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Serious game for the next generation of technical systems:

To improve the capabilities of R&D engineers in proposing ideas for the next generations of technical systems

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Abstract

Engineering design has to support R&D engineers in designing the next generation of technical systems. This task is one of the crucial tasks of R&D engineers to make companies ready for the radical changes in the market. Developed technology forecasting and design methods are not effective for this kind of long-term design and it is mostly followed in typical design sessions by focusing upon improving the characteristics of design proposals. Effective design stimuli in the form of design heuristics (consisted of design precedents and strategies), and design professional models are used to improve characteristics of design proposals. Despite lots of researches on the characteristics of design proposals, there is no direct research in the field for the next generation of technical system. Therefore, the ultimate objective of this research is to improve capabilities of R&D engineers for this task and as the main novelty, this research approaches this task through developing a special serious game called here after "Techno-shift".

To develop the mechanics of the Techno-shift game, an empirical study was done through protocol analysis to highlight the skills of R&D engineers in exploiting their knowledge and experiences in the form design heuristics during designing the next generation of technical systems. A set of criteria for assessing candidate ideas, a coding scheme to highlight the effective heuristics, and a set of stimuli for improving the R&D engineers' performance, became the three main other innovative features of the research.

Study the performance of 12 teams of R&D engineers (each one 2 members) in a design session, show the rate of team productivity is 0.62 (0.2 STD) on average. By applying the three developed criteria of novelty, technical plausibility, and relevance, on average, the teams generated 1 (0.95 STD) candidate idea. The 12 candidates are the 3.9% of the total generated ideas by all the teams.

Nature of speech, time horizon, and system hierarchy are the dimensions of developed coding scheme which 90 combination of codes can be constituted as design heuristics by considering their sub-classes. Among 90 combinations, only 15 codes are realized as the active skills of R&D engineers in designing the next generation of technical systems. Studies highlight that the effective skills, the codes before the candidate ideas in the protocols, are the same codes with different sequences and orderings.

Finally, pictorial presentation of trends of evolution of some technical systems, abstract of patents related to the function of target system, and an engineering procedure for designing the next generation of technical systems are the three stimuli which are developed and studied in the scope of this research. The study shows trend compare to other stimuli and control group is more effective in influencing quantity, technical plausibility and relevance of ideas positively, patent is more effective in increasing quantity of candidate ideas and none of stimuli are effective in increasing the novelty of ideas compare to the control group. Engineering procedure increased usage of effective codes by R&D engineers but it is not effective in guiding them to generate candidate ideas.

Based on the results of performed protocol analysis, the Techno-shift game was developed. The game mimics the production line of industries and starts with the 'Table of resources' and follows through the 'Idea generation line', where the player can propose new ideas by means of the 'Think stations and design heuristics', the 'Tips and tricks', the 'Examples for creativity stimulation' and the 'Idea cards'. Eventually, effectiveness, usability and robustness of the proposed serious game were studied in an empirical study with five groups where different players in profiles applied the Techno-shift game in same time for same and different target systems respect to the control group. The results show, although productivity in terms of total number of generated ideas was decreased to almost half for all the groups compare to the control group, but the effectiveness in terms of number of generated candidate ideas are increased to 7 to 9 times. Also the other indexes show that players are able to apply the games' rules, and less than 40% misunderstanding or misinterpretation are observed for applying heuristics and assessment criteria. Finally, there is no evidence to reject the robustness of the game, as the results of playing various versions of the game are not significantly different.

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Contents

Chapter 1

Introduction

The current research aims at supporting R&D engineers in designing the next generation of the technical systems. This chapter opens the big picture about the reasons for this research and the selected approach and designed contribution for this research.

1. The bigger picture

In an industry that is changing fast, firms must continually revise their design and range of products. This is necessary as a response to the continuous technological change and development of the competitors, and the changing preference of customers. The next generation of technical systems is a kind of radical innovations and radical technological changes which substitute current version of the system in the market. Interest in radical technological change originated with Schumpeter (1934), one of the first to claim that radical technological change is a powerful mechanism that can challenge the power of monopolists. Schumpeter's main argument was that the nature of radical technological change undermines the very foundation of large companies' competitive advantages – cost leadership due to large production volumes in an established technology – by rendering the established technology irrelevant. Therefore, distinguishing and developing the next generations of the technical systems is important for companies.

Relevant previous research can be searched and studied through researching the next generation of technical systems directly, or through other relevant types of innovation or changes in technical systems (such as breakthrough innovation and radical technological changes) indirectly. Characteristics of the next generation of technical systems can be defined by considering the various research related to innovation, radical innovation, radical technological change, technology paradigms, technology-push innovation, market-pull innovation, design-driven innovation, breakthrough innovation and radical novelty (Cooper & Schendel, 1976; Dosi, 1982; Coombs et al., 1987; Anderson & Tushman, 1990; Christensen & Rosenbloom, 1995; Tripsas, 1997; Geels, 2004; Verganti, 2008). In total, the next generation of a technical system is a kind of breakthrough innovation (Geels, 2004) defined by the overlapping characteristics between the outcomes of the technology-push (Dosi, 1982) and design-driven innovation (Verganti, 2008). In other words, the next generation of a technical system is the version of the system consisting of radical technological change, and radical meaning change, for existing and/or new customers.

Firms follow new product design and development through their own R&D program, or by relying on strategic alliances, acquisitions, and networks to tap into the innovations of others. The importance of R&D departments has been discussed by considering their roles in expressing the state of the industries. In the context of commerce, "research and development" normally refers to future-oriented longer-term activities in science or technology, using similar techniques to scientific research, but which are directed toward desired outcomes and with broad forecasts of commercial yield. A system driven by marketing is one that puts customer needs first, and only produces goods that are known to sell. If the development is technology-driven, R&D is directed toward developing products that market research indicates will meet an unmet need. Additionally, statistics relating to R&D departments such as budgets, numbers of patents or on rates of peer-reviewed publications are used to express the state of an industry, the degree of competition or the lure of progress (Bengisu & Nekhili, 2006). Patents are major outputs of R&D activities and represent the characteristics of new technology (Choi & Park, 2009); almost 80% of all technological information can be found in patent publications (Blackman, 1995).

Considering the main function of a firm's R&D department, different classifications for the tasks undertaken by such departments are developed and applied in the companies. New Product Research, New Product Development, Existing Product Updates, Quality Checks and Innovation are five classes of tasks that are expected from R&D departments. Also the research and development of new products, product maintenance and enhancement, and quality and regulatory compliance, are a three-class description of the same tasks. The next generation of technical systems, breakthrough innovation, and radical technological changes are the concerns of R&D departments along their responsibility for new product development. Literature shows these concerns are pursued in R&D departments using two approaches – forecasting and design - while companies also approach them in broader strategies.

Literature shows direct researches on the tools and methods for designing the next generation of technical systems. Technology forecasting among future studies, including technology forecasting, technology foresight, technology intelligence, technology road mapping, and technology assessment (Porter & Cunningham, 2004), is mostly used within R&D management to support R&D engineers for predicting the next generation of technical systems. Forecasting is described as a need to anticipate uncertainty information about the future (Armstrong, 2001). Technology forecasting methods approach the next generation of technical systems as long-term forecasting, and consequently, investing in the results as a long-term investment design projects. The most general models and methods used to describe and measure radicalness of innovation are (Dahlin & Behrens, 2005), technology cycles (Anderson & Tushman, 1990), s-curves (Foster, 1985), technological trajectories (Dosi, 1982; Christensen & Rosenbloom, 1995), hedonic price models (Henderson, 1993) and expert panels (Dewar & Dutton, 1986). For example, technological radical innovation and technological substitution can be described through the technology evolution path by a logistic growth curve (Griliches, 1957).

Although wide range research on improving the technology forecasting methods, there are some concerns, draw backs and limitations in using them in companies. A central concern of R&D investment in product innovations that employ new or untested technology is that of the necessary level of resource allocation required to grow the stock of knowledge (Coccia, 2009; Wiesenthal et al., 2012). In addition, some of the developed methods are more effective in forecasting the time of limitations of the current version of the system, rather than proposing the concept of the structure of the next generation. For example, the s-curve is extrapolated for each characteristic or function of the target system with respects to time. It shows the point at which the characteristic of function under investigation cannot be improved any more. In other words, the most methods show the limitations and problems, with designers having to proceed through proposing solutions for them as the next step. TRIZ-based anticipatory methods are the methods of design which are used to propose the concept of structure of the next generation of systems. The more developed methods in this field, exploit some of the previous methods of forecasting as the base and then they proceed by guiding designers through templates of the entire class of solutions and use analogy to propose solutions (Cascini, 2012). The mentioned methods use previous precise data of the system to forecast, which is not easy to find in many real projects and especially in a design session for designing the concept of the new version of the technical system. For example, s-curve analysis and its extrapolation require previous system growth data. However, providing the precise data does not guarantee the precise prediction for the next generation of technical systems, as previous research shows the forecasting not being reliable enough for long-term periods (Kucharavy & De Guio, 2005). In addition, technology forecasting methods are known as time consuming activities. As an example, using the FORMAT method takes on average 10-12 sessions, with each one lasting 2 hours by different team members; however, the consumed time for methods such as Delfi is higher in comparison to the FORMAT method. Finally, designers and R&D engineers find the developed methods as inconvenient as they are not generally easy-to-follow and they tend to follow the phases in a rather ad-hoc, unsystematic (Cross, 2001) and opportunistic way (Visser, 1990).

While technology forecasting methods are developed to directly support R&D engineers for designing the next generation of technical systems, the task is still followed in typical design sessions by focusing upon improving the characteristics of design proposals, mostly through using effective design heuristics, models and methods. The general characteristics of design proposals are defined and followed through quantity (Nijstad et al. 2002; Shah et al. 2003; Perttula & Sipila, 2007) and quality (Wierenga & Van Bruggen, 1998; Shah et al. 2003) of ideas. Consequently, the quality of an idea is generally defined by a proposition's originality and appropriateness in regard to the target task (Massetti, 1996; Runco & Jaeger, 2012). In some instances, a third specializing criterion such as unexpectedness (Gero, 1996) or un-obviousness (Howard et al. 2006; Howard et al., 2008) can be linked to the time that the idea was produced. In some other researches novelty, variety and quality of design proposals are applied (Shah et al. 2003; Schunn et al., 2010).

Design heuristics are mostly derived from the cognitive studies of professional designers while performing a variety of different design tasks. From a more abstract level, heuristics are used for developing design models and methods. Cognitive research shows that experts utilize heuristics effectively, and their usage of them is a feature that distinguishes them from novices (Klein, 1998). Expert designers employ cognitive heuristics in order to enhance the variety, quality, and creativity of potential designs while they mostly use them unconsciously. Experienced designers use strategic knowledge, but do not identify or communicate their existing strategic knowledge (Kavakli & Gero, 2002). Design heuristics are the sentences (hints and tricks) which serve as a starting point for transforming an existing concept, altering it to introduce variation, or define variations among individual design elements (Yilmaz & Seifert, 2011). In general, each discovered strategy or usage of precedents as the results of previous researches in the design cognition field can be considered as a potential concept for a strategy-based or precedent-based heuristic to be suggested and prescribed to the designers. Design strategies are the most appropriate suggestions for sequences and patterns of sequences, time dedicated to problem formulation and solution generation, and the rate of transitions among them in respects to the requested task (Lawson, 1979; Visser, 1990; Ball & Ormerod, 1995; Akin & Lin, 1995; Mc Neill et al., 1998; Atman et al., 1999; Cross, 2001). Literature also shows that the various scope of designers' precedents in various forms are applied in design consciously or unconsciously. Knowledge of the different time scopes of the target system or hierarchy of the related system to the target system or other systems (Gick & Holyoak, 1980; Wilson et al. 1980; Oxman, 1990; Jansson & Smith, 1991; Smith et al., 1993; Dunbar, 1997; Casakin & Goldschmidt, 1999; Leclercq & Heylighen, 2002; Nijstad et al., 2002; Downing, 2003; Pasman, 2003; Lawson, 2004; Eckert et al, 2005; Christensen & Schunn, 2007; Tseng et al., 2008; Weisberg, 2009; Eilouti, 2009; Linsey et al., 2010; Chan et al. 2011; Fu et al., 2013; Gonçalves et al., 2013; Doboli & Umbarkar, 2014; Moreno et al., 2014; Moreno et al., 2015) are part of the precedents, while the knowledge of design methods and tools (Archer, 1968; Booz et al., 1968; Radcliffe & Lee, 1989; Fricke, 1993, 1996; Basadur et al., 2000; Shneiderman, 2000; Kryssanov et al., 2001; Howard et al., 2008) are the other parts of precedents. Literature is not so rich in studying the effects of heuristics on design proposals in general. It is worth mentioning that despite the derived design heuristics for technical novelty, there is no specified research in design heuristics for the next generation of technical systems.

As mentioned, despite the two directly mentioned fields of researches to the issue, the other researches in innovation management discuss the effects of the different capabilities of companies and R&D engineers on innovation in general, and on breakthrough innovations specifically. The dynamic capabilities of organizations to achieve new and innovative forms of competitive advantage depend on honing internal technological, organizational and managerial processes inside the firm (Teece at al., 1997). Dynamic capabilities are not simply processes, but embedded in processes; they are the result of the firm's behavioral orientation to constantly integrate, reconfigure, renew and recreate its resources and capabilities (Wang & Ahmed, 2007).

Research shows that the companies focus upon future key technologies by monitoring recent developments of technologies; this is often undertaken via organizing task force teams which are expert-centric, time-consuming and labor-intensive as markets shift rapidly, technologies proliferate continuously, and thus innovation cycles become shorter (Lee et al., 2013). Considering the effect of the intensive work in the task force teams, the success of a radical innovation requires multiple facilitators within and across organizational boundaries. Knowledge sharing and unlearning are two important subjects that are discussed in the literature for increasing the capabilities of organizations and work groups in proposing innovation. Knowledge is widely considered a valuable organizational resource which unlike other organizational resources, it is typically resides in the minds of workgroup members and is only invoked during use. Such knowledge when sharing and processing can create organizational value by reducing the needs of information search, and processing among collaborating workers, consequently making them more efficient and effective in achieving their job goals (Konstantinou et al., 2009; Geiger et al., 2011; Lin & Joe, 2012). The competitive position and effectiveness of workgroups are likely undermined in the case of a lack of knowledge sharing (Lin, 2007). A key driver of knowledge sharing in workgroups is social capital, referring to the features of social organizations that facilitate coordination and cooperation among workgroup members (Putnam, 1995). Over the past two decades or so, the concept of social capital has captured the attention of sociologists (Putnam, 1995; Coleman, 1988) and organizational theorists (Nahapiet & Ghoshal, 1988) as a way of understanding why people in social communities, workgroups, and organizations share knowledge, ideas, and support with each other, even when there is no legal obligation or expectations of personal gain from doing so. Social relations positively affect radical innovation (Yang et al., 2014). The social network perspective provides an explanation about how inter-organizational relationships affect innovation (Subramaniam & Venkatraman, 2001). literature proposed that unlearning, a process of ridding an organization of old routines, and past knowledge or skills can facilitate the ability to adapt to a new environment and produce innovations (Akgün et al., 2006; Tsang & Zahra, 2008). Empirical studies, however, paid less attention to unlearning compared to learning (Bettis & Prahalad, 1995; Holan et al., 2004; Akgün et al., 2006; Tsang & Zahra, 2008; Van Mierlo et al., 2010). Research highlights two important dimensions of unlearning: discarding something, and replacing by something new (Tsang & Zahra, 2008). Discarding dimension of unlearning is observed in the literature by the topic of organizational forgetting (De Holan et al., 2004; Benkard, 2000), while others defined unlearning as changes in routines and beliefs (Akgün et al., 2003; Akgün et al., 2006; Akgün et al., 2007;), which is representative of the replacing dimension. Changes in routines and beliefs more strongly affect internal organizational employees because this dimension involves changes in the procedures, processes, or tools to which they are accustomed (Akgün et al., 2007). In contrast, the forgetting dimension mostly affects external suppliers and customers because these parties will lose the familiarity with or expectations of the firm in question that has accumulated over the years (Hsu & Hannan, 2005). Research shows how slack is a potentially important element of organizational resources (Voss et al., 2008). Slack resources as a dimension of organizational unlearning positively affects radical innovation, whereas the forgetting dimension has a negative effect (Yang et al., 2014).

As discussed above, despite the importance of the next generation of the technical systems for industries, the tools and methods developed for forecasting and designing the next generation of technical systems are not mature enough for supporting R&D engineers. On the other hand, the social networking and other organizational factors are effective on the capabilities of R&D teams in knowledge sharing and un-learning which are crucial for developing future key technologies. Therefore, it can be assume that developing a serious game which promote social networking and consequently knowledge sharing and un-learning, can be effective at supporting R&D engineers in designing the next generation of technical systems.

2. Serious game as tool for improving R&D engineer performance

The idea of playing a game dates back to the ancient past and is considered an integral part of all societies. The widespread diffusion of mobile gaming is also opening further perspectives for learning and online socialization in the future (Parsons et al., 2012; Liang, 2012). A large and growing population is increasingly familiar with playing games, however serious games do not target exclusively power-gamers (typically young males fond of First Person 3D immersive experiences). Power-gamers represent just 11% of the gaming community, while other types of players (e.g. social, leisure, occasional) are increasing in number (Bellotti et al., 2010).

A game is defined as a voluntary activity, obviously separate from real life, which creates an imaginary world that may or may not have any relation to real life, and which absorbs the player’s full attention (Michael & Chen, 2006). A game is played out within a specific time and place, is played according to established rules, and it creates social groups out of their players (Michael & Chen, 2006). In comparison to games, serious games have a pedagogy that is more than the story, art and software; rather their pedagogy must be subordinate to the story (Zyda, 2005). Games in general promote learning (Szczurek, 1982; VanSickle, 1986; Randel et al., 1992; Van Eck, 2006) therefore it is considered also that serious games promote learning.

Many reasons are discussed for using serious games for learning and self-learning, though three main ones are identified. Firstly, the thinking patterns of learners today have changed, with today’s students being native speakers in the language of digital media. The new form of digital entertainment has shaped their preferences and abilities and offers enormous potential for their learning, both as children and as adults (Prensky, 2001). Secondly, using the latest simulation and visualization technologies, serious games allow learners to experience situations that are impossible to be experienced in the real world for reasons of safety, cost, time, etc. (Squire & Jenkins, 2003; Corti, 2006; Jarvis & de Freitas, 2009; Hill et al., 2009). Thirdly, by exploiting the latest simulation and visualization technologies, serious games are able to contextualize the player’s experience in challenging, realistic environments, which supports situated cognition (Watkins et al., 1998); this means players can exercise freedom that can complement formal learning by encouraging learners to explore various situations (Klopfer et al., 2009), with limited barriers of monitoring, space and time. Although it is considered generally that serious games improve various skills, some research refers to the negative impact and raise some concerns of playing serious games. A not recent research argued that turning learning into fun denigrates the most important things we can do in life: to learn and to teach.

Despite the numerous serious games for many application domains, no specific serious game for design is introduced and discussed in the literature. Fortunately, there are very few studies about the effects of some existing serious games on design. In architecture and design, the impact of computer games was studied in relation to developing student confidence and abilities in spatial modeling, design composition, and form creation (Radford, 2000; Coyne, 2003). Playing with three-dimensional models was suggested and studied as a means for enhancing town planning (Thuillier, 2005), whilst it was reported that spatial abilities, more precisely the capacity for mental rotation, can be improved by playing games such as Tetris (De Lisi & Wolford, 2002).

Serious games must demonstrate the transfer of learning (to be 'serious'), whilst also remaining engaging and entertaining (to be 'games'). The balance between fun and educational measures should be targeted throughout the development, starting from the design phase. One of the biggest issues with educational games to date is the inadequate integration of educational and game design principles (Gunter et al., 2006; Kenny & Gunter, 2007; Kiili & Lainema, 2008; Lim et al., 2013). This is due to various factors including the fundamental fact that digital game designers and educational experts do not usually share a common vocabulary and view of the domain (Gunter et al., 2006). Designing a serious game is considered a multi-disciplinary task that requires the collaboration of experts in different fields (Zarraonandia et al., 2012). Content, theory and game design are considered as the three kernels of serious games (Greitzer et al., 2007). Depending on the pedagogical purposes of serious games, the serious games are classified into four classes initially, based on their mechanics being slightly different: games for classroom use, games for independent learning, games for social awareness and games in the medical domain. Considering the lack of a systematic tool for designing a serious game from a psycho-pedagogical level to a technical level, two approaches are seen in literature for developing initial methods for designing serious games: (i) focusing on some of the serious game descriptors which claim to be more effective on the success of a serious game, and (ii) focusing on the mechanics of the serious game. These two approaches are not completely separate as serious game mechanics are amongst the serious game descriptors. Included in the list of game mechanics are design, infinite game play, ownership, protégé effect, status, strategies, titles, action points, assessment, collaboration, communal discovery, resource management, game turns, Pareto optimal, rewards/penalties, urgent optimism, feedback, meta-game, realism, capture/elimination, competition, cooperation, movement, progression, selecting/collecting, stimulate/response, time pressure, appointment, cascading information, questions and answers, role-play, tutorial, cut scenes/story, tokens, virality, behavioural momentum, Pavlovian interactions, and goods/information (Arnab et al., 2015). Market, purpose, application domain, pedagogy level, skills, learning outcomes, assessment, social involvement, gameplay, deployment, target players, game components, reality, activity, modality, environment and interaction style are the descriptors and mechanics of serious games which must at a minimum be considered for designing a successful serious game.

Given the above mentioned benefits and concerns about serious games, it can be concluded that serious games are supportive in improving many of a target player's general and specific skills, if they develop based on styles, knowledge, skills and preferences of target people. In addition, the results of a few studies about serious games for design are promising for more precise studies in this field. The skills of target players, in terms of required, active and not-active skills, are one of the most important mechanics for designing the balance point for a successful serious game. In the scope of this research, the promotion of R&D engineer skills and performances in designing the next generation of the technical systems, are studied through a specific serious game developed for the same purpose and target players. Therefore, the required skills of R&D engineers in designing the next generation of the technical systems are studied through a design cognition and protocol study, with the target serious game being developed, based on the effective game mechanics of successful serious games.

3. Research questions and thesis outline

In two previous sections, the problem and the general idea for the solution were briefly mentioned; necessity to support R&D engineers in designing the next generation of technical systems discussed as the problem, and designing a serious game for this purpose, proposed as the general idea for the solution. Regards to the framework of Design Research Methodology (Blessing & Chakrabarti, 2009), the scope of this research can be reflected as a research Type 5. Table 1 shows DRM consists of four phases and the types of research projects in this framework are defined based on the type of research activities in different phases. Research clarification, Descriptive study I, Prescriptive Study, and Descriptive Study II are the four phases of research projects in DRM and the design activities can be Review-based study, Initial study, or Comprehensive study in each of these four phases. The Research Clarification aims at formulating a realistic and vivid research goal, Descriptive Study I clarifies the description of the existing situation, Prescriptive Study proposes solutions for improving the existing situation towards the desired situation, and Descriptive Study II assesses the effects of developed solution respect to the desired situation.

Research	Phases			
Types	Research clarification	Descriptive study I	Prescriptive study	Descriptive study II
1	Review-based	Comprehensive		
2	Review-based	Comprehensive	Initial	
3	Review-based	Review-based	Comprehensive	Initial
4	Review-based	Review-based	Review-based Initial/ Comprehensive	Comprehensive
5	Review-based	Comprehensive	Comprehensive	Initial
6	Review-based	Review-based	Comprehensive	Comprehensive
7	Review-based	Comprehensive	Comprehensive	Comprehensive

Table 1- Types of design research projects in DRM framework; adapted from (Blessing & Chakrabarti, 2009)

Current research as a research Type 5, consists of four phases. Research clarification is studied literature-based to clarifies the strong and weak points of previous researches focused on supporting R&D engineers in designing the next generation of technical systems. The study is pursued in the field of future studies and design simultaneously. As a results of this phase, besides the strong and weak points of technology forecasting methods in designing the next generation of technical systems, the characteristics of next generation of technical systems, and the effective strategies and precedents for improving the novelty and creativity of design proposals are highlighted. The studies clarify that designers are capable to exploit their available knowledge and experiences in the form of precedent-based heuristics for designing but there is not a specific research on effective heuristics in designing the next generation of technical systems. Descriptive Study I is performed to study the performance and skills of R&D engineers in real design sessions for proposing the concept of the next generation of technical systems. This phase of research is designed by reviewing the literature in the field of design cognition for the tools and methods for capturing the normal behavior and thinking patterns of designers. The results of reviewed-based research in the first phase and the comprehensive research in the second phase together, let the research go further in the phase of Prescriptive study by designing the Techno-shift game. Another literature review is done at the beginning of this phase in the field of serious game to realize strong and weak points of serious games, and also the systematic approaches for designing a serious game. Finally, the impacts of the developed game on the performance of R&D engineers as the target players is studied initially in the Descriptive study II. Comprehensive study of impacts, requires another PhD thesis. Validity of the research is pursued by planning rational steps forward by applying the valid researches in the corresponding research fields.
To proceed the research, the required literature of all phases, are studied simultaneously from the beginning of the research. The parallel study of all phases let the empirical studies of the second phase to be designed and performed more relevant to the requirements of third phase. Figure 1 shows the image of effects of simultaneous literature review on the plan of whole research.

