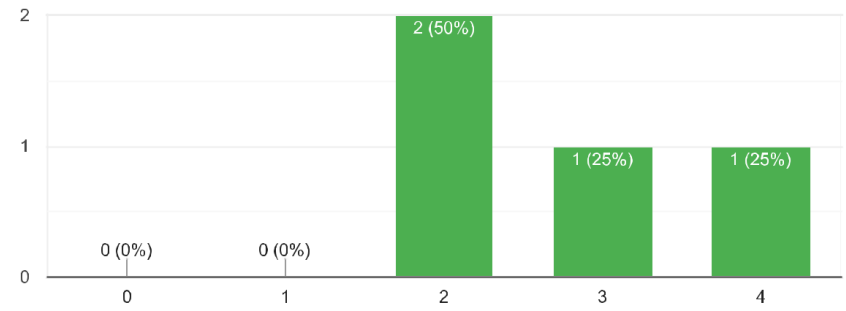
I felt annoyed

4 responses



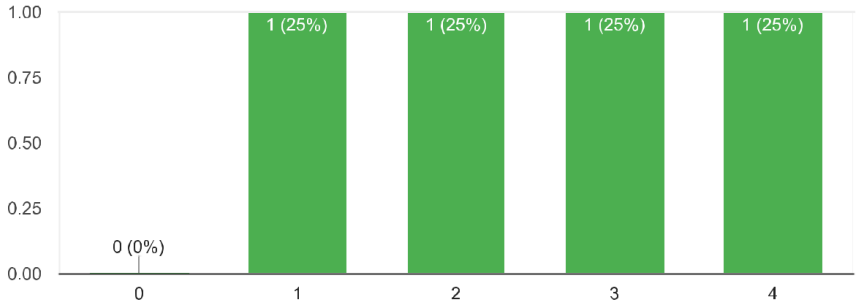
I lost track of time

4 responses



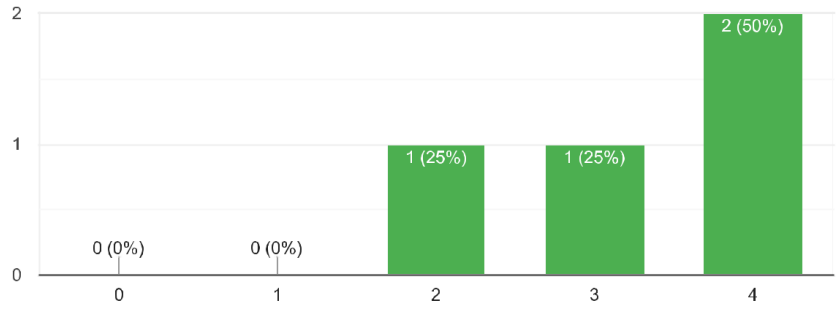
I felt challenged

4 responses



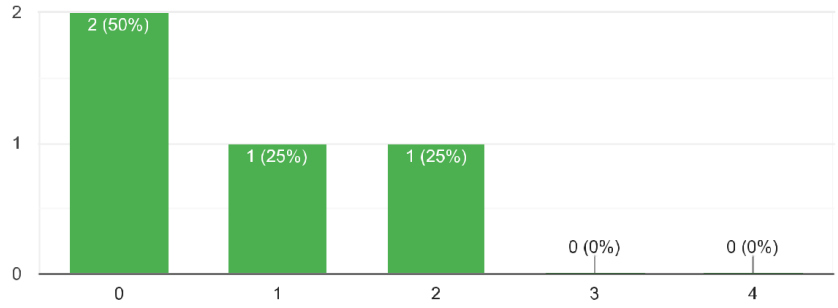
I was deeply concentrated on the game

4 responses



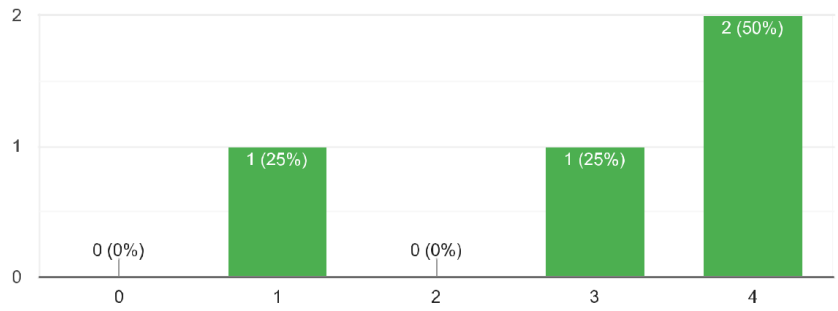
I felt frustrated

4 responses



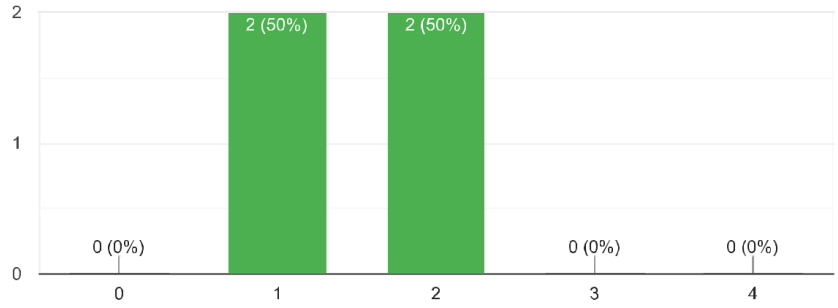
It felt like a rich experience

4 responses



I had to put a lot of effort into it

4 responses



What did you like the least during the game?

4 responses

Limited time, 3 or 4 hours would be better because we need time to understand the rules, the informations, etc.

we did'nt have the time to perfectly connect our mind from the game to RID methodology draw on the game table

The fact that it was not easy to read the cards and the mixing of the cards

I was troubled by the multitude of cards to manage at the same time.

What did you like the most during the game?

4 responses

The dynamics and popularization of a mode of reflection.

Innovation is driven by user experience and good knowledge about the usage situation, maybe the best way to solve a problem. We understand that design a solution whitout questions about user and usage is impossible, the solution will never fit and will not correctly give an aswer to a pain point

The teams work and exchange with the trainers; to answer questions to unlock cards so we have to actually learn on the subject; to use a serious game

The team work