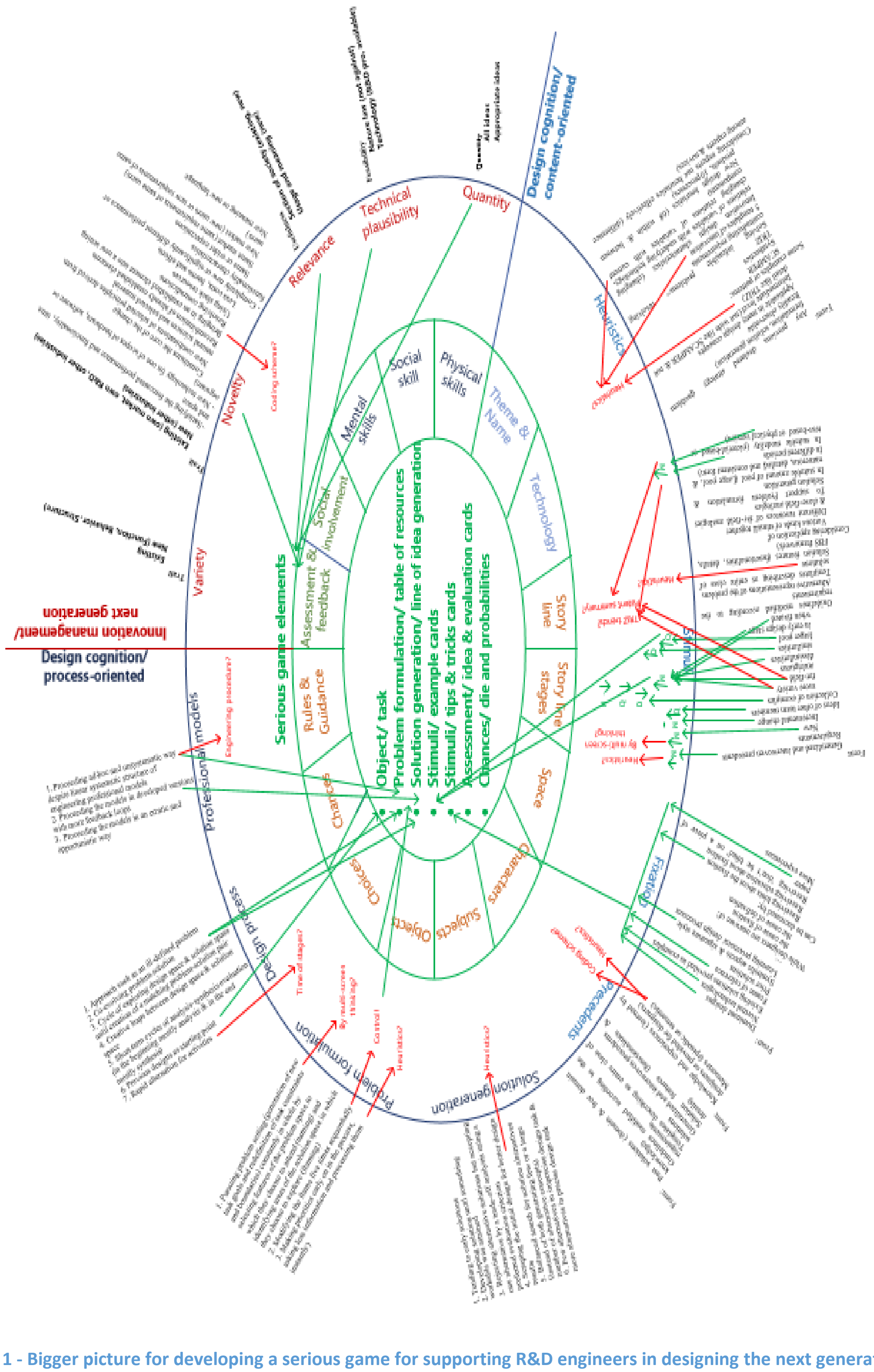


Figure 1 - Bigger picture for developing a serious game for supporting R&D engineers in designing the next generation of technical systems

The figure consists of four layers of text. The outer external part represents the reviewed literature on the characteristics of the next generation of technical systems, technology forecasting methods, and design strategies, precedents, and heuristics (Chapter 2). The third layer from external part represents the reviewed literature on the systematic approaches for designing the mechanics of a serious game (Chapter 2). The mechanics in blue and dark blue are selected based on the research scope, the mechanics in dark green are clarified based on the characteristics of the next generation of technical systems, and finally the mechanics mentioned in orange must be designed and developed based on the observed behavior of professionals with the same task. The second and fourth layers are the reflections of the first and third layers on the research plan. The fourth layer (central part) shows the main elements of the developed serious game – in respects to the main mechanics of serious games in third layer - with some of them being derived directly from the literature of first layer (Chapter 4). The arrows in red in the second layer represents the voids or doubts about literature in first layer which must be studied through observing the professionals to be applied for constructing the other serious game mechanics in fourth level (Chapter 3).

The empirical studies of the second and fourth layers are designed and performed through two main research questions and eleven sub-questions.

Research question # 1: How should the serious game for promoting R&D engineer's performance in designing the next generation of technical systems be structured?

The first research question is studied and discussed in Chapter 3. To approach the first question, the required skills of target players and the level of activeness of them must be clarified. In order to develop a serious game, the active and passive skills of target players in respect to the ultimate goal of the game must be considered. The elements of the game must be developed to not only improve their active skills, and also transfer their passive ones into active ones. Effective stimuli on the required skills of R&D engineers on the other hand, can help design the elements of the games. Although some general skills of target players are discussed in other researches, the precise observation in regards to the exact ultimate goal of the game is necessary. Therefore, this main research question can be approached as the active and passive skills of R&D engineers in using effective heuristics for designing the next generation of technical systems.

Given the patterns and strategies in design reviewed in the literature (Chapter 2), the set of criteria for assessing the acceptable candidate ideas for the next generation of technical systems among generated design proposals in section 1 of the same chapter, the developed coding scheme for capturing the heuristics used by designers in the same task in section 2 of the same chapter, and also the set of developed stimuli for promoting the skills and performance of R&D engineers in the same task in section 3 of the same chapter, the following checks still needed:

Check #1: What are the average R&D engineers' performance in terms of the quantity of total generated ideas, the quantity of candidate ideas, the quantity of ideas with acceptable degree of novelty, the quantity of ideas with acceptable degree of technical plausibility, and the quantity of ideas with acceptable degree of relevance for the next generation of the technical systems?

Check #2: What are the effects of suggestive stimuli on the R&D engineers' performance in terms of the same indexes mentioned in Check #1, while the suggestive stimuli are proposed according to the most effective stimuli of the quantity and quality of design sessions mentioned in literature?

Check #3: How many different heuristics are used by designers to propose the next generation of technical systems (skills)?

Check #4: Which heuristics are used more by designers to propose the next generation of technical systems (active skills)?

Check #5: Which heuristics used by designers are more effective than the others (effective skills)?

Check #6: What are the effects of suggestive stimuli on the heuristics used by R&D in proposing the next generation of technical systems?

The information of above checks is going to applied for structuring the game and also assess the effects of developed game on R&D engineers.

Research question # 2: How effective is the developed serious game?

The second research question is studied in Chapter 4. To approach this research question, the target serious game was developed and applied to the group of R&D engineers as target players. The results are compared with other similar participants in different situations. The following checks show how the second research question is approached in this study:

Check #7: Does the developed game work with less elements than configured?

Check #8: Is the developed game more effective than design sessions with same task?

Check #9: Does the developed game work the same for the same technical system?

Check #10: Does the developed game work the same for any technical system?

Check #11: Does the developed game work the same for different kind of players?

Therefore, this dissertation is written in five chapters. After clarifying the problem under investigation, the research objective, the target tool for achieving the objective and developing a set of corresponding research questions in Chapter 1, the necessary literature is reviewed in Chapter 2. The next chapters discuss the proposed methodology and research contribution in relation to the captured skills of R&D engineers in designing the next generation of technical systems (Chapter 3), and the development of a serious game for supporting R&D engineers for the same purpose, as well as the effectiveness of the applied serious game in different conditions (Chapter 4). Finally, in Chapter 5, the findings with respect to the literature and the performed methodology are discussed, with future lines of research proposed.

Chapter 2

State of the art

As mentioned in the Chapter 1, the current research is planned as a research type 5 regards to the DRM framework which is consisted of four stages. To proceed the research, the required literature of all phases regardless the four above mentioned phases, are studied simultaneously from the beginning of the research. This chapter provides a brief introduction to the main topics of the thesis. Since the research covers a wide range of subjects, a compromise between breadth and depth had to be found. This chapter is meant as a general preface to the actual research work.

The chapter is divided into three Sections. Section 1 illustrates the basic terminology and concepts of designing the next generation of technical systems as one of the tasks of R&D engineers, and the developed tools and methods for supporting them in designing the next generation of technical systems. Section 2 concerns serious game as a tool for supporting professionals in serious tasks, and section 3 discusses protocol analysis as an approach to capture the current skills and behaviors of designers, especially R&D engineers.

1. Next generation of technical systems

Innovation is known as the main attempt and activity of any company in order to sustain itself in the market. Among the many various kinds of innovation in products, services and processes, designing the next generation of products, where the technology of performing tasks is radically changed, is a crucial one due to magnitude of the impact of it in the market, and consequently upon market competitor companies also. This kind of next generation of technical systems are mostly known as breakthrough innovations, which satisfy the same or wider expectations of system users with less cost, harms and efforts and therefore conquer the market dominantly. Previous researches in this subject aim to support companies to realize the nature of such innovation in advance and also support them to deliver it at the right time to the market. In this section, previous researches related to the nature of this kind of innovation and the supportive tools for approaching and measuring it, are reviewed.

The bigger picture clarifies that the ultimate goals of the researches in the related fields can be considered as supporting companies to be aware of these kind of forthcoming radical technological changes, as well as the possibility to role as frontiers. Studies show various approaches to these goals. ‘Practical definitions through related characteristics’, ‘measuring and anticipating methods’, ‘developing and designing methods’ and ‘effective and preventive organizational and environmental factors’ are the vital research issues in the related fields, however they are approached differently. The related researches reviewed in this section clarify the characteristics of the next generations of technical systems and developed methods for capturing these characteristics from one hand and shortcomings of the discussed methods from the other hand. This review highlights the characteristics can be focused in a serious game for promoting the R&D engineer’s capabilities in designing the concept of the next generation of the technical systems.

1.1. Characteristics of the next generation of technical systems

The next generation of technical systems is a kind of innovation; innovation is defined as a novel idea turned into an artifact that successfully addresses the market needs and therefore is accepted by customers (Burki & Cavallucci, 2011). To study the nature of the next generation of technical systems as kind of innovation, it is worth to take into account the previous research in the field of innovation to clarify the main corresponding factors and drivers. The classification of innovation is directly related to the ultimate purposes of the researchers in different fields. The magnitude of the impacts of innovation in the market, the drivers and triggers of innovation, the nature and magnitude of core changes and the target object of changes, are some viewpoints in classifying innovation. While some research studies one of these factors, some others study compositions of more than one factor in a model to interpret innovations. Some of these models are more relevant in clarifying the nature of next generation of technical systems.

Radical and incremental terms are used to highlight the magnitude of innovation. Radical innovation is used to show significant changes, while incremental innovation is used to present minor changes and improvements (Trott, 2008). Incremental innovation are the improvements within a given frame of solutions ("doing better what we already do") while radical innovations are the changes of the frame ("doing what we did not do before") (Garcia & Calantone, 2002). Also the newness and degree of changes are used to show the magnitude of an innovation, such that to consider an innovation as a radical, something completely new or significantly different must appear and respectively, to consider an innovation as incremental, just some degree of changes are observed (Schilling, 2010). For example, when a product satisfies completely new requirements or satisfies the same requirements significantly to higher degree, radical changes are proposed, otherwise only some incremental improvements are done. The magnitude of innovation is also discussed in the literature with continuous and discontinuous changes (Veryzer, 1998).

The market (Caves & Porter, 1977; Porter, 1979; Johne, 1999) and technology (Pavitt & Wald, 1971; Rosenberg, 1976; Mowery & Rosenberg, 1979; Pavitt & Soete, 1980; Soete, 1981; Dosi, 1982) are the two main well-known drivers used in research to clarify different kinds of innovation, with the magnitudes of changes within these drivers also being considered. The relation of these two drivers while considering their magnitudes are discussed by a scenario matrix (Allen, 1986). Figure 2 shows how both dimensions are divided into current and new situations to represent four different kinds of innovations in total. The concepts of these dimensions are a perquisite for understanding the kinds of innovations proposed by the matrix. In the scope of innovation for the next generation of technical systems, the market dimension is considered as representative for both different target users (Wedel & Kamakura, 2002; Howaldt & Mitchell, 2007) and the different requirements and needs of them (Kumar & Reinartz, 2012). Technology is defined as a set of both practical and theoretical knowledge; practical related to concrete problems and devices, and theoretical while practically applicable (although not necessarily already applied). This includes know-how, methods, procedures, experience of successes and failures, and also of course, physical devices and equipment (Dosi, 1982). It can therefore be summarized that the technology dimension is considered as representative for hardware, software and orgware related to the technical systems (IIASA, 2013).

Considering the meaning of the market and technology, the four kinds of innovation proposed by the matrix can be described as:

- Radical innovation: significant changes in the technical system by applying new technology (in hardware, software or orgware) for a new market (new users or new requirements of the same users);
- Technology substitution: significant changes in the technical system only by applying new technology for the same market;
- Market innovation: significant changes in the technical system only by considering a new market;
- Incremental innovation: only some improvements in the same market and same technology.

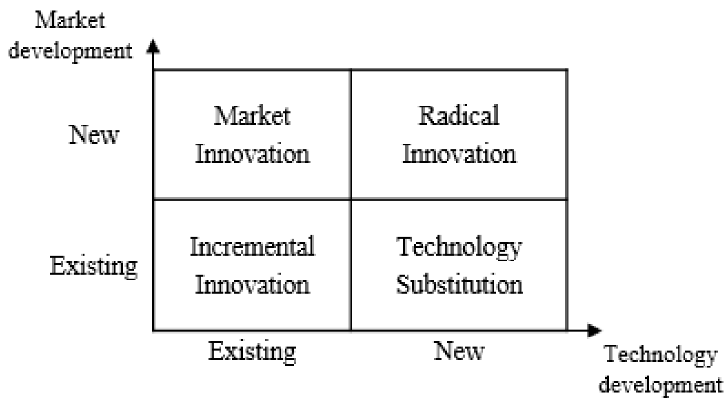


Figure 2 - Scenario Matrix for innovation by considering market and technology dimensions (Allen, 1986)

There are other kinds of innovation mentioned in previous research, which can be interpreted in relation to these four kinds of innovations. For example, it is possible to consider disruptive innovation as radical changes within the market dimension. Disruptive innovations are considered as a kind of change in the product where its performance is decreased in respect to some requirements; it does though remain acceptable for some portion of market due to a lower cost, more simplicity, convenience or some other characteristics (Christensen & Rosenbloom, 1995).

Among the four proposed kinds of innovation by the matrix, incremental innovation is out of the scope while discussing the characteristics of the next generation of technical systems. In other words, in the scope of the next generation of the technical systems, at least radical changes must be done respect to one of dimensions of technology and market. Based on the scenario matrix, two following classes of the next generation of the technical systems can be clarified:

- Radical technological change base: conclude two kinds of innovation “radical innovation” and “technology substitution” of scenario matrix;
- Radical market change base: conclude two kinds of innovation “radical innovation” and “market innovation” of scenario matrix.

Between the two above radical change bases in the next generation of technical systems, the radical technological change base is the most crucial for companies. Technological product innovations account for one fourth to one third of organizational growth (Zirger, 1990; Lee & Sukoco, 2011). In other words, although innovation in general helps firms to grow and compete, radical innovation in particular provides firms with better position and performance outcomes (Germain, 1996); radical innovations are defined as fundamental changes in new products that represent revolutionary changes in technology (Ettlie, 1984; Dewar & Dutton, 1986; Song & Thieme, 2009).

Interest in radical technological change originated with Schumpeter (1934), one of the first to claim that radical technological change is a powerful mechanism that can challenge the power of monopolists. Schumpeter’s main argument was that the nature of radical technological change weakens the foundation of large firms’ competitive advantages – their cost leadership due to large production volumes in an established technology – by rendering the established technology irrelevant. Many empirical studies have tested Schumpeter’s ideas (Cooper & Schendel, 1976; Anderson & Tushman, 1990; Henderson, 1993; Tripsas, 1997; King & Tucci, 2002). Schumpeter’s arguments were considered important enough to be brought up in the US government’s anti-trust law suit against Microsoft Corporation (Evans & Schmalensee, 2000). It is argued that a near-monopolist like Microsoft only holds a temporary market position, since a new radical technological change will upset the current status, sooner or later.

Despite a growing acceptance of and interest in the theory, there are some clear shortcomings about the definition and consequently, the measurements of such changes and methods to develop them vary greatly (Dahlin & Behrens, 2005). Researches in the field of economy approach this subject by studying the changes in the market (Mowery & Rosenberg, 1979); researches in the fields of management and technology management of industries approach the subject by studying company capabilities and characteristics in corresponding industries (Tellis & Golder, 1996); and researches in the field of design approach the same subject by studying the technical characteristics of current and forthcoming technology, and their relation as practical definitions (Dosi, 1982). According to the different expectations from definitions in these three fields and from different available data sources, the corresponding measuring and developing methods vary also.

Researches mostly labels radical technological change when a radical invention has been successful in converting an industry (Dahlin & Behrens, 2005). Invention, radicalness and fundamental changes in an industry are three main issues that are discussed in most researches aimed at defining radical technological changes. More focused and detailed discussions assume that there is one determining invention that initiates a new technological trajectory; this particular invention has not previously been observed in that particular setting, which starts the chain of improvements or constitutes the core of the change (Silverberg, 2002). This particular invention is the change agent in existing industries, or the starting point for new industries; this is often introduced to the society by an individual or organization that will not obtain any economic benefits from it (Tellis & Golder, 1996). These definitions consider the fact that many inventions and radical inventions fail in their early stages of its birth and growth, and due to this fact, the radical invention which is the core of a radical technological change, is one that has a great impact on the elements and the combinations of elements used in the ensuing inventions (Dahlin & Behrens, 2005). It is also worth taking into account the relationship between innovation, invention and any technological change. Very simply, any invention is a useful and novel idea which is not obvious to the field experts based on patent law, and from the other hand, there are some novel technological solutions that are turned into innovations while they are not accepted as inventions according to patent law.

Based on the mentioned researches results, it can be considered that the definitions of radical technological changes are deployed in two levels; from a wider perspective, they consider technological trajectory whereas at a more detailed level, they consider radical invention. Technological trajectory in the former is defined in respects to the technology paradigm and in the latter, radical invention is defined by types of changes and improvements.

Similar to the scientific paradigm (Kuhn, 1962), a technology paradigm is defined as a model and a pattern of solutions of selected technological problems, based on selected principles derived from natural sciences and on selected materials. Therefore, a technological trajectory is considered as the pattern of normal progress and problem solving activity, on the ground of a technology paradigm. In other words, a technology paradigm embodies strong prescriptions on the directions of technical change to pursue, and those to neglect. Once given these technological and economic dimensions, it is also possible to obtain, broadly speaking, an idea of "progress" as the improvement of the trade-offs in relation to those dimensions (Dosi, 1982).

On the other hand, from a more detailed perspective, radical invention is defined versus the concept of incremental invention. Many studies distinguish between run-of-the-mill inventions, often labeled incremental, from those inventions that break with traditions in a field, often labeled radical, discontinuous, generational, or breakthrough (Cooper & Schendel, 1976; Anderson & Tushman, 1990; Christensen & Rosenbloom, 1995; Tripsas, 1997). Continuous changes are often related to progress along a technological trajectory, while discontinuities are associated with the emergence of a new paradigm (Dosi, 1982).

Despite common acceptance in defining radical invention versus continuous invention, few studies however, clearly define the difference between these two categories. Even fewer studies, in addition to lacking definitions, measure the difference between radical and incremental inventions; they offer little guidance regarding ways of identifying and validating if, and when, an invention is radical (Dahlin & Behrens, 2005).

In accordance to the scenario matrix (Fig. 2) for clarifying various kinds of innovations, there are some economic theories that approach the definition of radical technological change by involving the concepts of market and technology in the technological changes. The first approach points to market forces as the main determinants of technical change; these are known as demand-pull theories. The second approach defines technology as an autonomous or quasi-autonomous factor, at least in the short term, where the corresponding theories are known as technology-push theories (Pavitt & Wald, 1971; Rosenberg, 1976; Mowery & Rosenberg, 1979; Pavitt & Soete, 1980; Soete, 1981; Dosi, 1982). Such a clear-cut distinction is of course hard to make in practice, but remains useful for the sake of exposition (Dahlin & Behrens, 2005).

Researches within the fields of management and design, approach these determinants in a more detailed level. They add design as a driver for innovation along market and technology. In this perspective, design deals with the meanings that people give to products, and with the messages and product languages that one can devise to convey that meaning (Verganti, 2008). In other words, design goes back to the latin de signare, meaning to make something, distinguishing it by a sign, giving it significance, and designating its relation to other things, owners, users or gods (Krippendorff, 1989). This semantic dimension of design has also been actually recognized and underlined by several design scholars and theorists (Heskett, 1990; Cooper & Press, 1995; Buchanan & Margolin, 1995; Petroski, 1996; Friedman, 2003; Karjalainen, 2003; Lloyd & Snelders, 2003; Bayazit, 2004; Norman, 2004; Redström, 2006). Researches in marketing, consumer behavior, and anthropology of consumption has also demonstrated that the affective/emotional and symbolic/ sociocultural dimension of consumption is as important as the utilitarian perspective of classic economic models, even for industrial clients (Douglas & Isherwood, 1980; Csikszentmihalyi & Halton, 1981; Fournier, 1991; Sheth et al., 1991; Kleine et al., 1993; Mano & Oliver, 1993; Brown, 1995; Du Gay, 1997; Holt, 1997; Holt, 2003; Bhat & Reddy, 1998; Schmitt, 1999; Pham et al., 2001; Oppenheimer, 2005; Tsai, 2005). This definition allows design to be linked more precisely with other theories of innovation (Garcia & Calantone, 2002) and its peculiar nature to be better pointed out.

By considering such definition for design, design-driven innovation is considered as a kind of innovation where innovation starts from comprehending subtle and unspoken dynamics in socio-cultural models, and results in proposing radically new meanings and languages that often imply a change in socio-cultural regimes (Verganti, 2008). Figure 3 shows the design-driven innovation within the technology-push and market-pull approaches.

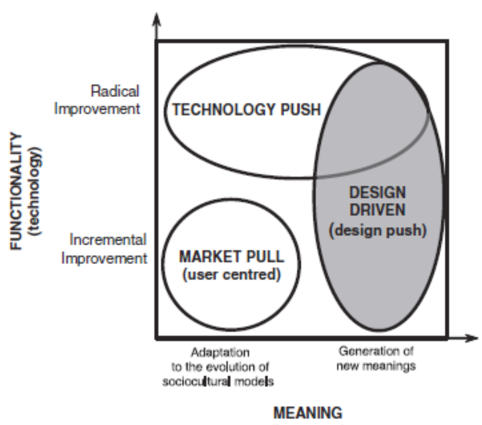


Figure 3 - Innovation Strategies (Verganti, 2008)

The figure shows that these three drivers can be interpreted along two dimensions; meaning and functionality. If functionality aims at satisfying the utilitarian needs of customers, the product meaning meets their affective and socio-cultural needs. Designers give meaning to products by using a specific design language through a set of signs, symbols, and icons (of which style is just an example) that delivers the message.

As picture shows along this new considered driver, the scope of market-pull and technology-push innovation can be clarified as below (Verganti, 2008):

- Market-pull innovation is an innovation that starts from the analysis of user needs and subsequently searches for the technologies and languages that can actually satisfy them.
- Technology-push innovation is the result of the dynamics within technological research.

The overlap between technology-push and design-driven innovation in the upper left corner of Figure 3 highlights that breakthrough technological changes are often associated with radical changes in product meanings. In other words, shifts in technological paradigms are often coupled with shifts in socio-cultural regimes (Geels, 2004). Thus considering the three-driver model in clarifying the scope of innovation, breakthrough innovations are a critical kind of next generation of technical systems for companies. It is worth taking into account that the more radical an invention, the less likely it is to be commercialized (Shane, 2001; Dahlin & Behrens, 2005) as the next generation of a technical system.

Studies focusing on the sources of novelty argue that radical novelty is achieved through recombining already established elements (Fleming, 2001), or by introducing and bringing in an established element into a new setting (Hargadon & Sutton, 1997; Van de Poel, 2003). In both cases, the investigators imply that radicalness is a combination of elements and settings not previously observed. Some other researches show that radical innovation (Bledow et al., 2009) and radical invention (Altshuller, 1988) are results of solving contradictions. The TRIZ method proposes a set of rules to resolve a broad variety of contradictions (Altshuller, 1988). Some recent researches extend TRIZ into the Generalized Contradiction model, in which combinations of contradictions are identified for given engineering problems (Dubois et al., 2009).

Reviewing previous relevant research, various definitions highlight the characteristics of the next generation of technical systems; the Table 2 summarizes this research.

Next generation of technical systems

Relevant researches	Summarized characteristics
1. Kind of innovation: Next generation of technical systems are a kind of innovation; innovation is defined as a novel idea turned into an artifact that successfully addresses market needs and therefore is accepted by customers (Burki & Cavallucci, 2011).	- A novel idea turned into an artefact that successfully addresses the market needs and accepted by customers
2. Kind of radical innovation: An innovation is a radical one when something completely new or significantly different appeared, and respectively an innovation is an incremental one when just some degree of change is observed (Schilling, 2010).	- A radical one is when something completely new or significantly different appeared
3. Kind of radical technological changes in respect to the technology-market scenario matrix: Radical technological change is defined in relation to technology and market as the two main factors in configuring different kinds of innovation (Allen, 1986): - Radical innovation: significant changes in the technical system by applying new technology (either in hardware, software or orgware) for a new market (new users or new requirements of same users); - Technology substitution: significant changes in the technical system only by applying new technology for the same market.	- Significant changes in the technical system by applying new technology (in either hardware, software or orgware) for a new market (new users or new requirements of same users) - Significant changes in the technical system only by applying new technology for the same market.

4. Core of radical technological changes: Researches mostly labels radical technological change when a radical invention has been successful in converting an industry (Dahlin et al., 2005). More focused and detailed discussions assume that there is one determining invention that initiates a new technological trajectory; this particular invention is not previously observed in that particular setting, which starts the chain of improvements or constitutes the core of the change (Silverberg, 2002). - Very simply any invention is a useful and novel idea which is not obvious to the field experts based on patent law. - A technology paradigm is a model/pattern of solutions of selected technological problems, based on selected principles derived from natural sciences and selected materials. A technological trajectory is considered as the pattern of normal progress and problem solving activity on the ground of a technology paradigm (Dosi, 1982).	- A determining invention that initiates a new technological trajectory - Useful and novel idea which is not obvious to field experts - Constitutes the core of the change - Model and pattern of progress and problem solving activity on the ground of a technology paradigm (based on selected principles derived from natural sciences and on selected material technologies)
5. A breakthrough innovation by considering the design as an effective factor: the next generations of technical systems are known as breakthrough innovations; they satisfy the same or widen expectations of system users with less costs, harms and efforts and therefore conquer the market dominantly. - The overlap between technology-push and design-driven innovation highlights that breakthrough technological changes are often associated with radical changes in product meanings. Design-driven innovation starts from the comprehension of subtle and unspoken dynamics in socio-cultural models and results in proposing radically new meanings and languages (Verganti, 2008).	- A breakthrough innovation which satisfies the same or wider expectations of system users with less costs, harms and efforts and therefore conquer the market dominantly. - A breakthrough technological change associated with radical changes in product meanings (new meanings and languages that often imply a change in sociocultural regimes)
6. Considering commercialization: the more radical an invention, the less likely it is to be commercialized (Shane, 2001; Dahlin & Behrens, 2005) as the next generation of a technical system.	- The more radical an invention, the less likely it is to be commercialized.
7. Resources of radical invention: Radical novelty is achieved through recombining already established elements (Fleming, 2001) or by introducing and bringing in an established element into a new setting (Hargadon & Sutton, 1997; Van de Poel, 2003). Radical innovation (Bledow et al., 2009) and radical inventions (Altshuller, 1988) are the results of resolving contradictions.	- Radical novelty is achieved through recombining already established elements or by introducing and bringing in an established element into a new setting. - Radical inventions are results of resolving contradictions.

Table 2 – Summarized literature related to the characteristics of a next generation of technical system

Table 2 states previous researches in a way that the characteristics of the next generation of technical systems are conceptually completed; it starts from the definition of innovation in the widest scope to the definition of breakthrough innovation as a more detailed one. In total, the next generation of technical systems is a kind of breakthrough innovation (Geels, 2004) which is defined by the overlapped characteristics between the outcomes of the technology-push innovation (Dosi, 1982) and design-driven innovation (Verganti, 2008). In other words, the next generation of technical systems is the version of the system consisting of radical technological change and radical meaning change for existing or new customers. Radical novelty, which is in the core of the next generation of technical systems, is achieved through recombining already established elements (Fleming, 2001) or by introducing and bringing in an established element into a new setting (Hargadon & Sutton, 1997; Van de Poel, 2003) and it provides new technological trajectory for solving the problems of the system (Dosi, 1982). Radical novelty is result of -

resolving a contradiction (Altshuller, 1988). The summarized characteristics can be classified into three categories of technology, market and design, corresponding to the drivers of radical and breakthrough innovation.

Innovation drivers	Mentioned characteristics in previous researches
Technology	- Completely new or significantly different performance or functionality characteristics - New technology (in either hardware, software or orgware) - Not obvious to field experts - Constitutes the core of the change - New combinations of selected principles derived from natural sciences and selected material - Less costs, harms and efforts - Recombining already established elements - Bringing in an established element into a new setting - Resolving contradictions - Satisfying the forecasted performance and functionality, time and space - Using slack resources
Market	- Accepted by customers - Same market (same requirements of existing users) with changes in the technology - New market (new users or new requirements of existing users) with changes in the technology - Useful - Same or wider expectations - Conquer the market dominantly - Acceptable level of novelty by the market
Design	- New meaning or new language

Table 3 - Characteristics of a next generation of technical system in three classes of technology, market and design

As Table 3 shows, most of the characteristics are mentioned in the literature are related to technology, and then market, supporting the idea that technological changes and market changes are more focused by companies in terms of research and development. It is expected that all above characteristics and specially the design aspect in more detail level, must be addressed in supportive methods for forecasting and designing the next generation of the technical systems. The forecasting methods are studied briefly in next section.

It can be concluded that despite the importance of next generation of technical systems for the companies, this version of the system is not addressed directly in the literature. In this section, the literature was reviewed to study different kind of innovations to highlight the crucial characteristics which are critical in designing the next generation of technical systems or their characteristics which affects the market and competitors radically. All the above characteristics must be considered in a set of criteria for assessing any idea as having potential for the next generation of systems.

1.2. Methods and tools for approaching the next generation of technical systems

Considering the main function of a firm's R&D department, different classifications for R&D tasks are developed and applied in the companies: New Product Research, New Product Development, Existing Product Updates, Quality Checks and Innovation. New product research and development, Product maintenance and enhancement, and Quality and regulatory compliance are a three-class description of the same tasks. The next generation of technical systems, breakthrough innovation, and radical technological changes are concerns for R&D departments along their responsibility for the new product development. These concerns are pursued in R&D departments for the next generation of technical systems through two approaches – forecasting and design. Each approach is now studied separately.

1.2.1. Technology forecasting methods

To be prepared for innovation in general and specifically for the next generation of technical systems, some information must be known in advance by decision-makers such as the time of emergence, the characteristics, the way characteristics can be achieved in a product or process, and the role players. Researchers in the field of future technologies differentiate between technology forecasting, technology foresight, technology intelligence, technology road mapping, and technology assessment (Porter & Cunningham, 2004). The research community has tried to address the mentioned information for breakthrough innovation and radical technological changes through technology forecasting (TF) methods. A forecast usually answers the question "What will happen?", while a plan describes "What should happen". However, the definitions and expectations of technology forecasting methods are quite fuzzy in literature (Roper et al., 2011), and it can be interpreted in different ways depending on the characteristics of any specific research field.

Forecasting is described as a need to anticipate uncertainty information about the future (Armstrong, 2001). Respectively a technology forecasting method is a systematic process which aims at producing valuable predictions by describing the emergence, performance, features or impacts of a technology at some time in the future, where its usefulness is conditional to the final decision-maker (Working Group, 2004). In fact, a suitable and reliable technology forecasting method should bring, at least, new knowledge to the users and related beneficiaries about the value of technology forecast; this is presented through event, time, and place characteristics (Kucharavy & De Guio, 2005). Technology forecasting methods need four essential elements in order to bring useful knowledge to the decision-maker: the technology being forecast, characteristics statement, time for forecast and probability (Martino, 2003).

It is worth considering some parts of the forecasting results such as performance and functionality characteristics of the technology (product, machine or process) under analysis, are crucial in the level of technology and R&D management. Furthermore, the time and place of emergence of the technology are important at the strategic level for the companies. Forecasting performance and functionality characteristics lead R&D departments to design the technology and propose the state(s) of technology that can cover the forecasted value.

There are no universal forecasting methods and, in fact, more than one hundred are available in the literature (FORMAT deliverable 2.3, 2013-http://www.format-project.eu/deliverables). Since many technology forecasting methods are available in the literature, several attempts have been made to integrate and cluster them (Gordon & Glenn, 2003; Technology Future Analysis Working Group, 2004). As technology forecasting is understood and used differently depending on the field of research, the developed methods are different respectively. For instance, economy and management rely on forecasting based on statistical prediction of the market state, such as anticipation of quantitative values by building complex models of extrapolation (Roper et al., 2011).

Expert opinion, trend analysis, monitoring and intelligence, statistical, modeling and simulation, scenarios, valuing/decision/economics, descriptive and matrices, and creativity are a well-known nine-category classification that organizes in accordance to the characteristics of the methods (Technology Future Analysis Working Group (TFAWG), 2004). In this classification, soft (qualitative) and hard (quantitative) methods are highlighted. The qualitative methods correspond to those methods that create a future scenario based on users' knowledge and judgment, whilst the quantitative methods are those that use quantitative regression and, in some cases, a set of rigorous rules to envision the future. Furthermore, this classification shows how forecasting is developed by two sub-classes; exploratory methods and normative methods. Exploratory methods begin from the present and show events and trends that might happen, while normative methods begin from the future, asking what trends and events would make it possible. Among the nine categories expert opinion, trend analysis, monitoring, modeling, and scenarios are five categories which are used more by practitioners (Roper et al., 2011). It is worth considering that in this classification, the selection of a forecasting method is suggested mainly by data availability rather than by users' knowledge. Some research highlighted that the usefulness and accuracy of a method are strongly influenced by users, therefore some classifications are proposed based on knowledge sources instead of data availability

(Armstrong, 2001). Technology forecasting methods based on knowledge sources are classified into judgmental (exploiting the user's knowledge and experiences qualitatively) and statistical (exploiting the available data) sources.

With a broader perspective, there is also a classification based upon the conceptual models behind developing the forecasting method for two hundred methods available in literature (FORMAT deliverable, 2.3, 2013-http://www.format-project.eu/deliverables). Causal, Phenomenological, Intuitive, and Monitoring and mapping are a four-category classification proposed based on the conceptual models behind developing the forecasting method (Kucharavy, 2013). For instance, analogy, morphological analysis, laws and patterns of system evolution are classified as causal models; extrapolations of time series data, regressions as phenomenological models; Delphi surveys, structured and unstructured interviews as intuitive models; and finally scanning of literature and published sources, scenarios, mapping existing information are classified as monitoring and mapping (FORMAT deliverable, 2.3, 2013-http://www.format-project.eu/deliverables).

The variety of technology forecasting methods highlights the various analysis needs and requirements in respect to the nature and desired characteristics of the technology under analysis, desired time period and probability. In the scope of this research, it is important to know which classes of technology forecasting methods alone or in combination of each other, are used more for forecasting breakthrough innovations and radical technological changes, and which are compatible with design and R&D engineers' knowledge too. The most general models and methods used to describe and measure innovation radicalness are (Dahlin & Behrens, 2005): (1) technology cycles (Anderson & Tushman, 1990); (2) s-curves (Foster, 1985) and technological trajectories (Dosi, 1982; Christensen & Rosenbloom, 1995); (3) hedonic price models (Henderson, 1993); and (4) expert panels (Dewar & Dutton, 1986). For example, technological radical innovation and technological substitution can be described through the technology evolution path by a logistic growth curve (Griliches, 1957). Previous research used for showing emerging technologies and radical changes include patent analysis and technology foresight tools such as scenario planning and growth curve analysis (Daim et al., 2006), fuzzy Delphi method (Shen et al., 2010), Gompertz curve (Bengisu & Nekhili, 2006), on two-level self-organizing map, analytic hierarchy process, and data envelopment analysis-assurance region of hybrid approach (Yu et al., 2013), technology cluster analysis (Lee et al., 2015), network approach (Prabhakaran et al., 2015) and analysis of chronological changes in research topics by text mining (Furukawa et al., 2015).

Although the research shows more usage of the above mentioned methods, the accuracy of forecasting results must be considered too. With respects to the least expectation of forecasting result, an invalid forecast may be a result of a mistake, in terms of event (what happened), time (when), and place (where). In general, in order to judge a technology forecasting result, it is necessary to be able to measure both a forecasted value and a real value; the difficulty arises because these two values are separated in time (Kucharavy & De Guio, 2005). There is some research that discusses in more detail the accuracy of forecasting results, in relation to the timescale of forecasting the technology under analysis; that being, short, medium and long term. It is proposed to use the life cycle of a product/technology from the market viewpoint as a unit for measuring the difference between short-term, medium-term and long-term forecasts (Kucharavy & De Guio, 2005). Literature shows most mistakes are made in medium and long-term forecasting dealing with new-to-the-world and radically different technologies and products, due to lack of data for any analysis (Schnaars, 1989; Kahn, 2002; Kucharavy & De Guio, 2007). The lack of data is a critical issue which is shown itself in forecasting results include time of emergence, the characteristics, and the state how the characteristics can be achieved in a product or process in terms of event, time, and place characteristics.

Apart from the shortages mentioned in the literature for effectiveness of technology forecasting methods in radical innovation and consequently next generation of technical systems, the nature of technology forecasting methods can be discussed respect to the characteristics of the next generation of technical systems. Considering reviewed literature in technology forecasting methods respect to the reviewed literature in characteristics of the next generation of technical system, reveals the next generation of technical systems is kind of breakthrough innovation, include new meaning (new message and new requirement) for product, which a radical novelty, by recombining already established elements or bringing in an(/some) established element(s) to the set, can generate it. Therefore, a specific technology forecasting method for anticipating the next generation of technical systems, can start by design issues instead of technology and market issues.

There are few studies about the methods approach design-driven innovations include radical invention precisely, and literature shows the most used technology forecasting methods rely on analysis of data of the current and future market and/or the data of available or future technologies. Some of TRIZ-based technology forecasting methods and some similar methods which propose some principles and heuristics for design, can be used more than other methods for the aim of this research. It is worth considering that these methods are more design focused, causal, qualitative, normative, and judgmental so the logic of the game can benefit of these characteristics.

1.2.2. Design Heuristics

While technology forecasting methods are developed to directly support R&D engineers for designing the next generation of technical systems, this task is still mostly followed in typical design sessions by focusing upon improving the characteristics of design proposals; this is mostly through using effective design heuristics, models and methods. On the other hand, through reviewing the technology forecasting methods in previous section, it is discussed for forecasting and designing the next generation of technical systems, design heuristics and principles must be considered besides the technology and market information. Therefore, in this section the design heuristics are reviewed.

In the domain of engineering design, design is studied through considering its broad sections using the terms, the design 'problem', the design 'process', the design 'type/output/proposal', the design 'activity/ move/ action' and the design 'organization/team/personnel' (Pahl & Beitz, 1996; Ulrich & Eppinger, 1995; Ullman, 2002). The studies in the field of design, discuss different design problems and consequently different kinds of design actions and moves, their sequences and their portions in design process, and also the presence, relations and effects of different kinds of precedents and fixations in quantity and qualities of requested and expected design proposals. These studies follow by studying the effective or preventive information, knowledge, skills and even unconscious capabilities of designers in interpreting, changing and modifying initial information of design, using their own skills and knowledge, or using provided knowledge for them while they try to generate solutions as design proposals. These findings and patterns are considered as potential hints for design heuristics, which are mostly derived from the cognitive studies of professional designers while performing a variety of different design tasks. Design heuristics as known concept in design cognition are the hints and tricks which are used as a starting point for transforming an existing concept to design solution (Yilmaz & Seifert, 2011) by providing strategies to access readily information needed to guide problem-solving (Pearl, 1984). 'Use an environment as part of the product' and 'Utilize opposite surface' are two examples for design heuristics. The former is observed in designs where the living or artificial environment is incorporated into the product by designing around it, rather than distinguishing from it; whereas the latter guides the designer towards developing uses for spaces afforded by an existing concept (Yilmaz & Seifert, 2011). It is worth mentioning the term heuristic points that a heuristic does not guarantee reaching the best solution, or even a solution, and it just provide an easier way to generate an acceptable solution (Yilmaz & Seifert, 2011).

Design heuristics can be studied as cognitive heuristics (Nisbett & Ross, 1980) that are captured in the designer's memory, or heuristics are applied in design proposals (Yilmaz & Seifert, 2011). Cognitive research shows that experts utilize heuristics effectively, and this skill distinguishes them from novices (Klein, 1998). Expert designers apply cognitive heuristics in order to improve the variety, quality, and creativity of potential designs, though they mostly use them unconsciously. Experienced designers use strategic knowledge while do not identify their strategic knowledge (Kavakli & Gero, 2002). This pattern fits with findings on the application of procedural skills (Anderson, 1982) and supports the opinion that the heuristics must be so well learned to be used as procedural skills, because conscious access to their content is limited. A Research also shows that novices are provided heuristics for creating new concepts, they are able to apply heuristics easily to a simple product design task, and that the usage of heuristics increases the creativity of concepts (Yilmaz & Seifert, 2011).

Several methods and methodologies like SCAMPER (Eberle, 1995), Synectics (Gordon, 1961), and TRIZ (Altshuller, 1988), have proposed wide variety of product or process heuristics to be used by designers in the conceptual design phase. SCAMPER and Synectics both provide very broad heuristics at an abstract level such as substitution, rearranging, iterating, and eliminating, without providing much guidance about their application. But on the other side of spectrum, the TRIZ heuristics were designed to address specific technical trade-offs in engineering design (Altshuller, 1988). Through analysis of patents and used principles and heuristics in them, TRIZ provides a systematic method for finding and using analogies in the form of a technical matrix of 39*39 common engineering problems and 40 possible solution types (Yilmaz & Seifert, 2011). In contrast to the very general and very specific heuristics, a research proposed heuristics in the intermediate level. This research assumed the heuristics in the intermediate level would provide a closer link to their applications in design and highlighted the usage of 68 intermediate level product heuristics within and between product, and 10 process heuristics, by investigating 218 design proposal generated by a professional designer for a task; it claimed that each single proposal includes 1 to 18 heuristics (Yilmaz & Seifert, 2011).

In addition, other researches discuss some heuristics for innovative or novel design without referring or applying them as an effective heuristic. Some researches refer to "finding and solving the contradicting requirements through specific resolution rules for tackling infeasible design problems when the requirements of the problem are not fully-specified and the optimization is not useful" (Altshuller, 1988; Bledow et al., 2009; Dubois et al., 2009). Another research clarified five common templates in product innovation including introducing dependencies between previously unrelated variables, producing control dependencies between unrelated components, eliminating one component of the design with and without changing the main functionality, and splitting one component into subcomponents that jointly have the same functionality as the original component (Goldenberg et al., 1999). It is also suggested by another research that "changing the nature of relations between design variables without modifying the design logic for the considered technology and without adding new types of components" can be considered as a hint for innovative design. (Maimon & Horowitz, 1999).

Professional designers apply heuristics effectively and novices produce more creative ideas when provided heuristics, therefore the heuristics can be considered as an option for supporting R&D engineers in designing the next generation of technical systems. Design heuristics can be studied in three different categories; precedents, strategies and design professional models. The following sections review the previous researches on precedents, strategies and design professional models respectively.

1.2.3. Design precedents

Design cognition in general considers design as a dynamic process of transforming prior experience and knowledge into the form of design knowledge. Designers follow this dynamic process through generalization and typification of precedents according to required situations, constraints, and goals to embody the knowledge across different domains (Oxman, 1990). This process is a kind of reflection-in-action process in which designers have reflective conversation with the situation (Schön, 1983) while treating the given problems as ill-defined problems (Thomas & Carroll, 1979). Problems are framed by designers to perceive current situation (Dorst & Dijkhuis, 1995).

Precedents in design are defined as prior knowledge and experiences, used in designing from the memory of designers, or any other sources are provided by designers, directly or by assistantship of facilitators or researchers of design sessions (Jones & Thornley, 1963; Tulving, 1991; Visser, 1995; Eckert & Stacey, 2000; Pasman, 2003; Lawson, 2004; Dix, 2004). To study the effects of precedents in design, precedents can be proposed as stimuli through the type of information in different modality. Prior solutions of the target technical system (Pasman, 2003; Lawson, 2004; Eilouti, 2009), the collection of examples of other technical systems close or far to the target technical system, hints for considering requirements (Downing, 2003), templates describing an entire class of solutions (Senbel et al., 2013), hints about specific characteristics of prior solutions or other examples such as function and behavior (Doboli & Umbarkar, 2014), and hints about specific characteristics among prior solutions or examples such as similarities and dissimilarities, are some of precedents discussed in the literature and used as stimuli. Precedents are provided for designers during design sessions in the type of simple singular representation of previous knowledge and experiences where a specific concrete example is used to develop a new solution, or structural representation of previous knowledge and experiences, where more general and abstract level design solutions are derived from a number of examples (Ball et al. 2004). One or a collection of prior solutions for the target technical system, relevant designs and examples of other technical systems close or far to the target technical system are considered as a kind of simple representation of precedents. On the other hand, heuristics, ways of designing, templates of an entire class of solutions, solution characteristics and hints are different kinds of structural representations of precedents.

While some researches discuss the least characteristics of repertoire of precedents, like a large magnitude pool of solution (Simonton, 2010), numerous, detailed, and consistent to offer a comprehensive sampling of the possible features of solution spaces (Akin, 2002; Senbel et al., 2013), some others discuss in more detail the various kinds of consistency of repertoire of precedents, which are presented as different kinds of stimuli: (i) more generalized and interwoven knowledge (Oxman, 1990), (ii) pictorial-based or text-based representations (McKoy , 2001), (iii) functionally classified (Nijstad et al. 2002), (iv) classified based on FBS framework (Benami & Jin, 2002), (v) classified based on analogy principles (Eckert et al, 2005; Christensen & Schunn, 2007; Blanchette & Dunbar, 2001; Leclercq & Heylighen, 2002; Ball et al., 2004) such as those based on domain knowledge (Suwa & Tversky, 1997), (vi) close-domain knowledge in the form of references to past design which are often used in process planning, cost estimation, and evaluation of concepts for a new product (Eckert et al, 2005), (vii) cross-domain knowledge (Casakin & Goldschmidt, 1999; Christensen & Schunn, 2007; Leclercq & Heylighen, 2002) and (viii) far-field knowledge (Gick & Holyoak, 1980; Casakin & Goldschmidt, 1999).