Do you have any suggestions for improving the game?

4 responses

-> Simplify the rules or just give a big picture at the beginning, and explain more in details step by step.
-> Make the game board more useful (during the game to improve the praticality/use, after to understand and to keep a trace of the process).
-> Mark key milestones clearly and materialize them.
-> Customize the game owing to the users..., it's expensive and time consuming but it would be a way to further enhance ownership and commitment.
-> Present a more concrete deliverable (content and form).

Paper support can be "graphicaly" improve. Ex : the support to represent the value buckets is not the reel modelisation of RID's value buckets. A bit of data visualisation but great job ! Very good game !

To number the DK cards on both sides; to add a pawn that represents the advancement of the company on the board; to represent the budget and the time spent compared to something because we don't know what "50" means in reality compared to the total budget or time of the company.

I think there is potential to improve the game by working on the form.

Pre-questionnaire for the beginners

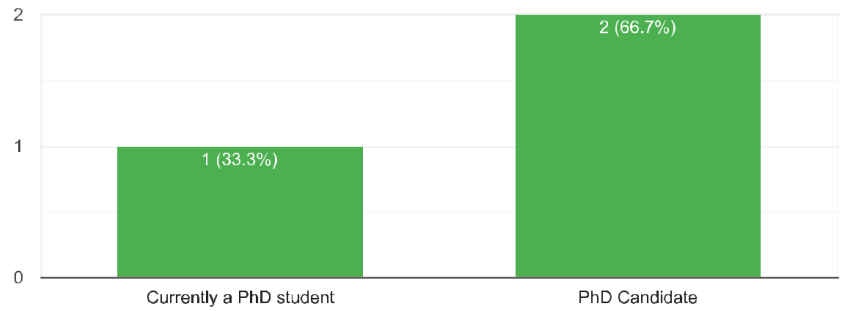
Pre-questionnaire for the validation of the RID serious game (Beginners)

3 responses

Publish analytics

Could you please briefly describe your current work position or educational background?

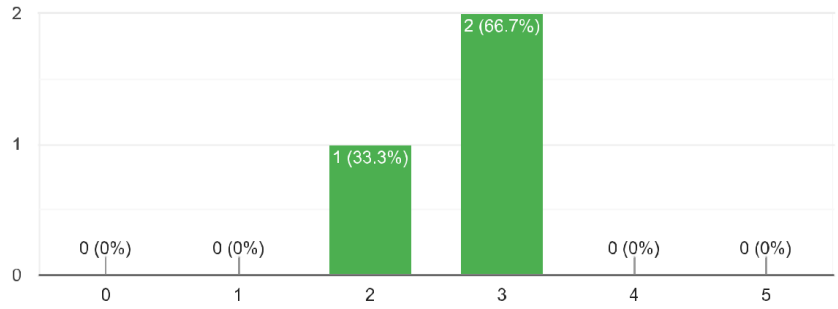
3 responses



How do you evaluate your expertise in the following methodologies (from 0 to 5)?