Previous researches show that the effects of different precedents are mostly studied in respect to the quantity, novelty, variety of the design results; very few studies consider quality and utility too. Precedents in general help designers to find new ideas (Eilouti, 2009), increase the number of solutions (Tseng et al., 2008), and avoid the rediscovery of well understood solutions (Akin, 2002). The number of ideas is correlated to the number and commonality of input precedents as they stimulate more associations (Dugosh & Paulus, 2005). A larger pool of solutions increases the number of combinations inspired by the pool (Simonton, 2010) and also most kinds of stimuli configured of precedents, such as providing the ideas of other group members to each individual group member (Nijstad et al., 2002) and contextual cueing through hinting at an area for a solution (Liikkanen & Perttula, 2006), increase productivity in terms of the number of ideas generated. While most researches show a positive effect of precedents on the quantity of ideas, some researches show that productivity is uninfluenced by stimuli configured of precedents, such as examples (Smith et al., 1993). It is even claimed that example solutions reduce the quantity of solutions that designers generate in response to a brief (Jansson & Smith, 1991; Purcell & Gero, 1992).

Previous researches show creativity or novelty of results are promoted by stimuli which are prepared and presented as structural precedents at an abstract level (Zahner et al., 2010; Goldschmidt, 2011) during early design stages; creativity then decreases during later design iterations or when the participant has been unable to solve the design problem for difficult open-ended design problems (Tseng et al., 2008). To study the novelty and creativity of design proposals, fixation must be considered too as it is generally supposed that fixation reduces the creativity and novelty. Fixation is a concept that refers to the conscious or unconscious dependencies of designers to various forms of tendencies, such as dominant designs and normal technologies (Abernathy & Utterback, 1978; Tushman & Anderson, 1986; Anderson & Tushman, 1990; Constant, 1980), existing solutions provided as examples (Jansson & Smith, 1991), frames of reference (Akin & Akin, 1996), prior solutions (Tseng et al., 2008), symbolic aspects and designer signature style (Lawson, 2004), and learning processes and the design process itself (Hatchuel et al., 2011). Research results show stimuli such as exposure of dissimilarity of design examples (Marslen-Wilson & Tyler, 1980), generalized and interwoven representation of previous knowledge through a higher level of abstraction (Oxman, 1990), with more variety (Nijstad et al., 2002), and novel artworks (Ishibashi & Okada, 2006) enhance creativity. Furthermore, far-field as a kind of cross-domain analogies increases the novelty of solutions (Tseng et al., 2008; Chan et al. 2011; Fu et al., 2013; Gonçalves et al., 2013); this finding is promising as some other research results have discussed the significant role of far-field analogies in outstanding inventions and discoveries (Dunbar, 1997; Weisberg, 2009). The distance serves to promote the construction of analogies (Linsey et al., 2010; Moreno et al., 2014; Moreno et al., 2015) while even cross-domain stimuli (e.g. in bio-inspiration) can lead to fixation on specific features, rather than general principles (Mak & Shu, 2008; Helms et al., 2009). Other research show that pictorial-based representations of examples increases the novel solution concepts compared to text-based examples (McKoy et al., 2001). Although most design fixation studies focus on the effects of visual or verbal stimuli, experiments have shown that fixation can be reduced through dissecting physical products (Toh et al., 2013) and by constructing physical models or prototypes (Kershaw et al., 2011; Youmans, 2011; Crilly, 2015). On the other hand, there is also some researches which raises doubt about the effects of singular precedents on novelty and creativity. These researches discuss that providing examples (Smith et al., 1993) and more precedents (Heylighen et al., 2007) may constrain the novelty of ideas, as people simplify and eliminate to cope with higher complexity (Chua & Iyengar, 2008), however the ability to handle more design options increases with experience (Chua & Iyengar, 2008). Other researches show previous solutions reduce creativity due to fixation (Jansson & Smith, 1991; Smith et al., 1993) as people tend to create something that highly resembles the appearance of existing solutions, even though they were asked to design an unordinary solution (Ward, 1994). A recent research shows that precedents such as previous solutions and solution features, don't increase solution novelty as solutions converged toward a few dominant designs (Doboli & Umbarkar, 2014). This research shows that creativity increases if new requirements are added to the original problem specification (Doboli & Umbarkar, 2014); whilst deeper studies show that incremental modifications of requirements do not increase novelty (Doboli & Umbarkar, 2014). It is also worth considering that the degree of fixation may be affected by the modality of solution examples. A physical example can cause a higher degree of fixation compared to a pictorial one, but it can also facilitate the generation of non-redundant ideas (Viswanathan & Linsey, 2013). Designer may be unaware that they are fixated at the time of fixation (Bilalić et al, 2008b; Linsey et al., 2010), may not in retrospect believe that they were fixated (Bilalić, & McLeod, 2014), and may not have insight into the cause of defixation (Maier, 1931). It is claimed that awareness of fixation can decrease this effect in design through having given knowledge of fixation and a hint about the fixation (Lane & Jensen, 1993; Crilly, 2015); receiving education about fixation has therefore the potential to mitigate its effects (Howard et al., 2013). Even having subjects write 'don't be blind' on a piece of paper sometimes helped to reduce the prevalence of fixation effects (Luchins, 1942). An awareness of fixation might be developed over repeated projects and in response to feedback that reveals prior fixation episodes (Crilly, 2015).

Precedents help designers to perceive deeper and to better interpret results (Eilouti, 2009; Senbel et al., 2013), they expose hard-to-anticipate and global properties (Senbel et al., 2013), and they increase utility (Doboli & Umbarkar, 2014). Precedents improve design quality and utility throughout all iterations (Doboli & Umbarkar et al., 2014). In general, the usage of precedents may reduce the diversity of design solutions (Doboli & Umbarkar, 2014) as it is shown that example solutions reduce the variety (Jansson & Smith, 1991; Purcell & Gero, 1992). In more detailed studies, it is seen that although the presentation of similarities of examples decreases the variety of ideas (Marslen-Wilson & Tyler, 1980), more ambiguous stimuli tend to be less fixating, enabling designers to produce more and more diverse ideas as a result (Benami & Jin, 2002).

Reviewing the above mentioned literature highlights the different kinds of precedents, though only the effects of some of them are studied on quantity, novelty and quality of design proposals. These are summarized in Table 4.

No.	Stimuli	Type of stimuli	Effects on design proposal	Reference
1	Precedents	Precedents	Increase quantity	Tseng et al., 2008
2	Precedents	Precedents	Help to find new ideas	Eilouti, 2009
3	Precedents	Precedents	Help to avoid rediscovery of well understood solutions	Akin, 2002
4	Larger pools of previous solutions	Singular precedents	Increase the number of combinations inspired	Simonton, 2010
5	ideas of other group members	Singular precedents	Increase quantity	Nijstad et al., 2002
6	Contextual cueing	Structural precedents	Increase quantity	Liikkanen & Perttula, 2006
7	Examples	Singular precedents	No influence on quantity	Smith et al., 1993
8	Examples	Singular precedents	Reduce quantity	Jansson & Smith, 1991; Purcell & Gero, 1992
9	Precedents in abstract level	Structural precedents	Increase novelty	Oxman 1990; Zahner et al., 2010; Goldschmidt, 2011
10	Precedents during early design stages	Precedent	Increase novelty	Tseng et al., 2008
11	Dissimilarity of design examples	Structural precedents	Increase creativity	Marslen-Wilson & Tyler, 1980
12	Precedents with more variety	Precedent	Increase creativity	Nijstad et al., 2002
13	Novel artworks	Precedent	Increase creativity	Ishibashi, 2006
14	Far-field examples	Singular precedents	Increase novelty	Tseng et al., 2008; Linsey et al., 2010; Chan et al. 2011; Fu et al., 2013; Gonçalves et al., 2013; Moreno et al., 2014; Moreno et al., 2015
15	Far-field examples	Singular precedents	Increase inventions and discoveries	Dunbar, 1997; Weisberg, 2009
16	Cross-domain examples	Singular precedents	Lead to fixation on specific features rather than general principles	Mak & Shu, 2008; Helms et al., 2009
17	Pictorial-based representations of examples	Singular precedents	Increase novelty	McKoy et al., 2001
18	Dissecting physical products	Singular precedents	Reduce fixation	Toh et al., 2013
19	Constructing physical models or prototypes	Singular precedents	Reduce fixation	Kershaw et al., 2011; Youmans, 2011; Crilly, 2015
20	Examples	Singular precedents	Reduce novelty	Smith et al., 1993
21	More precedents	Precedent	Reduce novelty	Heylighen et al., 2007; Chua & Iyengar, 2008
22	Previous solutions	Singular precedents	Reduce novelty	Jansson & Smith, 1991; Smith et al., 1993
23	Previous solutions	Singular precedents	No influence on novelty	Doboli &Umbarkar, 2014
24	Solution features	Structural precedents	No influence on novelty	Doboli & Umbarkar, 2014
25	New requirements	Structural precedents	Increase novelty	Doboli & Umbarkar, 2014
26	Incremental modification of requirements	Structural precedents	No influence on novelty	Doboli & Umbarkar, 2014
27	Physical example	Singular precedents	More fixation	Viswanathan & Linsey, 2013
28	Physical example	Singular precedents	Help to generate non-redundant ideas	Viswanathan & Linsey, 2013

29	hint and education about the fixation	Structural precedents	Reduce fixation	Luchins, 1942; Lane & Jensen, 1993; Howard et al., 2013
30	Precedent	Precedent	Increase utility and quality	Doboli & Umbarkar, 2014
31	Precedent	Precedent	Reduce diversity	Doboli & Umbarkar, 2014
32	Examples	Singular precedents	Reduce diversity	Jansson & Smith, 1991; Purcell & Gero, 1992
33	Similarities of examples	Structural precedents	Reduce diversity	Marslen-Wilson & Tyler, 1980
34	More ambiguous examples	Singular precedents	Increase diversity	Benami & Jin, 2002

Table 4 - Previous studies about effects of different kind of stimuli on the design proposals

The Table 4 shows that among 34 studies, 8 studies discuss the effects of precedents generally, while 17 and 8 discuss the effects of singular and structural precedents respectively. Also the table shows that among 34 studies, that 6, 18, 5, 1 and 4 studies discussed the effects of precedents on quantity, novelty, fixation, utility and diversity respectively.

The studies in the table also show that most kinds of precedents increase quantity, while there are some studies which show that a singular representation of precedents are not effective in increasing quantity or even they reduce it. Furthermore, most kinds of precedents in general are mostly effective in increasing novelty and creativity, though there are some studies which show doubts about the positive effects of a singular representation of precedents on novelty. In other words, in order to increase quantity and novelty of design proposals, it is more convenient to apply a structural representation of precedents as stimuli. Additionally, among the different forms of stimuli configured of precedents, examples are used more as stimuli and can be applied to increase the number of ideas for the next generation of technical systems. The studies show that despite some doubts about the positive effects of examples on the quantity and novelty of design proposals (rows 7, 8, 16 & 20), they are positively effective (rows 12,13,14,15 & 17). Previous solutions are another form of precedent that are also effective in increasing novelty and diversity, if they are presented with more diversity and ambiguity (rows 4, 12 & 34); however, there are some doubts about any influence of them on novelty or even reducing novelty (rows 22, 23 & 24).

Above mentioned summary of related studies to the precedents in the field of design cognition, reveals that despite lots of researches about the effects of variety of structure, form, nature of knowledge, time scope, hierarchy of knowledge and their volume on the quantity and quality of design proposals, their specific contents and characteristics are not analyzed and discussed precisely. In other words, there are some researches discuss the effect of the knowledge of the different time scopes of the target system or hierarchy of the related systems to the target system or other systems (Gick & Holyoak, 1980; Wilson et al. 1980; Oxman, 1990; Jansson & Smith, 1991; Smith et al., 1993; Dunbar, 1997; Casakin & Goldschmidt, 1999; Leclercq & Heylighen, 2002; Nijstad et al., 2002; Downing, 2003; Pasman, 2003; Lawson, 2004; Eckert et al, 2005; Christensen & Schunn, 2007; Tseng et al., 2008; Weisberg, 2009; Eilouti, 2009; Linsey et al., 2010; Chan et al. 2011; Fu et al., 2013; Gonçalves et al., 2013; Doboli & Umbarkar, 2014; Moreno et al., 2014; Moreno et al., 2015) on the quality of design proposals, but they did not analyze the precise positions of the studied systems on the hierarchy of target system or the way to bring the necessary knowledge in to the target system especially in the case of designing radical innovations or the next generation of technical systems. The findings of these kind of researches can be used only as structuring general precedent-based heuristics, not specific heuristics right to the point.

1.2.4. Design strategies

Design strategy is an important subject in the design research field. Strategies are searched and defined as sequences of activities and moves in the design process related to problem formulation and solution generation phases, of which time to dedicated to them. The understanding of design strategies makes it possible to manage design activities more efficiently and consequently improve design proposals through the results of the process.

Understanding the design creative process will give insight into where and when resources should be focused in order to enhance creative performance and the quality of the product designed (Howard et al., 2008). Design cognition studies designers' thinking patterns and behaviors to discover the closest process designers experience through design. Design cognition in general considers design as a dynamic process of transforming prior experience and knowledge into the form of design knowledge. Designers follow this dynamic process through generalization and typification of precedents according to required situations, constraints, and goals to embody the knowledge across different domains (Oxman, 1990). Some review researches highlighted at least three main areas of interests in design cognition research for extracting design strategies; the process strategies that designers employ, how designers formulate problems, and how designers generate solutions (Cross, 2001).

Design problems are mostly open-ended that either they are incompletely specified or fully specified but seem unfeasible. In general, these kinds of problems are considered as ill-defined problems. Protocol studies show that designers treat the given problems as ill-defined problems (Thomas & Carroll, 1979). Ill-defined problems are approached and solved through co-evolving problem and solution. Rather than generating fully abstract relationships amongst the given information of the design problem and then deriving the appropriate object to be considered, designers generate a design solution and then improve its qualities. In other words, the designers straightly generate solutions or partial solutions before they fully formulate the problem. This is a reflection of the fact that designers are solution-led, not problem-led (Eastman, 1970).

Designers start by exploring the problem space, and find, discover, or recognize a partial structure of design space. That partial structure is then used to provide them with a partial structuring of the solution space, which they use to generate some initial ideas for the form of a design concept. They transfer the developed partial structure back into the problem space, and again consider the implications and extending the structuring of it. This cycle continues up to create a matching problem-solution pair (Cross & Dorst, 1998). Proposed initial ideas and solutions often directly remind designers of issues to consider so the problem and solution co-evolve (Kolodner & Wills, 1996). The creative leap as the crucial factor connects these two partial models by a concept which enables the models to be mapped onto each other. This bridge recognizably embodies satisfactory relationships between problem and solution (Cross, 1997).

Design procedures are iterative (Conradi, 1999). Iterative design includes successive iterations that continuously use previous solutions as starting points to create designs with new goals, extra functions, and substructures inspired by previous designs (Pugh & Clausing, 1996; Howard et al., 2008). The solution-focused nature of designer behavior appears to be the appropriate behavior for responding to ill-defined problems. The results show that the overall quality of design proposals is related to rapid alternation of activities (Atman et al., 1999).

There is a broad assumption that co-evolving of problem and solution in design proceeds in cycles of analysis-synthesis-evaluation activities. Although such patterns of design process activity frequently have been proposed or hypothesized, there has been little empirical confirmation (Gero & Kannengiesser, 2004). In addition to the short-term cycles of analysis-synthesis-evaluation, there is a trend over the whole design process to begin by spending most of the beginning time analyzing the problem, then mainly synthesizing the solution and finishing by spending most last time on the evaluation of the solution. In other words, a designer begins a conceptual design session by analyzing the functional aspects of the problem. As the session progresses, the designer focuses on the three aspects of function, behavior and structure through the cycles of analysis, synthesis and evaluation. Towards the end of the design session, the designer's activity is focused on synthesizing structure and evaluating the structure's behavior (Mc Neill et al., 1998).

Problem formulation is the second main class to review the results of design cognition studies in design strategies. The formulation of appropriate and relevant problem from an ill-defined problem, which is presented as a design brief, is not easy and it requires significant skills in gathering and structuring information, and judging the moment to move on to solution generation. Design problems are loosely defined by the client and other constraints are introduced by the designer from domain knowledge, or are derived by the designer during the exploration of particular solution concepts (Ullman et al., 1990). The generation of new task goals and redefinition of task constraints is a constant aspect of design behavior (Akin, 1978). In problem setting, designers select features of the problem space to which they choose to attend (naming) and identify areas of the solution space in which they choose to explore (framing) (Schön, 1983). Then there comes a time when the designers make a statement that summarizes how they see the problem and the structure of the situation that the problem presents (Lloyd & Scott, 1995). The work of framing is seldom done in one attempt at the beginning of a design process (Schön, 1988). Successful teams modify the frame five times sequentially, in contrast to the single frame used by unsuccessful teams. Unsuccessful teams also spend much more time on naming activities and identifying potential problem features, rather than on developing solution concepts (Valkenburg & Dorst, 1998). Problem structuring activities not only dominate the beginning of the design task, but also reoccur periodically throughout the task (Goel & Pirolli's, 1992). In general, successful groups in terms of creativity of their solutions, ask for less information, process it instantly, and consciously build up an image of the problem. They look for and make priorities early on in the process (Christiaans & Dorst, 1992).

The third main class of design cognition results for design strategies is considered the solution generation. Although designers change goals and constraints as they design, they stick to early solutions and their principal solution concept for as long as possible, even when detailed development of the scheme throws up unexpected difficulties and shortcomings in the solution concept (Rowe, 1987; Ullman et al., 1990). They produce various slightly improved versions until something workable is attained (Ball et al., 1994). If designers retrieved alternative solutions for a sub-problem, they quickly rejected all-but-one alternative through a trade-off analysis using a preferred evaluation criterion (Guindon, 1990a). The top designs are created by groups that chose to discard their initial design and start afresh with a new design concept as alternative (Smith & Tjandra, 1998). Generating few alternative concepts and generating a large number of alternatives are both equally weak strategies, leading to poor design solutions. Designers become fixated when having very few alternative concepts, while in the cases of large numbers of alternative concepts, they were forced to spend time on organizing and managing the set of variants. Successful designers are those operating a 'balanced search' for solution alternatives (Fricke, 1993; Fricke, 1996). It is worth considering that when the problem is precisely specified, designers generated more solution concepts in order to find a preferred concept; whereas cases of imprecise problem design task, designers tended to generate few alternative solution concepts (Fricke, 1993; Fricke, 1996).

While the process of design seems similar for most designers, the quality of the design result relates to the time and frequencies of design actions and moves for different designers with different expertise. For example, novices who spend a large proportion of their time defining the problem do not produce high quality designs. However, with senior students adequately setting up the problem before beginning analysis, the result is better (Atman et al., 1999).

Reviewing the above mentioned literature shows that seven strategies can be considered as dominant design strategies. Unfortunately, few studies have investigated the effects of the strategies on quantity, novelty and quality of design proposals. The following seven strategies can be clarified for a design procedure:

1. Considering design problems as ill-defined problems (Akin, 1978; Thomas & Carroll, 1979) that can perhaps never be converted to well-defined problems, so proceeding to find a satisfactory solution rather than an optimum (Cross, 2001);
2. Co-evolving the problem and solution until reaching a matching problem-solution pair through iterative cycles (Conradi, 1999); undertaken through exploring partial structure of design space and solution space, generating some initial ideas in the form of a design concept (Cross & Dorst, 1998), and bridging these two partial models through the articulation of the concept which enables the models to be mapped onto each other (Cross, 1997);
3. Starting design by using previous solutions as starting points to create designs with new goals, extra functions, and substructures inspired by previous designs (Pugh & Clausing, 1996; Howard et al., 2008);
4. Rapid alternation of activities, which they measured as transitions between design actions and moves (Atman et al., 1999);

5. Framing a problematic design situation by setting the boundaries, selecting particular things for attention, and imposing on the situation a coherence that guides subsequent moves (Schön, 1988). Only some constraints are given in a design problem; other constraints are introduced by the designer from domain knowledge, and/or are derived by the designer during the exploration of particular solution concepts (Ullman et al., 1990);
6. Framing five times sequentially while it is done dominantly at the beginning of the design task and reoccurs periodically throughout the task (Goel & Pirolli's, 1992); it is seldom done in one burst at the beginning of a design process (Schön, 1988);
7. Scrapping initial design ideas and starting afresh with new design concepts and a suitable amount of alternatives (Smith & Tjandra, 1998); a dominant influence is seen by initial design ideas on subsequent co-evolving problem and solution, even when severe problems are encountered and despite changes in the framing of the design situation (Rowe, 1987; Ullman et al., 1990).

Above mentioned summary of related studies to the strategies in the field of design cognition, highlights general strategies for more qualitative or creative ideas which are applied by expert designers or their effects were studied on novices. Generally, any supportive tool or method for designing the next generation of technical systems, must be familiar for target designers and lead them to use the effective strategies. In addition, these findings can be used as structuring general strategy-based heuristics and more studies are needed for specific strategy-based heuristics for generating the next generation of the technical systems.

1.2.5. Design professional models

As mentioned, there are design professional models which are developed and applied in real design situations based on the designers' previous experiences, and the needs and resources of real design conditions, such as background knowledge and experiences of team members, time, expected characteristics of outputs and so forth, in different kinds of design projects. In addition, there are some other models that are developed based on results of studies on design precedents and strategies at a higher abstract level. Therefore, reviewing these models helps to support the above discussed design precedents and strategies.

It is worth also considering that design models have more in common with models of creative problem solving and creativity in field of psychology, so research in the field of design models try to conclude them too (Howard et al., 2008). In recent researches (Basadur et al., 2000; Kryssanov et al., 2001) psychologists have moved from defining a creative process as a cognitive process, to a more activity-based one, which is more analogous to the design process. In doing this, many recent creative process models could be interpreted as extremely generic design process models. This is an interesting convergence of ideas for engineering design authors, who have promoted similar ideas for some time (Archer, 1968; Booz et al., 1968).

Reviewing the well-known engineering design models in a traditional and linear approaches show that they are common in six phases; establishing a need, task analysis, conceptual design, embodiment design, detailed design and implementation phase, where the first and last phases are considered more as pre- and post- activities instead of design model phases (Howard et al., 2008). It seems generally despite many attempts at proposing systematic models of the design process and structured approaches that should lead designers efficiently towards a good solution, most design in practices still appear to proceed in a rather ad-hoc and unsystematic way. Also there is an assumption that a certain quantity of knowledge must be gained for each phase of the process in order to complete a design. These spaces can be filled in random order or sequence, though there are certain dependencies inbuilt within each design project, and one space cannot fill by any more relevant information until knowledge is gained in another space. A prime example of this type of representation is the CeK theory (Hatchuel & Weil, 2003) which describes design as a process of movement between a concept space and a knowledge space. These types of models are probably valid and representative of actual design activities, though it is clear that their high level description makes them less useful to designers.

Although the simplification of design engineering models in six phases is effective for teaching novice designers and managing the design process, it does not closely represent real design engineering models (Howard et al., 2008). The major development of linear engineering design process for years is the inclusion of more feedback loops and the acknowledgment that the design process is more disordered process than most representations suggested for that (Parnas & Clements, 1986; Bucciarelli, 1994). Researches show designers use their hierarchically structured plan in an opportunistic way (Visser, 1990). Designers frequently deviate from a top-down approach, drifting through partial solution development, and jumping into exploring suddenly-recognized partial solutions; these were categorized as major causes of opportunistic solution development (Guindon, 1990b). Designers who follow a flexible-methodical procedure tend to produce good solutions. These designers work efficiently and follow a logical procedure. In comparison, designers with too-rigid adherence to a methodical procedure, or adopted very un-systematic approaches, produce mediocre or poor design solutions (Fricke, 1993; Fricke, 1996). Research also shows more efficient processes correlated positively with both the quantity and quality of design outputs (Radcliffe & Lee, 1989).

On the other hand, psychologists can be split into two categories namely the romantics and non-romantics (Boden, 1990). The romantics take a more spiritual view of creativity where it is viewed as a mysterious, subconscious process (Barron & Harrington, 1981; Plsek, 1997). This is still quite a common view of the creative process; however, this outlook provides little help to research in engineering design. Conversely, the non-romantic view has a number of very interesting aspects. Interestingly, even in the psychology domain, the form is predominantly described as a linear sequence of steps or stages. Earlier descriptions of the creative process are considered as inspirationalist views (Shneiderman, 2000). These views are perhaps the most valuable to engineering design. One of the older process models is the four-stage process of preparation, incubation, illumination and verification (Wallas, 1926) which remains the most well recognized model despite the criticisms around it. This model suggests the unexpected emergence of an idea, which is now often deemed somewhat outdated. More recent descriptions of the creative process can be considered as structuralist views (Shneiderman, 2000). These views attempt to offer an explanation to emergence, and describing conscious idea generation as the deliberate connection of matrices of thought (Koestler, 1964). This process is likened to the belief that new ideas are generated through the combination of two or more old, existing ideas and it is typical of a structuralist view (Amabile, 1983).