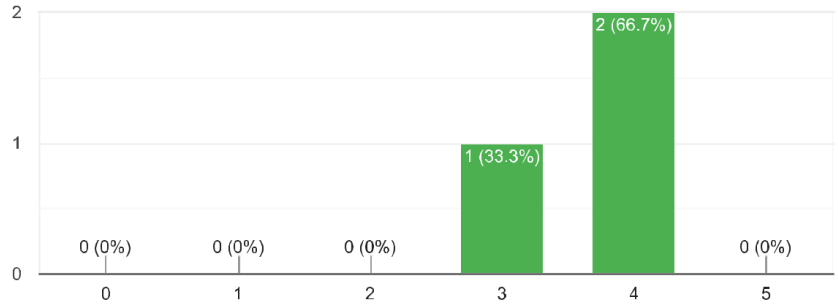
How do you evaluate your expertise in Design Thinking?

3 responses



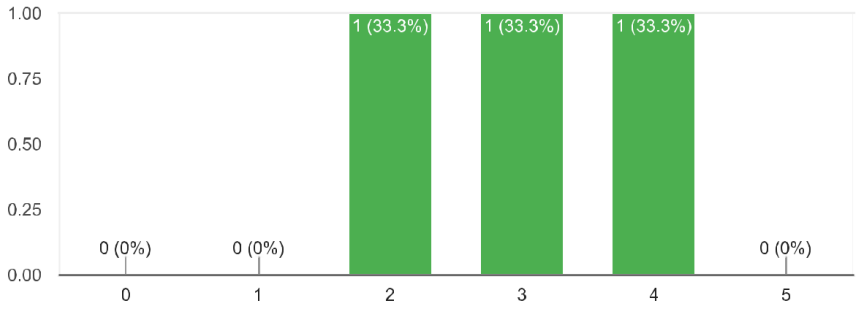
How do you evaluate your expertise in Creativity?

3 responses



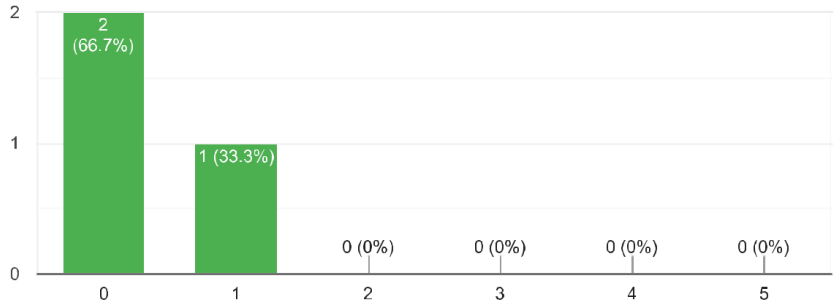
How do you evaluate your expertise in Project Management?

3 responses



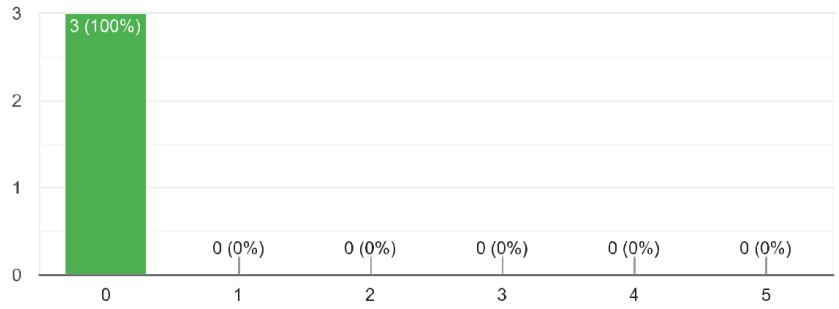
How do you evaluate your expertise in the C-K theory?

3 responses



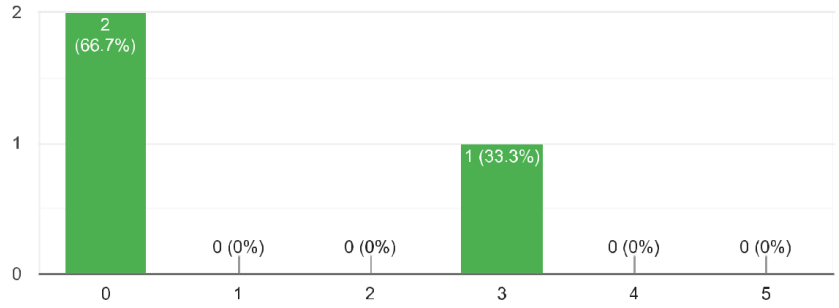
How do you evaluate your expertise in TRIZ?

3 responses



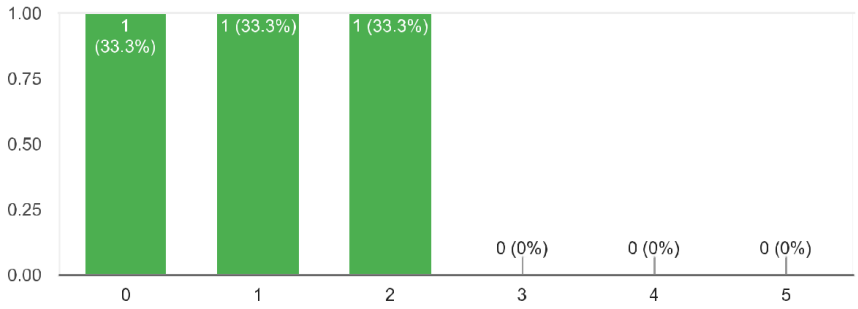
How do you evaluate your expertise in Blue Ocean Strategy?

3 responses



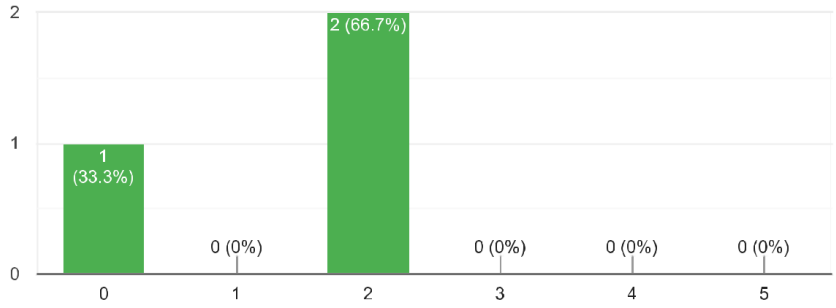
How do you evaluate your expertise in Lean Startup?

3 responses



How do you evaluate your expertise in Radical Innovation Design?

3 responses



When you think of the methodologies mentioned before, what are relevant words come to your mind? Please list them.

3 responses

Conceptualisaton, decision-making, optimisation, strategic design decisions, expectation management, requirement analysis

Applicability, flexibility, suitability, design, innovation, solutions

Design Client Creativity Innovation

Have you participated in any innovation projects? If so, how many?

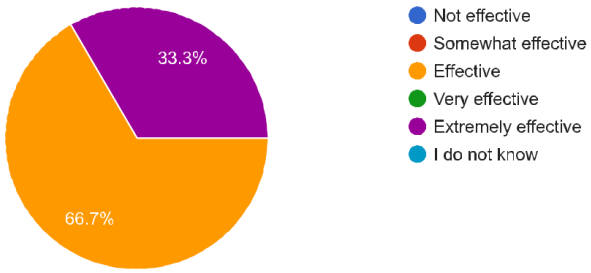
3 responses

No

Depends on its definition.

How do you evaluate the effectiveness of serious gaming as an educational approach?

3 responses



Can you argue your answer?

3 responses

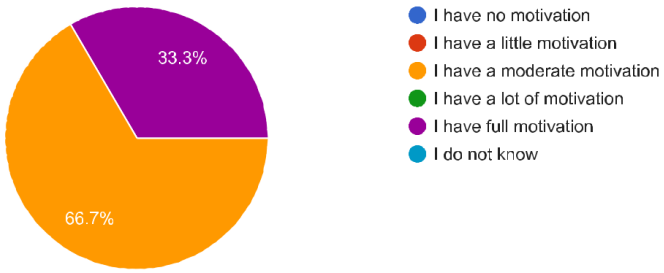
I have come across serious gaming as an educational approach several times with only good memories and compared to other approaches, I guess with better success. Best example is: http://gamesforcities.com/database/glut/

The context of challenge in the face of key situations can stimulate attention and interest, stimulating and developing reasoning/logical and decision making skills.