In general, one of the main differences of the models of design in engineering with creative processes in psychology is their difference in concluding divergent-convergent models (Howard et al., 2008). Divergent-convergent models differ from the traditional linear style by assuming some form of integrated evaluation and selection of ideas and concepts. This is potentially a useful outlook on design from a creativity perspective, as separating the generation and evaluation periods is considered good practice for both lateral thinking and brainstorming (Osborn, 1953).

Like what summarized after reviewing design precedents and design strategies, it can be concluded that there is no reviewed literature to discuss the efficiency and effectiveness of various design methods respect to different design tasks, not in a very general design session, nor in a specific design session for designing the next generation of technical systems. In addition, respect to what reviewed, any supportive heuristic for generating novel ideas, must consider design as an unsystematic, flexible, non-linear, opportunistic, activity-base process including divergent-convergent models. Besides, these findings can be used as structuring general strategy-based heuristics and more studies are needed for specific strategy-based heuristics for generating the next generation of the technical systems.

1.3. Methods and tools for measuring and assessing the next generation of the technical systems

Measuring the potentiality of an idea to be an innovation is a critical issue for both scholars and professionals, as the success of a novel idea in the market is an open discussion until the success is achieved. Considering the uncertainty of the nature of an innovation and how research defines the characteristics, various methods are developed and used for assessing innovation, radical innovation, radical technological changes and breakthrough innovations. These methods use different resources from three time periods of past, present, and future. Some of the methods are developed based on using the expertise of the professionals, and some others use patents, publications and share markets in both levels of strategic indexes or their concluded information. It would be far more useful to identify radical inventions at the time, or even before, they enter the market, since it would help solve a selection bias that plagues most studies. The assessment and measuring methods based on the definition of characteristics are both retrospective and prospective, though most of them are retrospective. The developed methods based on extrapolations of trends are a type of prospective methods, whereas the retrospective ones are developed mostly based on the analysis of the suggested novel idea as innovation. It is worth considering that by developing methods based on identifying radical inventions on market success, by only including innovations in a study and ignoring inventions that never reach the market, a set of bias emerged (Dahlin & Behrens, 2005). In other words, it is important not to confuse the definition of any kind of innovation and consequently radical technological changes behind them if any, with successful and unsuccessful radical invention in the market to reduce the biases.

1.3.1. Criteria and methods used for measuring the next generations of technical systems

Measuring the potential success of a novel idea as an innovation, is an uncertain activity until the success achieves in the market. Defining the detail characteristics of any kind of innovation in respect to its various ultimate purposes is a direction in the research fields to reduce uncertainty for both approaching and measuring the requested innovation type. Reviewing current research in the field does not show specific measuring criteria for the next generation of technical systems. Therefore, the characteristics discussed in section 1.1 for the next generation of technical systems can be considered as an initial attempt for developing measuring criteria.

As presented in Tables 2 and 3, the next generation of a technical system is a kind of breakthrough innovation (Geels, 2004) which is defined by overlapped characteristics between the outcomes of the technology-push innovation (Dosi, 1982) and design-driven innovation (Verganti, 2008) while the concept of market is hidden in design-driven innovation. In other words, the next generation of a technical system is the version of the system consisting of radical technological change and radical meaning change of the system for new requirements of existing or new customers.

Among the characteristics proposed for defining the next generations of technical systems in the literature (Table 3), most of them can be assessed prospectively and only four of them must be assessed retrospectively; these four items are highlighted in Table 5.

Innovation drivers	Mentioned characteristics in previous researches	Retrospective
Technology	Completely new or significantly different performance or functionality characteristics	
	New technology (in either hardware, software or orgware)	
	Not obvious to field experts	
	Constitutes the core of the change	*
	New combinations of selected principles derived from natural sciences and selected material	
	Less costs, harms and efforts	
	Recombining already established elements	
	Bringing in an established element into a new setting	
	Resolving contradictions	
	Satisfying the forecasted performance and functionality, time and space	
	Using Slack resources	
Market	Accepted by customers	*
	Same market (same requirements of existing users) with changes in the technology	
	New market (new users or new requirements of existing users) with changes in the technology	
	Useful	
	Same or wider expectations	
	Conquer the market dominantly	*
	Acceptable level of novelty by the market	*
Design	New meaning or new language	

Table 5 - Retrospective observable characteristics of a next generation of technical system

Considering the difficulty of gathering information for characteristics which have to be observed in the future, it is preferable that the methods of measurement, benefit the expertise of the professional instead of the other resources.
In the scope of this research and to study the potentiality of generated ideas to be accepted as the concepts for the next generation of the technical systems, it is worth considering the most convenience methods for assessing the target criteria.

1.3.2. Criteria and methods used for assessing the results of idea generation sessions

In general, despite different ultimate expected results of any design or idea generation session, there are some common criteria for assessing the generated ideas and design session results. In most research, the performance of a group is determined by the evaluation of the proposals in terms of two dependent variables: number of ideas (Nijstad et al. 2002; Shah et al. 2003; Perttula & Sipila 2007) and quality of ideas (Wierenga, 1998; Shah et al. 2003). Consequently, quality of an idea is generally defined by a proposition’s ‘originality’ and ‘appropriateness’ in respect to the target task (Massetti, 1996; Runco & Jaeger, 2012); in some instances, a third specializing criteria such as ‘unexpectedness’ (Gero, 1996) or ‘un-obviousness’ (Howard et al. 2006; Howard et al., 2008) can be linked to the time that the idea was produced. Table 6 shows the most used terms for the criteria by main definition in the field, which is supposed to show the quality of creative ideas (Howard et al., 2006).

Researchers	Originality			Appropriate								Third element					
	Novel	Original	New	Appropriate	Useful	Purposeful	value	meaningful	tenable	Satisfying	Adaptive	Leap	Change	Unexpected	Communicated	Transformation	Comparisons	Resources
Jackson and Messick (1965)	*			*												*	*	
Stein (1974)	*				*				*	*		*	*					
MacKinnon (1975)	*									*	*				*			
Rothenberg and Hausman (1976)			*				*								*			
Amabile (1983)	*			*														
Sternberg (1985)	*				*													
Lumsdaine and Lumsdaine (1995)			*					*										
Gero (1996)			*				*							*				
Marakas and Elam (1997)	*				*													
Thompson and Lordan (1999)			*		*													
Warr and O'Neill (2005)	*			*														
Chakrabarti (2006)	*					*												*
Howard et al. (2006)		*		*							*							
Lopez and Vidal (2006)	*					*					*							

Table 6 - The most used terms for the criteria for measuring the quality of design proposals and idea generation results

Some researches in engineering characterizes these criteria by the level of meeting goals (Shah et al., 2003) and inventiveness and orderliness (Sternberg, 1985). The four-criterion set of quantity, quality, novelty, and variety of ideas and design proposals is one of the other well-known set of criteria for characterizing a design proposal through exploration and expansion of design space (Shah et al., 2003; Schunn et al., 2010). In this scope, quantity refers to the number of different ideas generated (Shah et al., 2003). Quality is a criterion for studying the degree of feasibility of an idea and the degree of satisfying the design requirements which are discussed as relevance or appropriateness in other researches (Shah et al., 2003). Novelty is a criterion for highlighting the unusualness or unexpectedness of an idea compares to a set of target ideas (Shah et al., 2003) and it shows the well-travelled or little-travelled identification of ideas in the design area (Nelson et al., 2009). Variety is a criterion for studying dissimilarity and distance of an idea from other ideas in a set under analysis (Shah et al., 2003) and it shows the degree of exploration in solution space by an idea.

Considering different naming for same or similar concepts mentioned in the literature for assessing the ideas, the quality of an idea can be classified based on the desired concepts. Table 7 shows the similarities of concepts and one of the possible classifications for considering as a classification which is covered the most concepts.

Main criteria in the literature	Desired concepts	Proposed criteria
Quantity	Quantity	**Quantity**
Quality	Appropriate	**Relevance**
	Useful	
	Purposeful	
	value	
	meaningful	
	tenable	
	Satisfying	
	New	**Novelty**
	Novel	
	Original	
	Unexpected	
	Un-obviousness	
	orderliness	
	Unusualness	
	Leap	
	Change	
	Transformation	
	Comparisons	
	Variety	
	dissimilarity	
	distance	
	Feasibility	**Technical plausibility**
	inventiveness	
	Possibility	

Table 7- The main mentioned concepts in the literature for assessing a group performance

Regards to Table 7, it can be concluded, quantity and quality are the main criteria for assessing new ideas, and novelty, technical plausibility and relevance can cover the meaning and concept of these various aspects as the sub-criteria for quality.
However, these criteria are often difficult to measure in reality. There are few objective methods for evaluating the creativity of a product, and for the most part, evaluation is done by applying subjective judgments (Amabile, 1983). There is a belief though that only a field expert or line manager can judge whether these elements exist in a particular idea (Shalley & Gilson, 2004). In other research, some other methods were developed and applied to assess novelty, variety and quality of design proposals quantitatively (Shah et al., 2003; Schunn, et al., 2010). In respects to the difficulty of using these methods and the overall belief of professionals about the role of expertise in judgment, professionals prefer to use the subjective method.
In the scope of this research and to study the potentiality of generated ideas to be accepted as the concepts for the next generation of the technical systems, it is worth considering the most used criteria for assessing the design proposals and generated ideas to be compatible with literature.

2. Serious game

Supporting R&D engineers in designing the next generation of technical systems and promoting their performance is the ultimate goal of this research. According to what reviewed in the field of design cognition, the idea is to support R&D engineers to exploit their previous experiences and knowledge that they are not skillful to use them. Many recent researchers claim that serious game is a convenient approach for self-learning and improving target people's performance and skills. In this section after reviewing the definition of serious game and its role in learning, the mechanics of a serious game and the necessary information for designing it, are discussed.

2.1. Serious game for learning

The idea of playing a game dates to the ancient past and is considered an integral part of all societies. For instance, dice appears to be among the earliest games used by humans, the oldest known example is a 3000-year-old game set in south Iran (Press TV, 2007). Some of these games already served a "serious" purpose; for example, Mancala which is known as a game designed around 1400 BC, was used as an accounting tool for trading animals and food. The widespread diffusion of mobile gaming is opening further perspectives for future learning and online socialization (Parsons et al., 2012; Liang, 2012). Furthermore, a large and growing population is increasingly familiar with playing games, though serious games do not target exclusively power-gamers (typically young males fond of First Person 3D immersive experiences). Power-gamers represent just 11% of the gaming community, while other types of players (e.g., social, leisure, occasional) are increasing in number (Bellotti et al., 2010).
In regard to the term 'play' as a general term, a game has fixed goals to achieve. Different definitions are presented for game and each one emphasizes some important factors and characteristics of the game. Some definitions emphasize entertainment, amusement and fun (Prensky, 2001; Zyda, 2005; Michael & Chen, 2006), some stress that it is a voluntary activity (Avedon & Sutton-Smith, 1971), some emphasize the essence of activity as a kind of struggle towards a goal (Costikyan, 2000) and some others refer to targeting a disequilibria outcome (Avedon & Sutton-Smith, 1971). Considering the important factors in a game, the definition of a game can be summarized as a voluntary activity, obviously separate from real life, creating an imaginary world that may or may not have any relation to real life, and that absorbs the player's full attention (Michael & Chen, 2006). A game is played out within a specific time and place according to established rules, and it creates social groups out of their players (Michael & Chen, 2006).
The concept of serious game was first invented and stamped for emphasizing on explicit educational purpose (Abt, 1970). In other words, following from the Platonic differentiation between games for fun and games for learning, the term "serious game" was firstly used. Comparing the games, serious games have pedagogy more than story, art, and software, where pedagogy must be subordinate to the story (Zyda, 2005). Serious game as a term in a digital context was firstly used in 2002, when it used in the US to train people for tasks in particular jobs, such as army personnel (Rejeski et al., 2003). After that, a serious game was considered generally as a game designed for a goal different from pure entertainment (Prensky, 2003; Gee, 2003; Zyda, 2005; Michael & Chen, 2006; Bellotti et al., 2010).
Entertainment is explicitly brought up as an ingredient of serious game to further govern or incorporate serious objectives of the game such as training, education, health, public policy, and strategic communication objectives (Zyda, 2005). Some researches argue that the games should be fun first and then should encourage learning (Prensky, 2001), with fun being also described as a side effect of learning something new (Michael & Chen, 2006). In other words, serious games are the games that do not have entertainment, enjoyment, or fun as their primary purpose. This is not to say that serious games are not entertaining, enjoyable, or fun; just that there is another training purpose which is more important. It is worth considering that fun is neither the only form of entertainment for engaging players in a game and several other elements can be used for engagement; for example, play which leads to intense and passionate involvement, goals that motivate, and rules that provide structure (Prensky, 2001). It is not easy to distinguish a game as a serious game basing the definition of a serious game, whether the main purpose was prior than entertainment (Jantke, 2010).
There are related and overlapping domains considering learning and entertaining together, such as e-learning, edutainment, game-based learning, and digital game-based learning. E-learning is a general concept that refers to computer enhanced learning, computer-based learning, interactive technology, and commonly, distance learning (Hodson et al., 2001). Edutainment which is considered as education through entertainment, was popular during the 1990s with its growing multi-media PC market (Michael & Chen, 2006). In general, edutainment refers to any kind of education that also entertains even though it is usually associated with video games with educational aims. The primary target group was preschool and young children, with focus on reading, mathematics, and science. However, edutainment software failed in succeeding since it resulted in what has been described as "boring games and drill-and-kill learning" (Van

Eck, 2006). With the U.S. Army's release of the video game America's Army in 2002 (Gudmundsen, 2006), the serious games movement have started.

Many reasons are discussed for using serious games for learning and self-learning. The thinking patterns of learners have changed, and today's students are native speakers in the language of digital media. The new form of digital entertainment has shaped their preferences and abilities and offers an enormous potential for their learning, both as children and as adults (Prensky, 2001). In addition, using the simulation and visualization technologies, serious games allow learners to experience situations that are impossible to be experienced in the real world for reasons of safety, cost, time, etc. (Squire & Jenkins, 2003; Corti, 2006; Jarvis & de Freitas, 2009; Hill et al., 2009). And also exploiting the simulation and visualization technologies, serious games are able to contextualize the player's experience in challenging, realistic environments, and support situated cognition (Watkins et al., 1998), meaning the players exercise freedom that can complement formal learning by encouraging learners to explore various situations (Klopfer et al., 2009), with limited barriers of monitoring, space and time.

Games in general promote learning (Szczurek, 1982; VanSickle, 1986; Randel et al., 1992; Van Eck, 2006), therefore it is considered also that serious games promote learning. Although it is considered generally that serious games improve various skills, disciplined studies of gaming are few, and there is little evidence about the consequences of game play on the cognition of players (Squire, 2002; Squire et al., 2005). In other words, few studies investigate the impact of each serious game on general and target skills of players which the game is designed for.

Performing a survey with e-learning professionals and experts, and comparing the outcomes with a literature review (Bellotti et al., 2003) stresses a positive view, as serious games are perceived as effective learning environments (Mitchell & Savill-Smith, 2004) because games challenge and support players to approach, explore and overcome problems. The effectiveness of serious games is discussed recently in some researches (Connolly et al., 2012; Wouters et al., 2013). A huge study between 2005 and 2012 in more than 300 serious game sessions with professionals and engineers, using 12 serious games by TU-Delft in cooperation with various partners, highlighted that serious games are more effective in increasing insight into personal mastery, like social-technical complexity, rather than advance learning, like basic mathematical calculations. This does not make knowledge acquisition irrelevant because it is the locus and not the focus of their professional mastery. It should therefore be included in the narrative and game-play (Mayer et al., 2014). Games in general support the development of a number of different skills such as analytical and spatial skills, strategic skills and insight, learning and recollection capabilities, psychomotor skills, visual selective attention, etc. (Mitchell & Savill-Smith, 2004). It is observed also that players develop their thinking strategies towards more analogical thinking, rather than trial-and-error thinking (Hong & Liu, 2003). Self-monitoring, problem recognition and problem solving, decision making, strategic thinking, planning, activating short-term and long-term memory, collaboration, negotiation, and shared decision-making are discussed as potential benefits of games (Rieber, 1996; Squire & Jenkins, 2003; Mitchell & Savill-Smith, 2004; Kirriemuir & McFarlane, 2004; Ellis et al., 2006). Multiplayer games that can be played also on-line favor team-building and collaboration in facing challenges and issues (Connolly et al., 2007; Angehrn et al., 2009; Sedano et al., 2013; Wendel et al., 2013). It is worth taking into account that even a research studied the benefits of violent games and claimed that these kind of games can be beneficial in diminishing frustration (Mitchell & Savill-Smith, 2004).

On the other hand, some researches refer to negative impacts and some concern of playing serious games. Initial possible negative impacts were mentioned in three categories: (i) health issues such as headaches, fatigue, mood swings and repetitive strain injuries, (ii) psycho-social issues such as depression, social isolation, less positive behavior towards society in general, increased gambling and substitution for social relationships, and (iii) the effects of violent computer games, such as aggressive behavior and negative personality development (Mitchell & Savill-Smith, 2004). At a more precise level, the educational concerns are discussed. Some argue generally that intended learning outcomes, game objectives and features such as difficulty level, duration, aesthetic, and interaction modalities, might conflict each other (Clark, 2003). A not recent research argued that turning learning into fun, challenge and criticize unfairly one of the most important issues of life: to learn and to teach. Directing students away from reading, writing and scholarship, dulling their questioning minds with graphical games where quick answers take the place of understanding, and providing the trivial, are promoted as educational concerns (Stoll, 1999). In addition, wasting time, energies and motivations for learning is another concern. The observation of behavior and results of high-achieving science students and lower-achieving microbiology students on playing a serious game (Crystal Island) showed that learning is a complex gradual activity that needs several steps that have to be supported by various tools, for different types of target people to prevent wasting time and energies (Rowe et al., 2010).

Regarding potentiality of applying the serious games for learning from one hand and concerning points from the other hand, it is worth studying the characteristics which must be considered in applying serious games for learning and characteristics which must be considered in designing a serious game. Table 8, summarizes the above mentioned characteristics of serious games in the literature.

General points	No.	Highlighted points in the literature	Reference
Common characteristics	1	having explicit educational purpose	Abt, 1970
	2	a voluntary activity	Avedon & Sutton-Smith, 1971
	3	designed for a goal different from pure entertainment whilst having fixed goals to achieve respect to the play	Prensky, 2003; Gee, 2003; Zyda, 2005; Michael & Chen, 2006; Bellotti et al., 2010
	4	to train people for tasks in particular jobs	Rejeski et al., 2003
	5	having pedagogy more than story, art, and software, where pedagogy must be subordinate to the story	Zyda, 2005
	6	involving, engaging and absorbing the player's full attention through - entertainment, enjoyment, amusement and fun (as they being also described as the side effects of learning something new) - goals, rules or other parts of the game	Prensky, 2001; Zyda, 2005; Michael & Chen, 2006
	7	separated from real life, creating an imaginary world that may or may not have any relation to real life	Michael & Chen, 2006
	8	playing out within a specific time and place according to established rules	Michael & Chen, 2006
	9	creating social groups out of their players	Michael & Chen, 2006
Reasons as tool for learning and self-learning	10	changing thinking patterns of learners, their preferences and abilities both as children and as adults in digital media	Prensky, 2001
	11	possibility to experience situations that are impossible to be experienced in the real world for reasons of safety, cost, time, … due to using the simulation and visualization technologies	Watkins et al., 1998; Squire & Jenkins, 2003; Corti, 2006; Jarvis & de Freitas, 2009; Hill et al., 2009
	12	Possibility to practice freely with limited barriers of monitoring, space and time due to using the simulation and visualization technologies	Klopfer et al., 2009
Positive points	13	effective in learning	Szczurek, 1982; VanSickle, 1986; Randel et al., 1992; Van Eck, 2006
	14	more effective in increasing insight into personal mastery, like social-technical complexity, rather than advance learning, like basic mathematical calculations	Mayer et al., 2014
	15	effective in guiding players to approach, explore and overcome problems	Mitchell & Savill-Smith, 2004
	16	effective in improving analytical and spatial skills, strategic skills and insight, learning and recollection capabilities, psychomotor skills, visual selective attention	Mitchell & Savill-Smith, 2004
	17	effective in improving strategic thinking, analogical thinking, rather than trial-and-error thinking	Hong & Liu, 2003
	18	effective in improving strategic thinking, planning, communication, collaboration, group decision making, and negotiating skills	Squire & Jenkins, 2003; Kirriemuir & McFarlane, 2004;

	19	effective in improving self-monitoring, problem recognition and problem solving, decision making, better short-term and long-term memory, and increased social skills such as collaboration, negotiation, and shared decision-making	Rieber, 1996; Mitchell & Savill-Smith, 2004; Ellis et al., 2006
	20	effective in improving team-building and collaboration in facing challenges and issues by on-line games	Connolly et al., 2007; Angehrn et al., 2009; Sedano et al., 2013; Wendel et al., 2013
	21	effective in diminishing frustration by violent games	Mitchell & Savill-Smith, 2004
Concerning points	22	little evidence about the consequences of game play on the cognition of players	Squire, 2002; Squire et al., 2005
	23	might challenging learning by constituting quick answers instead of understanding	Stoll, 1999
	24	emergence of conflicts among game objectives and features such as difficulty level, duration, aesthetic, and interaction modalities	Clark, 2003
	25	emergence of negative effects on health issues such as headaches, fatigue, mood swings and repetitive strain injuries	Mitchell & Savill-Smith, 2004
	26	emergence of negative effects on psycho-social issues such as depression, social isolation, less positive behavior towards society in general, increased gambling and substitution for social relationships	Mitchell & Savill-Smith, 2004
	27	increasing emergence of aggressive behavior and negative personality development by violent games	Mitchell & Savill-Smith, 2004
	28	increasing wasting time and energies of various types of target players in learning by providing same steps and tools for all	Rowe et al., 2010

Table 8- Some of reviewed Characteristics and effects of serious game in the literature

Table 8 shows the potential positive impacts of applying serious games in learning (rows 9 & 13 to 21) are more discussed and studied respect to the negative impacts (rows 23, 25, 26 & 27). Positive impacts are more related to personal characteristics and skills respect to the advanced learning and it is suggested that advanced learning should be included in the narrative and game-play. In addition, some of concerning points can be considered in designing a serious game in order to avoid their emergence on players' behaviors.

The well-known educational serious games are classified into four classes initially; games for classroom use, games for independent learning, games for social awareness and games for the medical domain. Skills Arena (Shin et al., 2012) for arithmetic skills of elementary school students, Making History (Watson et al., 2011) for letting high students know about the history of World War II, and Computer programming (Muratet et al., 2009) to teach computer programming skills to university students are examples of serious games for classroom use. Lost in the Middle Kingdom (Shepherd et al., 2011) for learning a second language is an example for independent learning. Data games that allow a contribution to scientific research with innovative ways for learning from the exploration of real world data, such as Foldit (Cooper, 2010) to learn about proteins, can be considered as an example for both classroom usage or independent learning. 3rd World Farmer (Hermund et al., 2005) for highlighting the hardships of maintaining a farm in developing countries, IBM City One or IBM INNOV8 (IBM, 2010) for awareness about problems facing today's cities related to transportation, energy infrastructure, and water management in order to design smarter cities, and Clean World (Barbosa et al., 2014) for clarifying today's environmental challenges, are examples of games for social awareness. Finally, knee arthroplasty procedure is a game in the medical domain for training surgery residents (Cowan et al., 2012). It is worth to study the effects of list of serious games on both general skills and advanced learning purposes of each developed game on their target and general players. Such this systematic study was not found in the literature.

Despite numerous serious games for many application domains, no specific serious game for design is introduced and discussed in the literature. There are very few studies about the effects of some other serious games on design. In architecture and design, the impacts of computer games were studied on developing student confidence and abilities in spatial modeling, design composition, and form creation (Radford, 2000;

Coyne, 2003). Playing with three-dimensional models was suggested and studied as a tool for enhancing town planning (Thuillier, 2005); it was reported that spatial abilities, more precisely, the capacity for mental rotation, can be improved by playing games such as Tetris (De Lisi & Wolford, 2002).
Regarding the positive effects of some serious games on some of the professional abilities of designers from one hand and considering the above mentioned benefits and concerns about serious games, it can be concluded that a serious game can be used to improve many general and specific skills of designers, if it will be developed based on styles, knowledge, skills and preferences of target people.