Motivating

How do you evaluate your motivation to learn RID by playing a serious game?

3 responses



Do you have any comments or questions?

1 response

I'm not really oriented design

Post-questionnaire for the beginners

Post-questionnaire for the validation of the RID serious game (Beginners)

3 responses

Publish analytics

After playing the game, what have you learned about RID? Please describe it in a few sentences.

3 responses

I learned about the different steps, its structure, the importance of keeping the problem first, and the possible combinations of different elements, such as user profiles, usage situations, problems, etc.

RID is a practical approach to driving innovation that is composed of different steps that are essential for identifying, processing, and using knowledge to deliver usefulness to users and identify business opportunities.

It is a process of innovation incliding Knowled and problem formulation in order to design a solution

Does the game stimulate your motivation to learn more about RID? Can you argue your answer?

3 responses

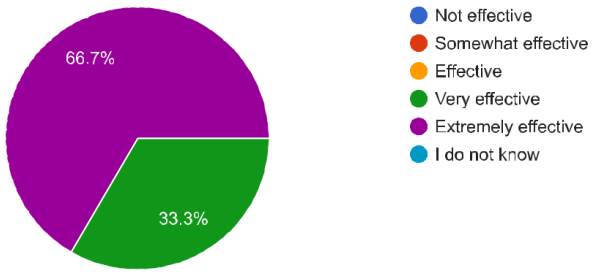
The fact that it ended in the middle without going towards the solutions created the interest or urge to continue. The ability to understand different components of RID a bit and seeing the potential contribution to the overall process further contributes to the interest to learn more about RID, as well as in the same sense or even more, the in-depth understanding of elements thereof.

Without a doubt, yes. Dealing with the identification, treatment, and application of knowledge expands the logical ability to reason, improving results.

Yes we've seen the first part of RID, I like to see the second part

How do you evaluate the effectiveness of serious gaming as an educational approach?

3 responses



Can you argue your answer?

3 responses

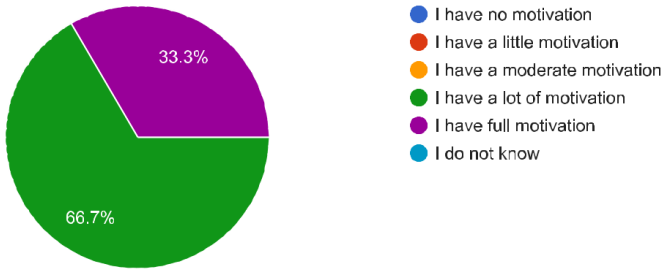
It's a quick and immersive approach which allows you to remove yourself from a learners' perspective but instead just play the game and learn "by accident." While it can't replace other learning methods, it can create a broader understanding, as well as interest and curiousity due to the non-traditional format.

Setting up the learning process with an investigative and critical approach can motivate and enhance learning. I believe this methodology is flexible enough to suit different learning profiles.

It is an excellent way to imply the students / managers/ targeted people and a simple approach to understand

How do you evaluate your motivation when playing the RID serious game?

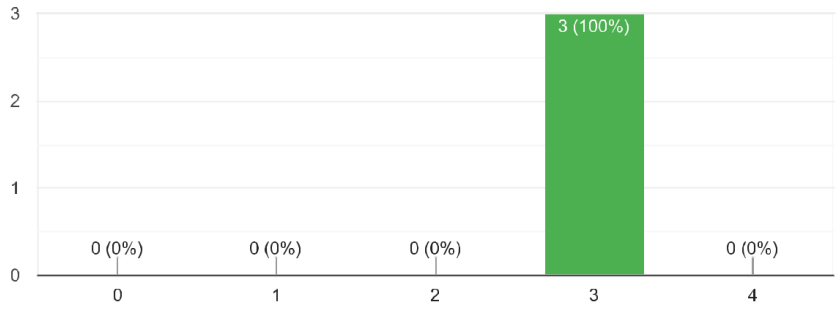
3 responses



Please indicate how you felt while playing the game for each of the items, on the following scale:

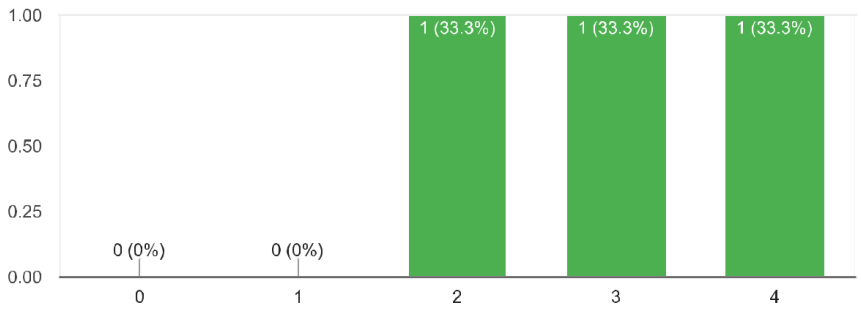
I felt skillful

3 responses



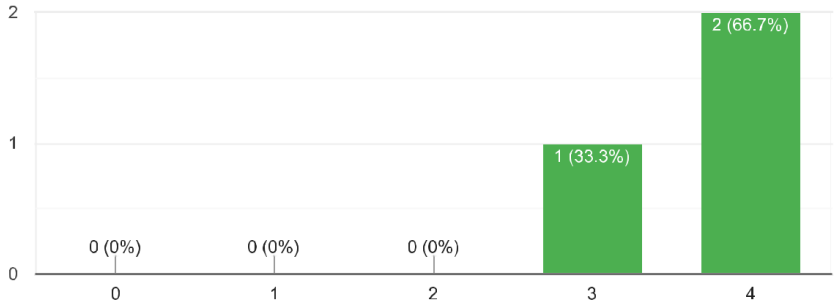
I was interested in the game's story

3 responses



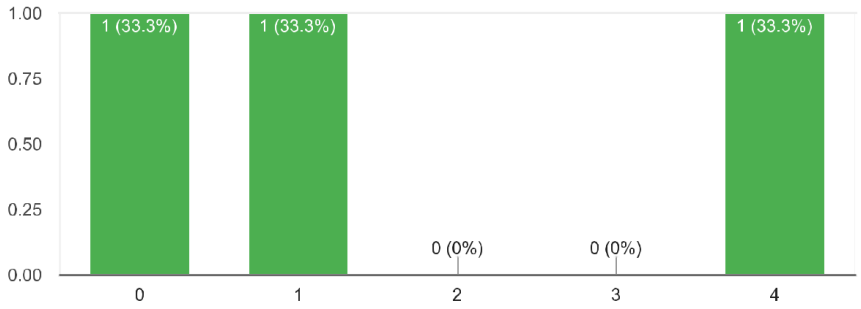
I thought it was fun

3 responses



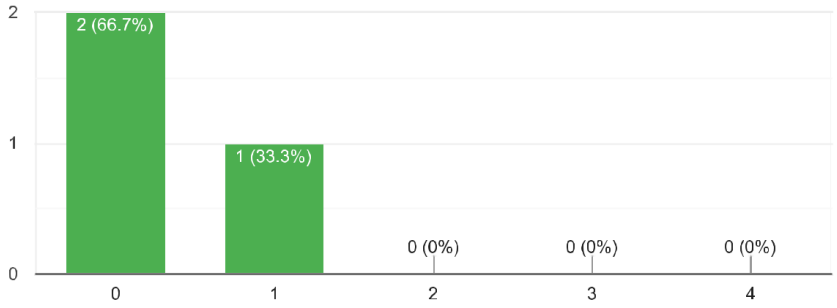
I thought about other things

3 responses



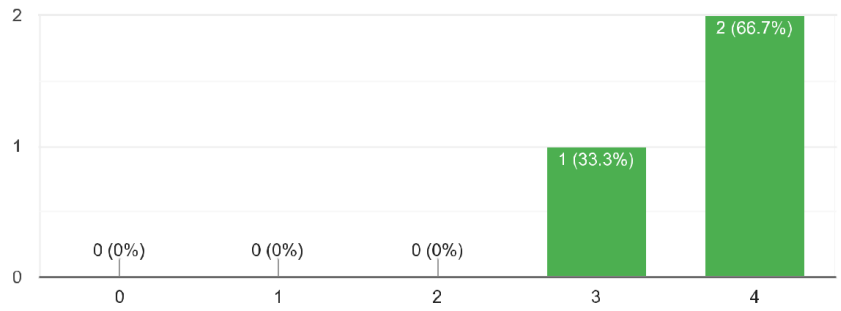
I felt bored

3 responses



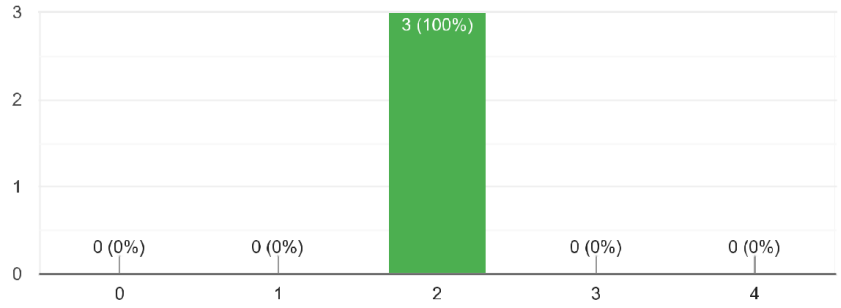
I enjoyed it

3 responses



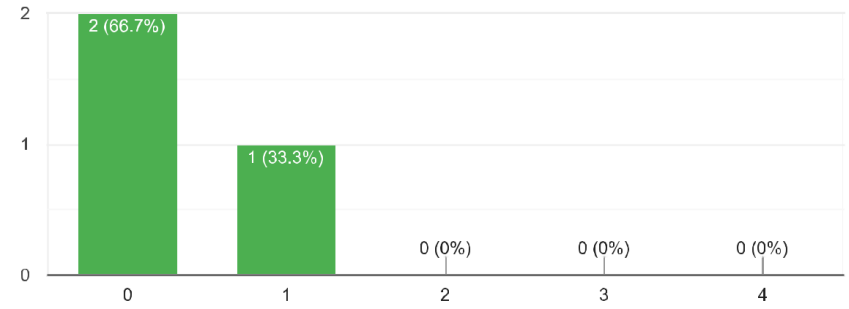
I was fast at reaching the game's targets