2.2. Serious game mechanics and descriptors

Serious games must demonstrate the transfer of learning (to be 'serious'), whilst also remaining engaging and entertaining (to be 'games'). The balance between fun and educational measures should be targeted throughout the development starting from the design phase. One of the biggest issues with educational games to date is the inadequate integration of educational and game design principles (Gunter et al., 2006; Kenny & Gunter, 2007; Kiili & Lainema, 2008; Lim et al., 2013). This is due to various factors including the fundamental fact that digital game designers and educational experts do not usually share a common vocabulary and view of the domain (Gunter et al., 2006; Kiili & Lainema, 2008; Lim et al., 2013). Therefore, there is a growing need for scientific and engineering methods and tools for efficiently building games as means that provide effective learning experiences (Greitzer et al., 2007; Bellotti et al., 2012; Marfisi-Schottman, 2013). This will allow covering a variety of topics with new tools that could help students that have difficulty with other instructional approaches. Serious game benefits from a certain theoretical foundation in the constructivist learning theories, that stress knowledge is created through experience while exploring the world and performing activities (Dewey, 1933; Montessori, 1946; Kolb, 1984). Constructivism stresses the importance of the learner to build own knowledge while the guidance is important too, in particular for novices (Kirschner et al., 2006). Designing a serious game is considered a multi-disciplinary task that requires the collaboration of experts in different fields (Zarraonandia et al., 2012). Content, theory and game design are considered as the three kernels of serious games. Content includes subjects such as museum, history, mathematics and science; theory includes the concepts of pedagogy, cognition, learning, psychology, flow, perception and behavior; and game design includes technologies of Artificial Intelligence (AI), Human-Computer Interaction (HCI), networking, computer graphics and architecture, signal processing and web-distributed computing (Greitzer et al., 2007).
Considering the very few discussions in literature about the systematic tools for designing a serious game from a psycho-pedagogical level to a technical level, two approaches are seen in literature for developing initial methods for designing the serious games; firstly, a focus on some of the serious game descriptors which are claimed as more effective in the success of a serious game, and secondly, a focus on serious game mechanics. These two approaches are not completely separate as serious games mechanics are among serious games' descriptors.
The LM-GM model has been recently proposed as a model for transferring the pedagogical elements to game mechanics, providing a systematic model for designing serious games' mechanics (Arnab et al., 2015). The principles of learning and game-play are different and frequently conflicting, but they can co-exist in well-designed serious games (Huynh-Kim-Bang et al., 2011). In other words, in a successful serious game high level pedagogical concepts are translated and implemented through low-level game mechanics. The LM-GM model includes a set of pre-defined game mechanics and pedagogical elements that are abstracted from literature on game studies and learning theories. Game Mechanics (GMs) express players' agency in the game world via actions (Järvinen, 2008; Sicart, 2008) and consequently are expressed at a lower level through several manipulation rules. Based on the topology of game-play rules (Frasca, 2003; Djaouti et al., 2008), two different types of game rules are identified; the rules at a lower level that allow the player to manipulate the elements of the game, and, at a higher level, the rules defining the goal of the game. The LM-GM model is developed based on combinations of the fundamental elements to provide the rules and goals of the games (Arnab et al., 2015). In this model, the Serious Game Mechanics (SGMs) are the game components that translate a pedagogical practice/pattern directly perceivable by a player's actions.

While game design patterns provide design solutions to common SG issues/requirements, SGMs are finer components that can be exploited in several different patterns (Marne et al., 2011).

Design, infinite game play, ownership, protégé effect, status, strategies, titles, action points, assessment, collaboration, communal discovery, resource management, game turns, Pareto optimal, rewards/penalties, urgent optimism, feedback, meta-game, realism, capture/elimination, competition, cooperation, movement, progression, selecting/collecting, stimulate/response, time pressure, appointment, cascading information, questions and answers, role-play, tutorial, cut scenes/story, tokens, virality, behavioral momentum, pavlovian interactions, and goods/information are the list of game mechanics (Arnab et al., 2015).

On the other hand, effective serious game descriptors that are applied for developing game design methods, are highlighted through taxonomies in the field. Several taxonomies have been proposed in the literature for classifying serious games according to different criteria where each of them shows one descriptor or set of descriptors of serious games; each descriptor is considered as a successful factor of serious games.

Application domains (Zyda, 2005), markets (Michael & Chen, 2006), skills (Kirriemuir & McFarlane, 2004; Riedel & Hauge, 2011), and learning outcomes (Egenfeldt-Nielsen, 2006) are the most popular criteria in classifying serious games. The classification of serious games based on the market (the application domain) and purpose (initial purpose of the designer) is one of the main known classifications that is used as reference. Items in the first dimension are government, defense, marketing, education, corporate, etc. and items in the second dimension are advergames, games for health, games at work, etc. (Sawyer & Smith, 2008). In regards to the application area, it is worth mentioning that educational games were clearly dominant up to 2002 with a market share of about 66% however, this market dominance decreased to about 26% from 2002 to 2009; games for advertising increased from about 11% to 31% in the same period of time (Djaouti et al., 2011). According to these statistics, education and advertising are dominant, occupying about 57% of the whole serious games market, while the rest of it is shared between other areas including health care, well-being, cultural heritage, and interpersonal communication.

The level of games - the psycho-pedagogical level and the technical level - is another classification used in the literature (Kickmeier-Rust et al., 2007) to claim that the game which is designed based on the curriculum, has a higher chance to be accepted and integrated into the class program by teachers (Norris et al., 2007). The instructional model that is focused on in some serious games (Becker, 2008) is the nine events of instruction (Gagné et al., 1992). These nine events can be summarized as gaining attention, informing learners of the objective, stimulating recall of prior learning, presenting stimulus material, providing learning guidance, eliciting performance, providing feedback, assessing performance, and finally enhancing retention and transfer. Close to the pedagogy, the literature also discusses that avoiding negative consequences (Lin et al., 2006), offering challenges (Inal & Cagiltay, 2007) and playing collaboratively (Yim, 2008) are important factor in players' immersion and consequently the success of the games.

In addition, assessing is an effective opportunity provided by serious games for education and training (Kelly et al., 2007; Doucet & Srinivasan, 2010; Marfisi-Schottman et al., 2013). Assessment is key for games and education, since it allows knowing and understanding the actual end-user condition, which is the basis for an appropriate treatment. Proper assessment (Shute & Ke, 2012) requires continuously tracking the user in all their game activities (Bellotti et al., 2009), allowing appropriate feedback, and also supporting adaption and personalization (Bellotti et al., 2013). Assessment should be done in real-time without interrupting the user's flow (stealth or embedded assessment) (Bente & Breuer, 2009; Shute & Ke, 2012). Adaption to different players' profile is a capability that is difficult to provide through human teachers in classes with many students, thus represents a significant added value for a serious game to be able to support efficient learning and teaching. Serious games using devices such as stereo cameras, eye trackers, tablets and smartphones, pointing devices, motion sensors, sensors related to the central and peripheral nervous systems (Peña de Carrillo, 2004), present opportunities to develop innovative solutions for continuous user monitoring and assessment; however, given the complexity of human nature and individual differences, an objective and systematic assessment of learner behavior and performance remains highly difficult.

Purpose (ranging from fun/enjoyment to training/learning), reality (ranging from imitation of real and fictitious contexts to proving abstract visualizations such as in games like Tetris), social involvement (ranging from single player games to massive multiplayer games), activity (ranging from active game types with a physical dimension to passive game types) is a hypercube taxonomy which is proposed for classifying the serious games (Kickmeier-Rust et al., 2009). Activity as one of the important descriptors in the success of the games is classified by physical exertion (Buttussi et al., 2010; Silva & Saddik, 2013), physiology (Cameirão et al., 2009), mental such as games for education (Consolvo et al., 2008; Shin et al., 2012), training (Cowan et al, 2010), or interpersonal communication (Hill et al., 2006).

Besides a collaborative classification of serious games which was applied in serious.gameclassification.com, is a reference at world level (Djaouti et al., 2008; Djaouti et al., 2011). This classification is a clear extension of market-purpose classification, by including gameplay (game-based vs. play-based), purpose (education, information, marketing, subjective message broadcast, training, goods trading, storytelling), market (entertainment, state & government, military & defense, healthcare, education, corporate, religion, culture & art, ecology, politics, humanitarian & caritative, media, advert, scientific research) and audience (general Public, professionals, students; age groups). A simple four-classes classification which was proposed by studying a database of serious games, considered primary educational content (such as academic, social change or health), primary learning principles (such as practicing skills or problem solving), target group age, and the platform on which the game is played, as the four classes (Ratan, & Ritterfeld, 2009).

In addition, a more structured database of educational serious games has been built in projects such as Imagine1, Engage learning2, and GaLA3/Serious Games Society (SGS)4. The GaLA SG Knowledge Management System5 includes a number of descriptors such as classification (genre, platform, application domain, learning curve, effective learning time, play mode, player assessment, provision of feedback, etc.), game components (UI, rules, goals, entity manipulation, assessment), pedagogy (theoretical frameworks: constructivism, objectivism, personalism, etc.) and outcomes (cognitive (Anderson et al., 2001), psycho-motorial (Harrow, 1972), affective (Krathwohl, 1964, 1964), soft-skills (Pellegrino & Hilton, 2012), deployment, target topics, prerequisites for use if any, context of use), and technologies employed for the development (such as game engine, development tools/platforms, AI algorithms).

Respectively, a three-dimensional taxonomy is proposed for the science of digital games with a focus on serious games. The first dimension considers the digital game as computer software. The second dimension considers the genre of the game, whereas the third has to do with the interaction of players with the game (Jantke, 2010). Most research agrees that digital serious games contain different media and modality, which can be a combination of text, graphics (Consolvo et al., 2008), animations (Lin et al., 2006), audio (Yim & Graham, 2007), haptics (Arnab et al., 2011; Orozco et al., 2012) and even smell (Chen, 2006), which are seen in games for therapy. Interaction style and environment are two other descriptors for the serious games. The interaction style defines whether the interaction of the player with the game is done using traditional interfaces such as keyboard, mouse, or joystick, or by using some intelligent interfaces such as a brain interface, eye gaze, movement tracking, and tangible interfaces. The environment can be defined by 2D/3D, virtual or mixed reality environment, location awareness, mobility, online and social presence.

Among all mentioned serious games' descriptors, the effective ones in the success of the serious games are applied for developing the design game methods. Two approaches are seen for evaluating a success of a serious game based on its educational purposes: success according to players' engagement and success according to players' learning levels. The evaluation of a serious game based on players' engagement is more focused on the period of playing, while the evaluation of a serious game based on games' educational purposes is more focused on the effects of the game on the player abilities and impacts on the society. Both approaches suffer from some considerable weaknesses such as a lack of comprehensive, multipurpose frameworks for comparative, longitudinal evaluation (Vartiainen, 2000; Blunt, 2006; Meyer, 2010; Mortagy & Boghikian-Whitby, 2010), few validated questionnaires, constructed or scaled from other fields like psychology or newly constructed for serious game and game-based learning (Mayes & Cotton, 2001; Brockmyer et al., 2009; Boyle et al., 2011), an absence of generic tools for unobtrusive data gathering and assessment in and around SGs (Kickmeier-Rust et al., 2009; Shute et al., 2009; Shute et al., 2010; Shute, 2011), a lack of proper research designs, other than randomized controlled trials that can be used in a dynamic, professional learning context (Kato et al., 2008; Knight et al, 2010; Szturm et al., 2011; Van der Spek, 2011; Wouters et al., 2011; Connolly et al., 2012), few theories with which to formulate and test hypotheses (Mayer, 2005; Noy et al., 2006) and few operationalized models to examine causal relations (Connolly et al., 2009; Hainey & Connolly, 2010).

Game flow is a foundational concept (Csikszentmihalyi, 1990) that is employed to measure players' engagement and consequently success of an educational game (Chen & Johnson, 2004). Game Flow consists of eight elements: concentration, challenge, skill, control, clear goal, feedback, immersion, and social interaction (Sweetser & Wyeth, 2005). Researches highlight that most games adequately meet two primary elements of clear goals and feedback, but the balancing of game challenges and player skills is often lacking (Broin, 2011). User's flow experience is achieved by balanced of game challenges and player's ability to overcome them; the game will be overwhelming and generates anxiety if it is beyond user's abilities and it is boring and fails to engage the user if it is so simple for user (Chen, 2007). However, designing such a balance is a challenge respect to the size of the potential audience in the typical case of video games. The best way for designers to avoid these counterproductive situations is to embed the player choices into the core activities of the interactive experience (Chen, 2007), and make the game automatically adaptive (Lopes & Bidarra, 2011) in particular through player state assessment (Liu et al., 2009).

A consequent research issue is how to measure the player flow status during the game, possibly with no invasiveness, for instance through neuro-physiological signal processing (Berta et al., 2013). Three pedagogical models are used more in the literature for evaluating the success of a serious game; Kirkpatrick's Four Levels of Learning Evaluation, Revised Bloom Taxonomy, and Kolb's Experiential Learning model. A useful summary and review of 11 evaluation models (Connolly et al., 2009; Hainey & Connolly, 2010; Hainey, 2010) explain why other types of evaluation models like the Technology Acceptance Models for serious game adoption (Yusoff et al., 2010) and Kriz and Hense's framework for theory-based evaluation used for simulation-games, are not taken into consideration (Kriz & Hense, 2004; Kriz & Hense, 2006; Bekebrede, 2010). The Kirkpatrick's Four Levels of Learning Evaluation is a popular learning impact assessment model, involving the levels of reaction, learning, behavior and results (Kirkpatrick & Kirkpatrick, 1998). A fifth level of evaluation has been added in new versions of the model by another research to consider also the return-on-investment and impact on clients and society, respectively (Nonaka et al., 2000). The Revised Bloom Taxonomy (Anderson et al., 2001) which is the most popular cognitive approach to serious game evaluation (Kolb, 1984) considers remembering, understanding, applying, analyzing, evaluating and creating for evaluation of players' cognitive skills. The Kolb's Experiential Learning model which systemizes the work rooted on Piaget's cognitive developmental genetic epistemology (Piaget, 1929), Dewey's philosophical pragmatism (Dewey, 1933) and on Lewin's social psychology, puts the experience at the center of the learning process. Active experimentation (doing), Concrete experiment (feeling), Reflective observation (watching), Abstract conceptualization (thinking) are the stages of this model (Nonaka et al., 2000). Figure 4 highlights the focusing on game success factors on designing a serious game.

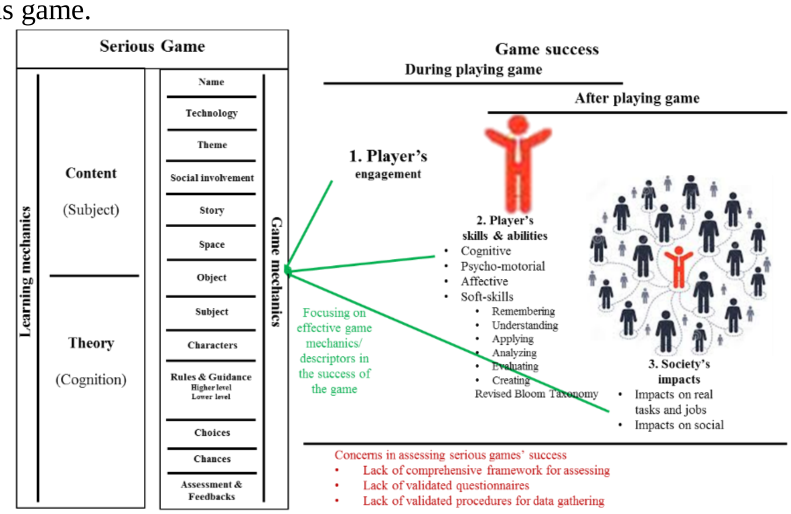


Figure 4- The focusing point for designing a serious game

Considering the above mentioned serious games mechanics, and the effective descriptors in successful serious games, the descriptors and mechanics of serious games which must be considered as a minimum for designing a successful serious game are: market, purpose, application domain, pedagogy level, skills, learning outcomes, assessment, social involvement, gameplay, deployment, target players, game components, reality, activity, modality, environment and interaction style. A recent research mentioned activity, modality, interaction style, environment, and application area as the potential characteristics for making a significant difference in serious game success (Laamarti & Saddik, 2014). This research also referred to music, guidance, challenge and consequences inside the game, with collaboration, curriculum, and pedagogical theory as other success factors of serious games. Furthermore, the more precise research highlighted that though most games adequately meet the two primary elements of clear goals and feedback, balancing game challenges and player skills is often lacking (Broin, 2011).
Respect to the reviewed researches, in the scope of this research the LM-GM model can be followed for designing the target game considering the more important descriptors in success of the serious games. Also it is decided to consider the user's ability for the scope of assessment and expanding the scope to the impacts of the designed game on the company for future studies.

3. Study the thinking patterns and skills of designers

As reviewed in previous section, active and passive required skills of target players are among the most important requirements for designing mechanics a serious game for a special target. In this section, the most reliable scientific method for capturing the skills of designers as the target people of current research is reviewed.
Thinking patterns, behaviors and skills of professional designers in different types of design respect to the various required design tasks and conditions, are used to develop and improve design tools, models and methods for both expert and novice designers. Study the nature of design to gain a better understanding and develop tools to aid designers, and automate some design tasks are considered as the minimum goals of design research (Gero, 1990). Among design research fields, design cognition is one of the fields that aim at realizing and clarifying conscious and unconscious designers' activities in different design situations, according to the characteristics of the various kind of design. Study the thinking patterns, behaviors, and skills of designers through design cognition can be commenced by have an image about design and its different types.
Design exists because the world around us does not suit us and the goal of designers is to change the world through the creation of artifacts. From this view, design is the opposite of the science which is developed as a means to understand and explain the world (Gero, 1990). Although there are several interpretations of design, one common thread of these definitions is that they tend to be as broad as possible (Love, 2000). Design is considered as the process of courses of action aimed at changing existing situations into preferred ones (Simon, 1982; Boland, 2004). This tendency also can be found in definitions more targeted towards product design, starting from that proposed in 1961 for the International Council of Societies of Industrial Design, where design is seen as the process that coordinates all factors contributing to a product, from its conception (functional, symbolic and cultural factors) to its production and distribution (Maldonado, 1991). As a consequence, corresponding research field became generic, so it is hard to distinguish its peculiarity with other fields of investigation, which in turn, slows down scientific progress in the field (Maldonado, 1991). Indeed, interpretations of design often tend to be very close to product development with a more user-centered focus (Walsh, 1996), and sometimes its interpretations are close to market research or creativity and even branding (Bachman et al., 1998).
There seems to be a general acceptance of the classification of design into routine, innovative and creative (Brown & Chandrasekaran, 1985; Coyne et al., 1987) which creative design has the capacity to produce a paradigm shift (Gero, 1990). Routine design is defined as design within a well-defined state space of potential designs, which is substantially smaller than the space of possible designs because of the constraints on the applicable ranges of values for variables. Innovative design is defined as design within a well-defined

state space of potential designs, considering applicable ranges of variable values in respect to routine design by manipulating these ranges. Creative design is defined as design that uses new variables producing new types and, as a result, extending or moving the state space of potential designs (Gero, 1990).
Whilst a design situation is defined by designers’ perception of the current state, goals, possibilities for design actions and activities, the closeness of the design situation description is considered the main criterion for results of design cognition studies (Dorst & Dijkhuis, 1995). For long time, it was normal to use concepts and languages of problem-solving behavior in cognitive science for design cognition and just recently it has been understood that designing is not normal problem-solving and consequently it is necessary to establish appropriate concepts for the analysis and discussion of design cognition (Cross, 2001). Design problems are mostly open-ended and incompletely specified based on organizational or personal perspectives, judgments, and predictions (Coyne, 2005; Darlington & Culley, 2004), and fully-specified, well-defined problems or fully-specified, infeasible problems (Shelly & Bryan, 1964; Schön, 1983; Goldschmidt, 1997). Design problems are considered as creative problem solving in respects to the known concepts and language of cognition science. It is reported that without creativity in design, there is no potential for innovation, which is where creative ideas are actually implemented (Mumford & Gustafson, 1988; Amabile, 1996). Furthermore, there is also no potential for transforming into commercial value (Thompson & Lordan, 1999; Culley, 2002). To emphasize this importance, the figures were released from the UK Treasury can be considered; the top innovating companies produce 75% of revenue from products or services that did not exist 5 years ago (Cox, 2005). Therefore, creative idea generation is considered as a vital part of engineering design (Howard et al. 2008).
For thirty years there has been a slow but steady growth in empirical research studies of design cognition which is highlighted through a cross disciplinary and domain independent literature review of 36 studies’ issues across more than 6 various domains of professional design practice from 1970 up to 1999 (Cross, 2001) from the pioneering work being undertaken in the field of architecture (Eastman, 1969; Eastman, 1970). The review highlighted two paradigms in describing design activities, of which the second paradigm has become dominant in the design research field. The first paradigm considers design as a rational problem solving process. This paradigm looks at design as a search process, in which the scope of the steps taken towards a solution is limited by the information processing capacity of the acting subject; the problem definition is supposed to be stable, and defines the solution space that has to be surveyed. In contrast, the second paradigm considers design as a process of reflection-in-action. This paradigm looks at design as a reflective conversation with the situation. Problems are actively set or framed by designers, who take actions and make moves for improving the perceived current situation (Dorst & Dijkhuis, 1995). If the academic field of design methodology wants to influence design practice and education, it should be sure to address the problems designers have in a way they experience them (Dorst & Dijkhuis, 1995).
In this research, design cognition is considered as one of the main fields of research for realizing the skills and the abilities of R&D engineers in designing the next generation of technical systems. To design an appropriate research for the purpose of this research, relevant methods of capturing experiences and problems of designers in design are reviewed.

3.1. Protocol analysis

Protocol analysis is an empirical, observational research method to study design. A protocol is a record of the time path of behaviors (Newell, 1966). Among all the empirical, observational research methods for the analysis of design activity, protocol analysis is a well-established empirical research tool (Craig, 2001; Cross et al., 1996) which is the most used one (Cross et al., 1996). Though the pioneer works began in the late 1960s, it did not gain much attention until the late 1980s and just after the Delft Protocols Workshop held in 1994, it has been used rapidly (Cross et al., 1996).
The language of designing consists of tightly connected verbal and non-verbal elements (Schön, 1983) and is a dual mode thinking coexistence of verbal-conceptual and visual-graphical elements in design activities (Akin & Lin, 1995). Therefore, many design theorists consider designers’ visual representations as well as verbal representation (Schön & Wiggins, 1992; Ferguson, 1992; Roozenburg, 1993; Lawson, 2004;

Lawson, 2006). To understand the design process, the used knowledge by designers, the cognitive actions that they take and the strategies they employ, both verbal-conceptual and visual-graphic elements in design activities are studied. Interviews, self-reporting, think-aloud and speeches are the resources for verbal-conceptual analysis, and final designs and intermediate sketches are resources for visual-graphical analysis. Protocol analysis provides a very valuable but highly specific research technique, capturing a few aspects of design thinking in detail; however, it fails to encompass many of the broader realities of design in context (Dorst, 1997). For instance, it is extremely weak in capturing non-verbal thought processes, which are so important in design work (Lloyd & Scott, 1995).

Protocol analysis can be considered as two main phases; designing the protocol and investigating the protocol. Protocol design is an activity to define the scope and condition of interested factors according to the ultimate goal of the study, as well as developing the appropriate and representative coding scheme. Protocol investigation starts by transcribing the talks and speeches, followed by protocol segmentation, and encoding the segmented sentences based on the developed coding scheme to reveal the patterns. Four main activities are considered as the main activities of designing a protocol: clarifying and stating the ultimate goal of protocol analysis, selecting the verbal, graphical or both as the data for analysis, designing the representative coding scheme, and finally defining the condition of experiment.

While clarifying the ultimate goal of protocol is considered as the first activity, it is just a transitional stage among the whole research and protocol analysis. Based on the ultimate goal, verbal, graphical or both kinds of the data are selected. For instance, in order to investigate the heuristics concluded in a design, graphical data can be selected to reveal the heuristics that designers try to apply; additionally, verbal data can be selected and both of them are complementary for wider and more accurate research. Protocol analysis is mostly used for verbal and both verbal-graphical data. Verbal data are collected in two approaches; through the recordings of a designer’s overt behaviors, like verbalization, sketches and audio-visual recordings captured by cameras (Akin, 1984), and also through interviewing or self-reporting by designers after the completion of the task (Ericsson, 2002). The first category can be designed as a verbal/think-aloud protocol for a single subject and a discussion protocol for group subjects (Waldron & Waldron, 1996) as concurrent protocols, while the second category can be designed as interviews (Cross, 2003; Lawson, 1994) or retrospective and introspective reports (Ericsson, 1993; Gabriel, 2000). In the retrospective form, designers are asked to describe their activities and in the introspective form, they are asked to add post-rationalization to the reports (Ericsson, 1993). Methodological discussions are focused on the issues of verbalization, such as validity and completeness of verbal reports, and the effects caused by verbal reporting (Ericsson, 1993; Gilhooly & Green, 1996; Ericsson, 2002). It is worth mentioning that among the different methods, the introspective report is the one that is not considered commonly as valid protocol data (Ericsson, 1993). Psychologists have also demonstrated that designer responses in interviews are not very reliable (Someren et al., 1994), so researchers mostly try to study the thinking process of designers by asking them to think aloud or talk aloud while designing in groups. Bibliometrics study showed that in protocol analysis, using the think-aloud method was one of the most popular design research methods (Chai & Xiao, 2012).

A coding scheme consists of a set of codes that are supposed to highlight the type of cognitive activities in respect to the objective of protocol analysis. Two major approaches are identified for analyzing protocols to realize design activities: process-oriented analysis and content-oriented analysis (Dorst & Dijkhuis, 1995; Dorst, 1997; Coley et al., 2007). As developing a coding scheme based on previous research is a critical activity in the scope of this research, this activity is studied in more detail level in Section 3.2.

Given the ultimate goal, the data type selected and the coding scheme developed, the scope of the experiment is designing. The most critical factors in designing the protocols are the stage of design, the context and field of target design, the characteristics of the design task, target designers with various demographic characteristics and professional experiences, and the duration of observation. Researchers are mostly focused on partial episodes of design rather than the entire process, either analyzing problems or proposing design alternatives (Jiang & Yen, 2009). Research shows that after industrial design and architecture, protocol analysis is most used and published in papers of engineering design, for studying the 92 design studies from scratch and 9 ones from existing design (Jiang & Yen, 2009). Protocol analysis is an extremely time-consuming research method, and the ratio of analysis time to sequence time of protocols is usually 10:1 ~ 1000:1, and even more extreme (Sanderson et al., 1994). To make protocol data in a manageable size, researchers usually need to make a compromise between the duration of analyzed task and sample size; most studies restricted their total size of protocols to being within 1000 minutes. Some researchers suggested that 2-hour duration is an appropriate time period for investigation (Christiaans, 1992; Cross et al., 1996; Dorst, 1997) as the concentration level of most participants could be well maintained within a 2-hour duration. Most designers develop a design concept with some details typically from 20 minutes to a few hours, and the time duration for protocol analysis is selected based on the number of designers to be studied. For example, for a sample size of 10-12, the selected time is usually less than 30 min (Jiang & Yen, 2009).

In respects to the ultimate goal of the studies, various types of participants are observed in design protocol studies. While most studies consider professional designers as the primary research, students of design majors both senior and junior are more convenient to be employed (Cross, 2003). Some studies explicitly compare the expertise of design experts with novice designers (Seitamaa-Hakkarainen & Hakkarainen, 2001; Kim et al., 2007); other studies employ a mixed set of participants to represent generic designers, but without explicit comparison (Dorst & Dijkhuis, 1995), and some other studies even compare junior students with final-year undergraduate (Christiaans et al., 1992; Atman et al., 1999) or undergraduate and graduate students (Ho, 2001). Some studies also include non-designers without specific design training as their research subjects, to investigate how ordinary people engaged in designing tasks, given it is considered that design is a specific form of general problem-solving capabilities (Archer, 1979; Cross, 1982; Allison & Cross, 2008).

Protocol investigation starts after performing the experiment by transcribing the talks and speeches, undertaking protocol segmentation, encoding the segmented sentences based on the developed coding scheme and revealing the patterns. Transcribing is considered a simple but time consuming activity which is a very delicate activity. Transcriptions must include all the voices, not only speeches, but also all intonations and silence. Protocols can be segmented for further study based on the time duration or semantic relations of talks. Previous primary research used pauses, intonation as well as syntactical markers to analyze protocols (Ericsson & Simon, 1993; Ball & Christensen, 2009), where they show that a 15-second interval time for scoring the protocols was just about right, as the designers seldom change subject or approach twice in such an interval (Akin & Lin, 1995). Recent studies use think flow or design moves as more appropriate strategies for segmentation, as a cognitive act may correspond to several verbal segments rather than a single segment (Someren et al., 1994). Design moves can be defined as the smallest coherent operation, detectable in design activity, and an act of reasoning that presents a coherent proposition pertaining to an entity that is being designed (Goldschmidt, 1992). A design move is a step, an act, an operation, which transforms the design situation relative to the state in which it was prior to that move. Moves are normally small steps, and it is not always easy to delimit a move in the think-aloud protocol of a single designer (Goldschmidt, 1995). In other words, moves in the problem space are the small steps in which reasoning proceeds (Goldschmidt, 1997). A bibliometric study of the Design Studies journal points to a high acceptance of the concept of design moves in protocol analysis (Gero & Tang, 2001; Bilda & Demirkan, 2003; Kan & Gero, 2008; Cai et al., 2010; Chai & Xiao, 2012). In terms of granularity, a think flow has a similar structure with the design story, which is composed of design issues, concepts, and related forms. A design issue refers to a particular point or a situation in a design problem. A concept is a solution which addresses an issue and it is realized as a specific artefact with a form (Oxman, 1994). Protocol segmentation is part of the study which depends strongly on the researchers' interpretations and experiences, so to perform a reliable study, whether the segmentation criteria are syntactical or conceptual, replication of the coding process by independent coders is essential (Krippendorff, 2004) using the Kappa coefficient (Ball & Christensen, 2009) or family of alpha coefficients (Krippendorff, 1995; Krippendorff, 2004; Krippendorff, 2012).

Encoding the segmented parts of the protocols is another activity of protocol analysis which depends strongly on the encoders' interpretations. Therefore, this activity is performed by two encoders using agreement coefficients to reach least reliability. In some cases, instead of two encoders, one encoder performs the task two times, on two complete separate occasions.

Pattern revealing is considered the last activity in protocol analysis. Researches show the evolution in pattern revealing. Previous research discusses their thoughts on raw data by providing an excerpt of a protocol straightforwardly (Eastman, 1969; Goldschmidt, 1992; Schon & Wiggins, 1992; Suwa et al., 1998; Valkenburg & Dorst, 1998; Visser, 1995). In more mature discussions, frequencies of encoded items are shown in tables and frequency graphs for both qualitative and quantitative studies (Stempfle & Badke-Schaub, 2002; Kruger & Cross, 2006; Tang et al., 2011). Other research tries to display repetitive design trends and patterns depending on the visualization methods (Akin & Lin, 1995; Suwa et al., 1998) to provide insights and further interpretation of the process (Dorst & Dijkhuis, 1995). For instance, by using linkography and through constructing the linkograph of cognitive activities of a designer or a design team, it is possible to interpret the design process in terms of its critical moves and designing reasoning (Goldschmidt, 1992; Goldschmidt, 1995; Van der Lugt, 2003; Dorst, 2004; Kan & Gero, 2008). However, it is difficult to analyze a design process with linkograph, because the representation method of links is constrained, and moves are connected to each other with a single type of relation.

In the scope of current research, revealing the skills of R&D engineers in designing the next generation of technical systems can be studied through protocol analysis with around 12 teams and a 90-mintue design session (1080 Minute together). To make possible capturing the thinking path of engineers, discussion method can be done with involving 2 R&D engineers in each team whilst design moves can be applied for transcribing the speeches. The more detail about the designed protocol analysis is described in chapter 3.

3.2. Coding scheme

A coding scheme consists of a set of codes that are supposed to highlight the type of cognitive activities that relate to the objective of the protocol analysis. Two major approaches are identified for analyzing protocols to realize design activities: process-oriented analysis and content-oriented analysis (Dorst, & Dijkhuis, 1995; Dorst, 1997; Coley et al., 2007). Process-oriented analysis emphasizes problem solving actions and design strategies which are highly related to the design process. In this scope, two kinds of activities can also be identified through protocol analysis for design process: design activities and design process management. The former refers to the activities directed towards the design problem-solving processes (Goldschmidt, 1992) while the latter is a meta-cognition activity referring to the activities towards the organization of the design process (Tawil, 2007). Content-oriented analysis however is focused on what designers look for, see, do, and possibly think (Dorst & Dijkhuis, 1995). More mature content-oriented studies exploit the theories of memories (Dix, 2004; Tulving, 1991) and the role of different kind of memories, especially semantic and episodic, in the problem-solving process (Sowa, 2006; Visser, 1995).

To follow each of the two approaches, some coding schemes are proposed and applied in researches to encode and highlight the cognitive activities. The coding scheme could be representative of the research's ultimate goal by encoded data and the links between subsequent observations to be used for finding patterns. To select one coding scheme for current research or building the new one, in following the most cited coding schemes are reviewed in detail.

Act, goal, context, topic and auxiliary topic is a five-class coding scheme with corresponding sub-classes that are applied to generalize both process and content of designers' cognitive activities (McGinnis & Ullman, 1992). Determining the problem, making a performance specification, and building the concept and plan, are some of the sub-classes of the goal class which are used to decode the design process. The three other classes of context, topic and auxiliary topic are divided to sub-classes such as user, company or product for context class and company policy, the maximum size of the product and materials for the topic and for auxiliary topic. This coding scheme is a simple classical analysis-model which is representative for both process and content by encoded data and the links between subsequent observations. It is claimed by authors that it is hard to score all observations with the proposed codes. The encoded data show the distribution and popping up of each code along protocol without highlighting the importance or priorities of corresponding codes and classes. In other words, in the conceptual phase, hardly any pattern can be found in the scored protocol data to echo strategies or heuristics in the design activity while the written-out protocols shows the consistency of designers in concept-building process.

In another study, the researcher used move, frame and underlying background theory, as a three-class coding scheme to encode the content of design cognitive activities (Schön, 1983). It is reported that data processing in this scheme is reasonably experienced, and it is easy to score if a clear definition is provided for each code. Additionally, the consistency of the design activity is much clearer in this description than the previous one. This coding scheme is considered closer for describing design-as-experienced, rather than looking at design as a rational problem process. The link process-content in design decisions is preserved, and so is the perception of the design problem.

Various sequences of function, behavior and structure is another well-known process-oriented coding scheme. Function describes what the design is for, behavior describes how the design works and structure describes the design in terms of its form or embodiment. Understanding whether an idea relates to either factor, can be used to create a more detailed measurement of an idea's novelty and appropriateness to the task. In this coding scheme, the transmission from function to behavior which is shown by function-behavior is considered as formulation, behavior-structure as synthesis, structure-behavior as analysis and behavior-behavior as evaluation. Researches show cycles of analysis-synthesis-evaluation activities in protocols (Gero & Kannengiesser, 2004; Howard et al. 2008). In addition to the short-term cycles of analysis-synthesis-evaluation, there is a trend over the whole design episode to begin by spending most of the beginning time analyzing the problem, then mainly synthesizing the solution and finishing by spending most the last time on the evaluation of the solution. In other words, a designer begins a conceptual design session by analyzing the functional aspects of the problem. Towards the end of the design session, the designer's activity is focused on synthesizing structure and evaluating the structure's behavior (Mc Neill et al., 1998).

Idea-precedent-interpreter is the other three-class content-oriented coding scheme with corresponding sub-classes. In the case of generalizations, participants produce knowledge by themselves through combining several personal experiences and/or reflecting theoretical knowledge upon their personal experiences. Verbal analysis should capture the knowledge of a designer and how it changes with acquisition (Chi, 1997). In content-oriented coding schemes, the ability to call personal experiences are shown as episodic precedents, and ability to generalize personal experiences are shown as semantic precedents. Word precedents represent prior knowledge and experience regardless of the domain that the knowledge was retrieved from. Precedents are classified depending on their memory types as episodic or semantic memories. The definition of episodic and semantic precedents is adopted from a theory of psychology which argues for the interdependency between episodic and semantic memories (Dix, 2004; Tulving, 1991). According to previous studies, it seems likely that episodic and semantic precedents participate differently in cognitive processes. It is expected that expanding the concept of precedents will promote a more precise understanding of designing and its knowledge construction (Sowa, 2006; Visser, 1995). Therefore, this coding scheme is used mostly to highlight the role of different kind of precedents on the ideas and infer the used heuristics and strategies. Episodic precedents represent things retrieved from episodic memory systems, which have specific contexts and a direct relationship with personal experience. Semantic precedents are composed of two different types of semantic memory. Some semantic memories come from theoretical knowledge that participants have learnt or studied. The other part of semantic memories is created through inference and generalizations of episodic knowledge. Therefore, precedents in general are the best guesses about which areas within the space are most promising to generate initial solutions and alternatives. Interpreters help to interpret the meaning of the design brief, and engage in redefining the problem space. Some research has argued that a design problem can be subjectively perceived and interpreted due to its nature (Lawson, 2006), while interpreting designer behavior includes redefining the design problem based on the understanding of their own resources and capabilities (Dorst & Cross, 2001). The design direction and outcomes therefore depend on the interpretation of the design task (Sifonis, 1995). An idea is defined as a design concept which is generated to satisfy the design brief, and has at least one determined feature related to the product itself. Depending on whether the problem is solved by the idea or the issues are addressed in the protocol, an idea can be classified into one of two subcategories. If the problem or issue is addressed for the first time in the protocol, the idea is considered as an initial idea. As an idea is developed with additional features and/or details, it is classified into the category of developed ideas.

In some recent researches, to understand the organization of knowledge constructed through generalization, a tripartite scheme of issue-concept-form was proposed. It was expanded by including analogy and metaphor, which supported the design processes. The conceptual model of knowledge organization and utilization suggests that designing is highly related to obtaining the precedents, and re-using them while accommodating their utility in the present issue (Oxman, 1994; Oxman, 1999).

The codes mentioned above are some of the most known codes. It can be concluded that different process-oriented coding schemes are applied by researchers to find strategies and also various content-oriented coding schemes are used to reveal the precedents. It is clear that only some of the coding schemes are based on specific design models or frameworks that can support reflecting the observations. in other words, the most coding schemes are just consisted of some codes to show some emergences or patterns of the codes. FBS framework is an example of a process-oriented coding scheme for revealing design strategies based on a known framework while the most of content-oriented coding scheme are not configured based on a model or framework.

Reviewing the above mentioned coding schemes it can be concluded that mostly the content-oriented coding schemes separate the sentences related to an idea from the discussions supports that idea (Schon, 1983; Oxman, 1990; McGinnis et al., 1992; Visser, 1995; Dorst et al., 1995; Chi, 1997; Sowa, 2006). An idea is classified and studied through the corresponding problem, suggested concept and suggested form. The supportive discussion also is classified as the parts related to the requested requirements by design task, the potential appropriate knowledge and previous experiences for formulating and solving the problems (episodic knowledge), and the analysing the appropriateness of the suggested knowledge (semantic knowledge). In the scope of this research, to capture the heuristics applied aby R&D engineers in designing the next generation of the technical systems, a content-oriented coding scheme can be useful.

Chapter 3

Methodological proposal and research contribution to capture the skills of R&D engineers in designing the next generation of technical systems

While some active skills of R&D engineers in designing the next generation of technical systems are not effective, some non-active skills are necessary. Although some general skills can be found in previous research as discussed in Chapter 2, the precise skills must be observed during a real design session in same task by involving least necessary R&D engineers to capture the overall skills. This chapter reports the second phase of the current research based on the DRM framework which is discussed in Chapter 1. The phase of Descriptor study I clarifies the description of the existing situation and it is performed to study the performance and skills of R&D engineers in real design sessions for proposing the concept of the next generation of technical systems. This chapter provides the methodological proposal and research contribution to capture the skills of R&D engineers in designing the next generation of technical systems. Logically, to observe R&D engineers in the same task, both their design proposals and their patterns of thinking must be considered, and the acceptable ideas and corresponding speeches with respect to the requested task's characteristics being clarified. Therefore, this chapter proposes a set of criteria for assessing design proposals, and develops a coding scheme for capturing the corresponding speeches in relation to the task. Both the empirical study for capturing the desired skills of R&D engineers and the results of the empirical study are presented.

1. A set of criteria (system of metrics) to evaluate the next generation of technical systems

As reviewed in Chapter 2, despite the huge interest among both scholars and industries in the field of innovation and technology forecasting, there is no specific set of criteria for assessing the design proposals as acceptable candidate ideas for the next generation of technical systems. Given this, two complementary research fields were reviewed in Chapter 2 which make it possible to develop a set of criteria for assessing the acceptable candidate ideas: (i) clarifying the characteristics of the next generation of technical systems and (ii) considering the general criteria which are used for assessing the design proposals.

The characteristics of the next generation of technical systems were reviewed in Chapter 2. Table 2 presented the previous researches in a way that these characteristics are conceptually completed, starting from the definition of innovation in the widest scope to the definition of breakthrough innovation as a more detailed one. Overall, the next generation of a technical system is a kind of breakthrough innovation (Geels, 2004) which is defined by overlapped characteristics between the outcomes of the technology-push innovation (Dosi, 1982) and design-driven innovation (Verganti, 2008). In other words, the next generation of a technical system is the version of the system consisting of radical technological change, and radical meaning change of the system, for new requirements of existing or new customers. Radical novelty, which is in the core of the next generation of technical systems, is achieved through re-combining already established elements (Fleming, 2001), or by introducing and bringing in an established element into a new setting (Hargadon & Sutton, 1997; Van de Poel, 2003). It provides a new technological trajectory for solving the system's problems (Dosi, 1982). Radical novelty is the result from resolving a contradiction (Altshuller, 1988). The summarized characteristics can be classified in three categories - technology, market and design - corresponding to the drivers of radical and breakthrough innovation. Considering the definitions related to the next generation of technical systems, the characteristics of technical systems were summarized in Table 3. Considering the uncertainty of the nature of the mentioned characteristics, various methods are developed and used for anticipating, forecasting and assessing them. These methods use different resources from three time periods of past, present, and future. Some of the methods are developed based on using professional expertise and others use patents, publications and share markets in both levels of strategic indexes or their concluded information. It would be far more useful to identify radical inventions at the time, or even before, they enter the market. The assessment and measuring methods based on characteristic definitions are both retrospective and prospective, though most of them are retrospective. Technology forecasting methods and methods of future studies are prospective methods, while the retrospective ones are developed mostly based on the analysis of any kind of innovation. In the scope of this research, the method of assessing potentiality of ideas must be an easy-to-use prospective, as it is supposed to apply as part of the target game that is going to support R&D designers in proposing the concept of the next generation of technical systems, in the design stage. It will also be used for capturing the natural behavior and skills of R&D engineers in the same task in an empirical study for developing the game. Therefore, among the mentioned characteristics, the ones which must assess retrospectively were highlighted in Table 5.

In addition, despite different ultimate expected results of any design or idea generation session, there are some common criteria for assessing generated ideas and design session results. In most researches, group performance is determined by the evaluation of the proposals in terms of two dependent variables: number of ideas (Nijstad et al. 2002; Perttula & Sipilä, 2007; Shah et al., 2003) and quality of ideas (Wierenga, & Bruggen,1998; Shah et al., 2003). Consequently, the quality of an idea is generally defined various concepts. Table 7 highlighted the three criteria of novelty, technical plausibility and relevance which can cover the most of concepts are referred in previous researches as some aspects of quality.

Considering the above summarized literature, it can be concluded that the set of criteria which represents the characteristics of the next generation of technical systems must be: (i) easy-to-use, (ii) retrospective and (ii) can be assessed subjectively. The set of criteria can be similar to general criteria for assessing design proposals as much as possible and should be simultaneously representative for the characteristics of the acceptable candidate ideas for the next generation of technical systems. Therefore, the set of criteria can be developed by considering the general criteria of assessing design proposals as main criteria and target characteristics as the sub-criteria. Quantity and quality are the two main criteria, with quality being divided into novelty, technical plausibility, and relevance. Quality can be assessed quantitatively while the number of qualitative ideas is reported. Table 9 shows the proposed criteria and sub-criteria for assessing and highlighting the candidate ideas for the next generation of technical systems.

Criteria	Sub-criteria	Mentioned characteristics in literature
Quantity	-	-
Novelty	1. Existing in the market/Already in use 2. Existing concept, not available on the market 3. Existing feature or trait in other fields of application, never applied to the domain of this product 4. Novel feature or trait	- Completely new or significantly different in meaning or functionality o Useful o Wider expectations for same market (New requirements of same users) o Same or wider expectations for new market (Same or new requirements for new users) o New meaning or new language o Conquer the market dominantly - New technology (in one of scopes of hardware, software or orgware) o Acceptable but not obvious to field experts o Acceptable level of novelty by the market o Constitutes the core of the change o New combinations of selected principles derived from natural sciences and selected material o Recombining already established elements o Bringing in an established element into a new setting o Resolving contradictions o Using slack resources - Less costs, harms and efforts
Technical plausibility	1. Against laws of physics 2. Not against laws of physics, but sounds infeasible 3. Sounds infeasible with current knowledge but presumably achievable with further research in the field 4. Sounds feasible with current knowledge	- New technology (in one of scopes of hardware, software or orgware) o Constitutes the core of the change o New combinations of selected principles derived from natural sciences and selected material o Recombining already established elements o Bringing in an established element into a new setting - Acceptable but not obvious to field experts
Relevance	1. Neither for the current usage of the system, nor for potential interpretations for the future society 2. No benefits foreseen for the current usage of the system in the current society, but potential relevance in specific (narrow) niches of members of future society 3. No benefit for the current usage of the system in the current society but potential benefits (interpretation) perceived for different usage in a future society 4. Benefits also for the current society	- Useful - Wider expectations for same market (New requirements of same users) - Same or wider expectations for new market (Same or new requirements for new users) - New meaning or new language Acceptable level of novelty by the market - Conquer the market dominantly

Table 9 - Criteria and sub-criteria for assessing candidate ideas for the next generation of the technical systems

The first and second columns show the criteria and sub-criteria while the target characteristics are mentioned in the last column. The characteristics are the same characteristics mentioned in Tables 2 and 3. As shown, quantity, novelty, technical plausibility and relevance are considered as the main criteria. In other words, quality is divided to three criteria; novelty, technical plausibility and relevance. Novelty is the main criterion used to assess the quality of ideas given it is the main characteristic of the next generation of technical systems. To avoid mental inertia by presenting many details for experts, any changes in

technology, market and design (Table 3) can be considered as a change in the traits of the technical system under the novelty criterion. Therefore, the sub-criteria can highlight any changes in the traits of the system, through the originality of the trait in any industry.
In the scope of this research, the selected ideas as candidate ideas must be representative for the next generation of corresponding technical systems. Therefore, all criteria together must cover the characteristics highlighted by literature for the next generation of technical systems, which are discussed in previous tables. As only some characteristics of the next generation of technical systems are covered by the novelty criterion, the other ones must be considered in other criteria. As the table shows, the other characteristics are classified to cover the quality of the task within the criteria of technical plausibility and relevance to market. Potential feasibility even beyond current technical knowledge without violating established physical laws is considered as technical plausibility. The usability of the idea for a societal group of customers and the degree of sensibility of them to the proposed idea, are considered as relevance. The sub-criteria for these two criteria are also presented in the table.
It is worth mentioning that the criteria and sub-criteria are defined to be prospective as much as possible and also be assessed subjectively by experts. Also as the table shows, for all the criteria related to the quality of ideas, the sub-criteria are defined in four levels in which the first level shows the lowest degree and the fourth level the highest degree of target criteria.

2. A coding scheme for capturing design heuristics used in designing the next generation of technical systems

As discussed in Section 1 of this chapter, ranking and distinguishing the next generation of technical systems can be approached, by simultaneously applying the three criteria of novelty, technical plausibility and relevance. In light of previous researches focused on the next generation of technical systems (Table 2), the characteristics can be summarized as adding the novel feasible technological or functional traits in the technical system, which are brought in the set from already established elements of available systems and technologies. Therefore, an appropriate coding scheme for this research must be capable of revealing and highlighting the thinking paths of designers in adding a novel trait in the technical system, as well as in the area they searched to find the acceptable novel feasible trait to bring into the set. To develop an appropriate coding scheme for this research, coding schemes used in previous studies, were reviewed in Chapter 2 for their suitability respect to characteristics of the next generation of technical systems.
Reviewed literature showed that to capture the normal behavior and expertise of designers in general, and also very specific design tasks, different coding schemes were proposed and applied in design cognition studies. Strategies and precedents are two main expectations of design cognition studies. Strategies are mostly the results of process-oriented protocol analysis. Design precedents are the results of content-oriented protocol analysis, which aim at showing the frequencies and transitions among the application of different kinds of designer knowledge and experience. Although extant research on process-oriented protocol analysis aim at increasing the productivity and quality of design sessions, by guiding designers to follow the patterns applied by successful designers among different modes of problem solving, content-oriented protocol analysis is more relevant to the aim of the current research. Considering precedents as the hints for designers to search the effective scopes of time and space for acceptable novel feasible trait to bring into the set, precedents applied by designers during protocols, especially the effective ones, are the raw data for analysis. In other words, content-oriented protocol analysis can reveal the role and usage of different kind of precedents in different parts of design session, leading to being able to define the heuristics and hints for designers. Episodic precedents, which have specific contexts and a direct relationship with personal experience, can be used to highlight the scope of effective search. On the other hand, semantic precedents, which are mostly the results of episodic knowledge generalizations, can be used to highlight the designer’s thinking paths in using the corresponding episodic knowledge.