3 responses



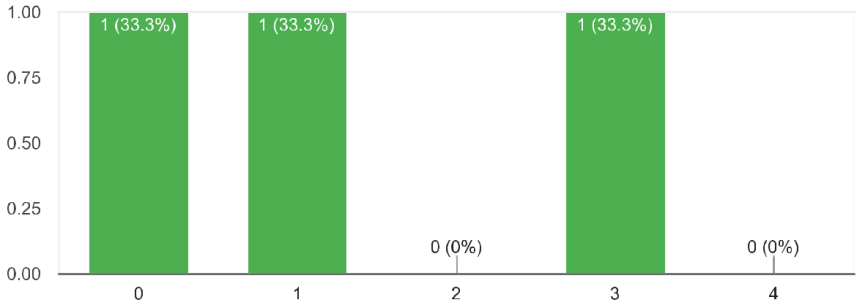
I felt annoyed

3 responses



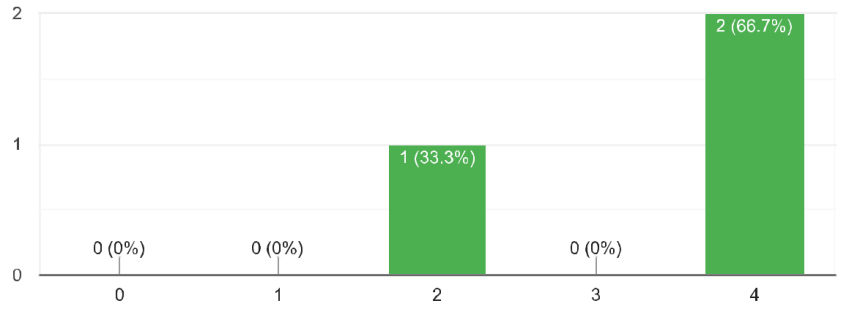
I lost track of time

3 responses



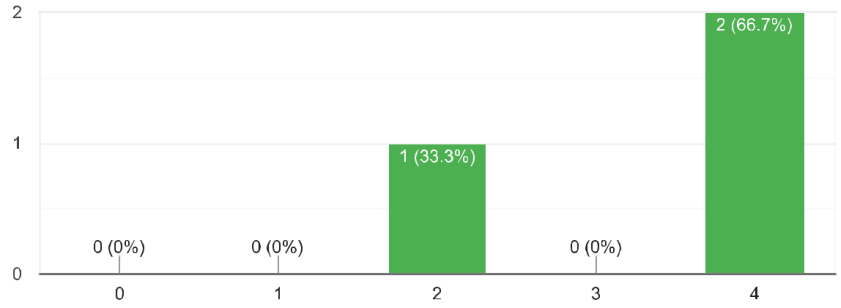
I felt challenged

3 responses



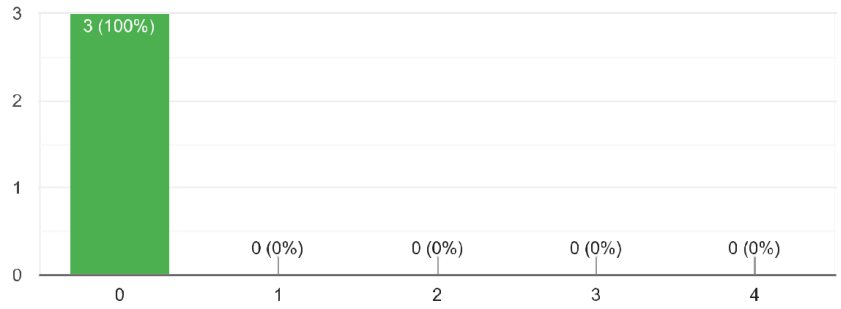
I was deeply concentrated on the game

3 responses



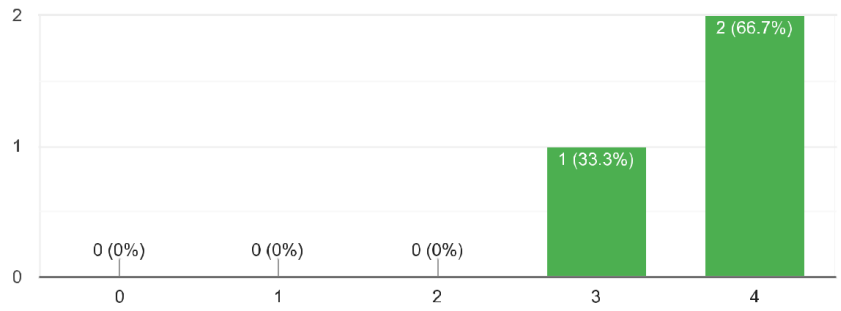
I felt frustrated

3 responses



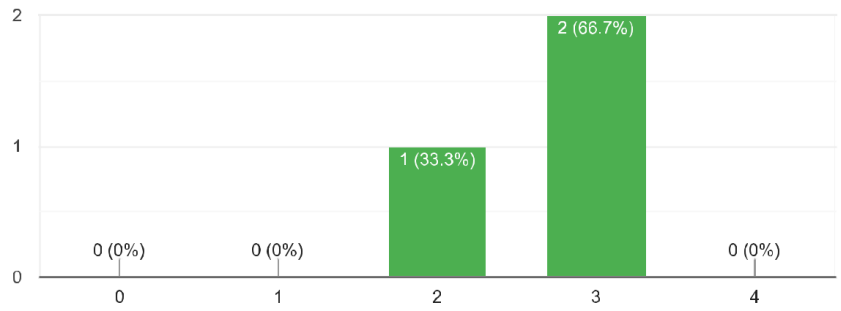
It felt like a rich experience

3 responses



I had to put a lot of effort into it

3 responses



What did you like the least during the game?

3 responses

The unclarity of the final goal to reach.

The time for the tasks coupled with the difficulty of fully apprehending all the orientations was a difficult part.

First explanation, it was long

What did you like the most during the game?

3 responses

The well-designed and structured approach of different steps and in-depth, high-quality knowledge behind it.

It was challenging and fun at the same time. The friendly atmosphere and the attention made it a very enjoyable time.

The interaction at each phase with the other players

Do you have any suggestions for improving the game?

3 responses

Aside those mentioned in the discussion, I believe most elements which could be improved are primarily linked to the game design in itself. This means having differentiable colours and cards, following along the game via the visual fields, making the information on the cards/graphs more accessible through simplification/visualisation, and having a more visual support for the steps, allocated times, and subsequent steps throughout the game.

I believe it is important to find a way to improve the understanding of the game's core points, such as the cards and the objective of each stage (as well as orientations on what not to do during each stage).

Should be more userfriendly in term of cards colors and some formats

Publications

Ma, Y., Vallet, F., Cluzel, F., & Yannou, B. (2019, July). Analysing The Relevance Of Serious Game Elements For Effectively Teaching Innovation Processes. In Proceedings of the Design Society: International Conference on Engineering Design (Vol. 1, No. 1, pp. 439-448). Cambridge University Press.

Ma, Y., Vallet, F., Cluzel, F., & Yannou, B. (2020, August). A Methodological Framework for Making the Transition From Traditional Innovation Teaching Towards Serious Games. In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (Vol. 83921, p. V003T03A021). American Society of Mechanical Engineers.