Literature shows that the various scope of designers' precedents in various forms is applied in design consciously or unconsciously. Knowledge of the different time scopes of the target system, or the hierarchy of related system to the target system (Pasman, 2003; Lawson, 2004; Eilouti, 2009), is a part of precedents; while the knowledge of any other system (Marslen-Wilson & Tyler, 1980; Jansson & Smith, 1991; Purcell & Gero, 1992; Smith et al., 1993; Dunbar, 1997; Benami & Jin, 2002; Nijstad et al., 2002, Tseng et al., 2008; Mak & Shu, 2008; Helms et al., 2009; Weisberg, 2009, Linsey et al., 2010; Chan et al. 2011; Fu et al., 2013; Gonçalves et al., 2013; Moreno et al., 2014) and also knowledge of design methods and tools (Archer, 1968; Booz et al., 1968; Radcliffe & Lee, 1989; Fricke, 1993; Fricke, 1996; Basadur et al., 2000; Shneiderman, 2000; Kryssanov et al., 2001; Howard et al., 2008) are the other parts of precedents. The mentioned precedents are applied in the form of collected prior solutions of the target technical system (Pasman, 2003; Lawson, 2004; Eilouti, 2009), collected examples of other technical systems close or far to the target technical system (Dunbar, 1997; Tseng et al., 2008; Weisberg, 2009; Linsey et al., 2010; Chan et al. 2011; Fu et al., 2013; Gonçalves et al., 2013; Moreno et al., 2014), hints for considering requirements (Downing, 2003), templates describing entire class of solutions (Senbel et al., 2013), hints about specific characteristics of prior solutions or other examples such as function and behavior (Doboli & Umbarkar, 2014), and hints about specific characteristics among prior solutions or examples, such as similarities and dissimilarities (Marslen-Wilson & Tyler, 1980).

The content-oriented coding schemes mostly separate the sentences related to an idea from the discussions that support that idea. An idea is classified and studied through the corresponding problem, suggested concept, and suggested form. The supportive discussion is also classified as the parts related to the requested design task requirements, the potential appropriate knowledge and previous experiences for formulating and solving the problems, and the analysis of the appropriateness of the suggested knowledge. One of the main characteristics of content-oriented protocol analysis, which are expected to reveal precedent-based heuristics, is the relation of their corresponding coding schemes with the semantic and episodic memories of the designers. Episodic precedents, which have a direct relationship with personal experience, are used to highlight the knowledge used by designers. Semantic precedents, which are mostly the results of episodic knowledge generalizations and the analysis of the appropriateness of the suggested knowledge, are used to highlight the designers' thinking paths in using the corresponding episodic knowledge. According to the above mentioned expectations and characteristics, Table 10 shows the characteristics can be selected for the target coding scheme.

No.	Characteristics of applied content-oriented coding schemes in the literature		Selected characteristics for target coding scheme		No.
1	Idea	- Corresponding problem - Solution concept - Solution form	Idea description	Idea	1
2	Supportive discussion for the idea	- Potential knowledge for formulating and solving the problems (Suggesting potential novel feasible technological or functional traits of available systems and technologies)	Episodic precedent application	Precedents	2
		- analyzing the appropriateness of the suggested knowledge (Selecting the novel feasible technological or functional traits of available systems and technologies)	Semantic precedent application		
		- Requested requirements by design task	Task requirements description	Interpreter	3

Table 10 - The characteristics of developing coding scheme based on characteristics of previous content-oriented coding schemes

As design is a kind of creative problem-solving (Mumford & Gustafson, 1988; Amabile, 1996) of ill-defined problems (Akin, 1978; Thomas & Carroll, 1979), precedent-based heuristics are the heuristics for formulating and solving the corresponding problems. It is expected the precedent-based heuristics for designing the next generation of technical systems, will be the best guess about the most promising spaces to be exploited for searching for novel feasible traits to be used as initial solutions and alternatives. The most promising spaces for creative problem-solving are described by the multi-screen model; also known as the system operator model and powerful thinking schema (Altshuller, 1988). This model is based on the three dimensions of system hierarchy, time, and interfaces of anti-systems for describing the promising spaces (Khomenko & Ashtiani, 2007). The promising spaces are defined by the problems and solutions, which are searched within the corresponding hierarchy of the target system or other systems in different time perspectives. Therefore, the coding scheme can exploit and benefit at least the dimensions of the powerful thinking schema, to reveal the used promising spaces for solutions. Table 11 shows the promising characteristics of dimensions of multi-screen model for the coding scheme aim at highlighting the applied heuristics for designing the next generation of technical systems.

No.	Characteristics of powerful thinking schema		Selected characteristics for target coding scheme		No.
1	System hierarchy	- Super-system - System - Sub-system	- Super-system & user - Similar system - Sub-system & object	System hierarchy	1
2	Time perspective	- Past - Present - Future	- Past - Present - Future	Time perspective	2
3	Relation of the system and anti-system	Anti-System by Function Anti-system by Functioning	Problems and solutions among system and anti-system	Supportive discussion for the idea	3

Table 11 - The characteristics of developing coding scheme based on characteristics of powerful thinking schema

This research proposes developing a coding scheme based on Tables 10 and 11. System hierarchy, time horizon, and nature of the speeches are the three dimensions considered for the target coding scheme.

1. System hierarchy: In respect to this scope, speeches are decoded in three different classes; system, super-system and similar systems. The systems in a hierarchy level can be classified in different layers, based on their relation to performing main and secondary tasks and the system functions of interest. Classifying the systems into the three scopes of system, super-system and similar system, is the least amount of classes that can show R&D designer tendencies in analyzing the available systems in the related hierarchy, to search and select novel feasible technological or functional traits in the technical systems, which are brought in the set. The scope of the system refers to the speeches related to the analysis of the sub-systems of the system, as well as the object that the system acts upon. The scope of the super-system refers to the systems; whether the system under investigation can be considered as one of the sub-systems of them, or systems that they consider as complements around the system or even the users of the system. Finally, the scope of the similar systems refers to the systems that there are no direct relations among them and the target system, but some similarities can be distinguished. Like the other two other classes, the similar systems can be classified as the systems which are or can be used as the alternatives for the system or the systems which designers observe some similar characteristics among them and the system under study. The designers use the similarities to learn more about the system. Therefore, in total, system hierarchy consists of three main levels and six sun-levels. Table 12 presents these six codes and examples for each of them.

No.	Classes	Sub-classes	Rep	Description	Example (Target system: Fridge)
1	System	Object	obj	The element that the target system acts upon	Food
		Sub-systems	sub	One of the components of the target system	Container, cooling system, …
2	Super-system	User	user	The element or person benefitting from the function of the target system	Fridge owner
		Co-systems	co	The systems which related to the target system and complete the process chain	Vegetable crusher
3	Similar systems	Alternatives	alt	The systems with similar functions	Air conditioner
		Analogous	an	The systems with any kind of similarity except function	Cabinet (kitchen furniture)

Table 12 – Suggested coding scheme for system hierarchy

2. Time horizon: Time is an artificial concept to put in order the observed events or to measure relative duration of processes. Discussion of the epistemology of time is beyond the scope of this research, but for considering time horizon as a dimension of coding scheme, the origin and perspective as the main factors should be taken into account. For this scope, speeches can be encoded as speeches related to past, present or future, whilst the origin is considered as the system's current condition, and past and future are considered as previous and next conditions of the same system. Another perspective can be considered when past and future, are conditions of other systems or processes, before and after the system in interest, whilst it performs its function. Some other perspectives can be defined and applied too, but for the scope of this research, the first perspective is more relevant as it captures how the designer's image of the three versions of the system (past, present and future version) can help them to propose the next generation of the system. In relation to technology forecasting methods and methodologies, these three different periods are also considered as crucial periods for proposing the next generation of systems. While most technology forecasting methodologies and methods study the past to propose the future, there are some methods that propose the future by studying the present and future. Therefore, by decoding the speeches based on this scope, the tendencies of R&D designers to these three periods will be clarified. Table 13 presents the codes and the examples for the classes of this scope.

No.	Classes	Sub-classes	Rep	Description	Example (Target system: Fridge)
1	Past	-	pa	Past is a set of events that may influence events in the present.	Fridge without freezer
2	Present	-	pr	Present is a set of events that occurs in a particular place of space.	Current generation of the fridge
3	Future	-	fu	Future is a set of events that may be affected by some events in the present.	Fridge controlled by IT technology

Table 13 - Suggested coding scheme for time horizon

3. Nature of the speech: Given Table 10 and the last row of Table 11, speeches can be decoded in three different classes; precedent, interpreter and idea description. The precedent class refers to speeches related to the most promising spaces to be exploited for searching and selecting novel feasible traits to be used as initial solutions and alternatives. The word precedent represents prior knowledge and experience, regardless of the domain that the knowledge was retrieved from. The precedents are classified depending on their memory types as episodic or semantic memories. Episodic precedents represent things retrieved from episodic memory systems, which have specific contexts and a direct relationship with personal experience. In the scope of this research, episodic precedents refer to the most promising spaces to be exploited for searching novel feasible traits to be used as initial solutions and alternatives. Semantic precedents are

composed of two different types of semantic memory. Some semantic memories come from theoretical knowledge that participants have learnt or studied and others are created through inference and generalizations of episodic knowledge. In the case of generalizations, participants produce knowledge by themselves, through combining several personal experiences and/or reflecting theoretical knowledge upon their personal experiences. In other words, semantic precedents refer to the speeches for selecting the most appropriate novel feasible traits to solve the problems and propose the next generation of technical systems. The interpreter class refers to the task's goal and constraints, which are given as part of the design task, or are defined by designers during design sessions. Interpreters help to interpret the meaning of the design brief, and engage in manipulating the problem space. An interpreter reports an interpreting behavior of a designer, which includes re-defining the design problem based on the understanding of goals and constraints (Dorst & Cross, 2001). Finally, the class of idea description refers to the speeches that describe the ideas generated and developed during design sessions. An idea is defined as a design concept which is generated to satisfy the design brief, and has at least one determined feature related to the product itself. Depending on the problems solved by the idea or the issues addressed in the protocol, an idea can be classified into one of two sub-categories. If the problem or issue is addressed for the first time in the protocol, the idea is considered as an initial idea. As an idea is developed with additional features and/or details, it is classified into the category of developed ideas. Table 14 presents this scope in more detail level and their corresponding examples.

No.	Classes	Sub-classes	Rep	Description	Example (Target system: Fridge)
1	Precedent	Episodic	ep	Direct personal prior knowledge and experience called in the protocol	- The fridge consists of … - We use vegetable crusher before storing vegetables in the fridge
		Semantic	se	Theoretical knowledge and analysis or generalizing prior knowledge	- The fridge became larger and larger from the first generation
2	Interpreter	Given	g	Given goals and constraints by design brief	- propose the next generation of the side by side fridge
		Find	f	Defined goals and constraints by designer	
3	Idea description	Initial	in	Generated idea to solve a problem or satisfy an issue for the first time in the protocol	- A fridge which pack the received food
		Developed	dev	Developing a proposed idea for solving a problem or satisfying an issue	- The fridge which pack the received food and store them automatically in the fridge (developed respect to the idea mentioned in the previous row)

Table 14 - Suggested coding scheme for nature of speeches

The requested heuristics are going to be configured by composing code sub-classes, which are effective in designing the next generation of technical systems. As an example, a "sys/sub & pr & int/g" is an option of heuristics which proposes defining a new constraint in a present version of the one of the sub-systems of the system.

3. A set of treatments for promoting R&D engineer performance in designing the next generation of technical systems

Stimulation is one of the most seen methods for improving the results of design sessions and designers' performance. Literature shows application of stimuli in order to increase both the general characteristics of design proposals, and also design for specific requirements and problems. There is a belief that there are some links between the nature and type of stimuli and the nature of the resulting ideas; given this, there are researches that discusses the characteristics of various kinds of stimuli (Howard et al., 2010), period of application stimuli in design sessions, the right modality (Sarkar & Chakrabarti, 2008) at the right level of detailness (Cardoso & Badke-Schaub, 2011), and also their effects on cognitive activities of designers in different fields of engineering and design.
The stimuli can be studied in three different classes corresponding to the main issues of design cognition; stimuli for proposing design strategies, stimuli for proposing design precedents, and stimuli for proposing combination of both in the form of design models, methods and procedures. Stimuli which are proposing types of precedents to the designers, lead them to search for effective knowledge and experiences in respect to the design task's requirements, while assessing their appropriateness. Stimuli which are proposing types of strategies, lead designers to apply effective strategies in respect to the design task's requirements. The aim of this research is to propose more appropriate stimuli for increasing the quantity and quality of candidate ideas generated by R&D engineers for the next generation of technical systems in a design session, according to the results of previous researches. Novelty, technical plausibility, and relevance are developed and considered in this research as the criteria for assessing the candidate ideas for the next generation of technical systems. Therefore, the stimuli which are more effective on each of these criteria can be considered as potential stimuli.
As reviewed in Chapter 2, literature shows among the precedents and strategies, the relation of various kind of precedents were studied respect to some of these criteria in previous researches, while the most dominant strategies were studied based on behavior of professional and successful designers. The appropriate precedent-based stimuli can be selected from the most effective precedent-based stimuli discussed in Table 4 in as far as combining the effective ones. In order to select or develop the appropriate stimuli, it is worth looking at the characteristics of stimuli, instead of looking only to their final forms. Structure (such as singular or structural representations of precedents), resource characteristics (such as the degree of novelty and degree of closeness), the representation medium (such as textural, pictorial and physical), and the field of precedents (such as target systems or other systems) are some of characteristics that can be considered. The selected characteristics must be effective in increasing the degree of the three criteria - novelty, technical plausibility and relevance - of each design proposal to become an acceptable candidate idea for the next generation of technical system.
In this section, respect to the previous researches, three stimuli are developed; two stimuli based on the results of previous researches in design precedents, and one stimulus based on the results of previous researches on both design precedents and strategies.

3. 1. Pictorial representation of trends of evolutions of some technical systems

As discussed after Table 4 in Chapter 2, mostly all kind of precedents increase quantity (rows 1, 2, 3, 4, 5, 6) while there are some studies which show singular representation of precedents are not effective in increasing the quantity or even they reduce it (rows 7, 8). Also the table shows that all kind of precedents in general are mostly effective in increasing novelty and creativity, and reducing fixation (rows 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 25, 28, 29), while there are some studies which show doubts about the positive effects of singular representation of precedents on novelty (rows 16, 20, 22, 23, 27). In other words, in order to increase quantity and novelty of design proposals, it is more convenience to apply structural representations of precedents as stimuli. In addition, Table 2 shows examples are more used as stimuli and despite some doubts about the positive effects of them on the quantity and novelty of design proposals (rows 7, 8, 16 & 20), they are positively effective (rows 12,13,14,15 & 17). On the other hand, examples are a kind of singular representation of precedents; it can be suggested and studied that using examples for some structural representation forms of precedents can be more effective, as structural representations seem more effective in increasing both quantity and quality. Additionally, pictorial representations of precedents are positively effective in increasing novelty (row 17), so it can be recommended that one form of stimuli for increasing the number of candidate ideas for the next generation of technical systems can be built, based on three previous findings in the form of pictorial representation of examples for one form of structural representation of precedents.

Templates describing an entire class of solutions, are one kind of structural representation of precedents, which can be applied in the composed form. Trends of evolution of the technical system are a type of template for describing an entire class of solutions for the next generation of technical systems, which can be used in the composition. Trends and patterns of evolution are one of the most powerful TRIZ tools both for identifying a system's evolution potentiality, and to speed up the generation of new solutions for technical problems; a more advanced use of the tool allows strategic forecasting of medium/long term scenarios (Mann, 1999; Domb, 1999; Sawaguchi, 2001; Zlotin & Zusman, 2001). New technology trends have been added to the original ones discovered by the first TRIZ researchers (Mann, 2002); further studies have demonstrated the validity of these patterns of evolution, even in other fields like business and management, arts, biology, etc. (Mann, 2000; Terninko et al., 2001; Timokhov, 2002; Domb, 2003). Looking at the technical field, several studies have been performed by Altshuller himself to check the applicability of the patterns in any area of technology (according to Zlotin & Zusman, 2001 though no publications were presented by Altshuller about this topic, he repeatedly addressed such a task in numerous seminars and discussions). Figure 5 shows the relations of laws of evolutions of technical systems and the least number of trends.

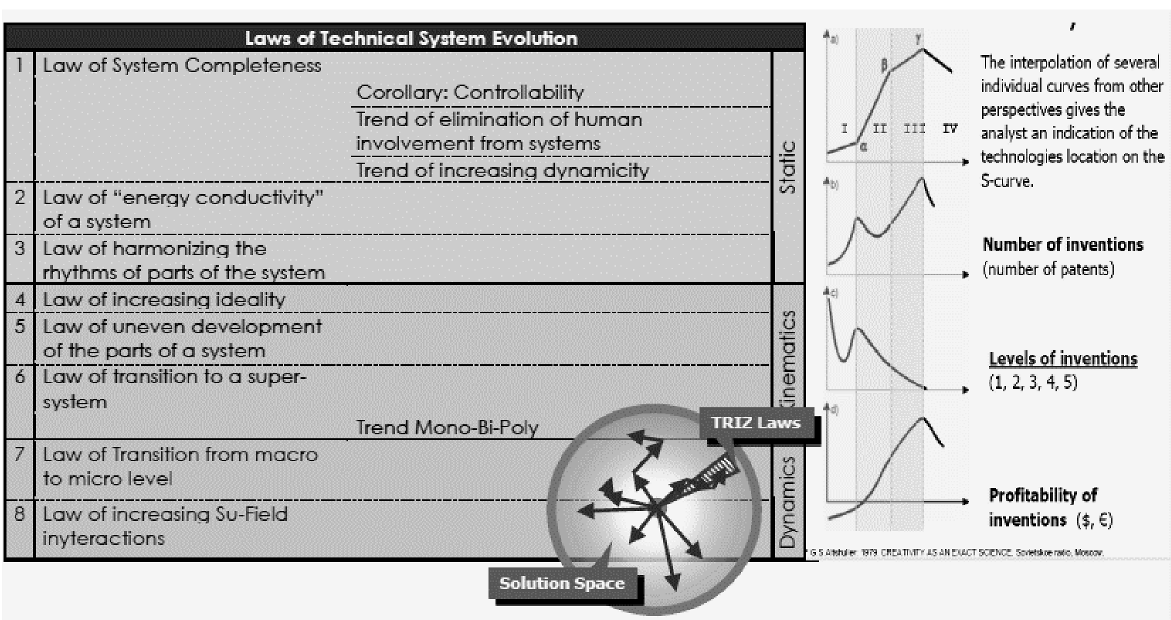


Figure 5 - Relations of laws of evolutions of technical systems and the least number of trends (Cascini, 2012)

Based on the used trends in evolution of any technical system, a structured approach for plotting the evolution path of the system is proposed. The output of the process is an evolution tree representing the passed path and possible paths to the future of the technical system under study (Shpakovsky, 2006). Figure 6 shows this tree for one technical system.

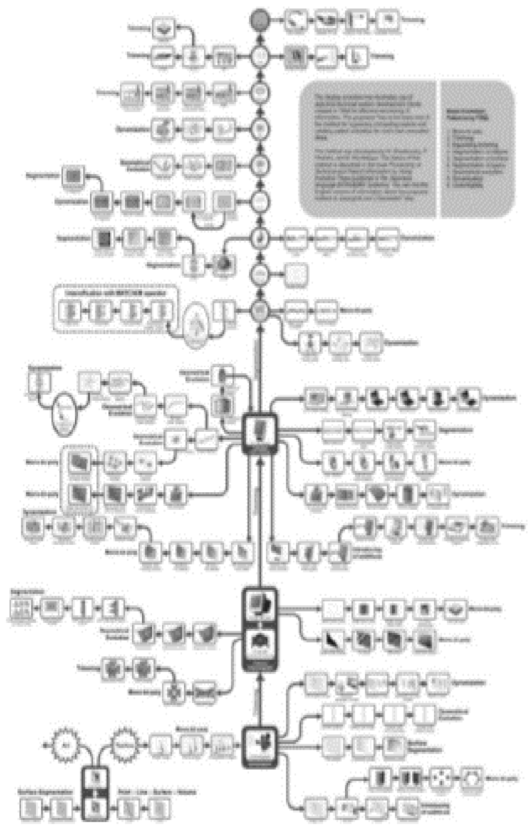


Figure 6 - Tree of evolution of display (Shpakovsky, 2006)

For this research, it is recommended to apply a picture of evolution path of some simple technical systems as stimuli for improving R&D engineers' performance in designing the next generation of technical systems.

3. 2. Abstract of some patents related to the function of target system

The literature reviewed in Table 4, shows previous solutions are one form of design precedents. This form of precedents is effective in increasing novelty and diversity if they are presented with more diversity and ambiguity (rows 4, 12 & 34). There are though some doubts about any influence of them on novelty, or even in reducing novelty (rows 22, 23 & 24). It is also discussed that novel artworks are positive in increasing novelty (row 13). Considering the positive effects of examples together with previous solutions and novel artworks, composition of novel artwork, previous solutions and examples with more diversity and ambiguity can be considered as one of other appropriate form of stimuli.

Patents are a type of legal representation of novel artworks. A patent is a set of exclusive rights granted by a sovereign state to an inventor or assignee for a limited period of time, in exchange for detailed public disclosure of an invention. An invention is a solution to a specific technological problem. A patent may include many claims, each of which defines a specific property right. These claims must meet relevant patentability requirements, such as novelty, usefulness, and non-obviousness (WIPO, 2008).

According to the characteristics composed as a potential combination, both the previous solutions of the target system and examples of other technical systems can be considered as the target system to search and select patents. In other words, the stimuli can consist of both options.

3. 3. An engineering procedure for designing the next generation of technical systems

The literature reviewed in Chapter 2, shows design models and procedures and also design strategies and precedents together were applied as stimulus for improving the results of design proposals. Reviewing the researches in the field of strategies revealed seven strategies which are applied by successful designers in design generally.

The result of researches in the effects of design professional models shows that they are mostly similar in six phases, with designers tending to follow the phases in a rather ad-hoc, unsystematic and opportunistic way. The major development of linear engineering design process for years has been the inclusion of more feedback loops. Creative processes are also common in four phases, with recent researches attempting to offer an explanation to idea emergence, describing conscious idea generation as the deliberate connection of matrices of thought, proceeding a divergent-convergent model.

Analyses of the system's function, the evolution of the structure of the system respect to the other system in its hierarchy, the solved problems and the applied solutions, the existing problems, and generating the new solutions, are the five main concepts, which are selected from previous studies in design strategies and precedents, to develop a stimulus for the research. The four first concepts were seen as design strategies for redefinition of the new task goals, task constraints, the boundaries of the system, and new requirements of the design task in cycles of analysis-synthesis-evaluation activities (Akin, 1978; Mc Neill et al., 1998; Gero & Kannengiesser, 2004). These concepts are similar concepts applied in some TRIZ-based anticipatory design of future products and processes; technology change and forecasting (Kucharavy & De Guio, 2008) and the network of evolutionary trends (Cascini et al., 2009; Cascini et al., 2011). Both of these two methods benefit from the same concepts in problem definition. Function analysis of the target system and other systems in its hierarchy are a common analysis among these two methods, to help engineers to reset the boundaries and modify requirements for formulating the problem. The first method proceeds by searching the problems and solved problems to propose the next generation of the system, based on the fact that the problems must be solved (Kucharavy & De Guio, 2005). The second method proceeds by searching possible versions of the target system through templates of entire solutions, with respect to trends of evolution of technical systems (Cascini, 2012). In regards to the first stimulus developed for this research, it is more appropriate to select the first method as the main method for the third stimulus, because the trends of the evolution of technical systems, which is used for developing the first stimuli, is part of the second method too; given this, it is more logical to study different concepts for each stimulus as much as possible. Figure 7 shows the overall image of the steps of the selected method.

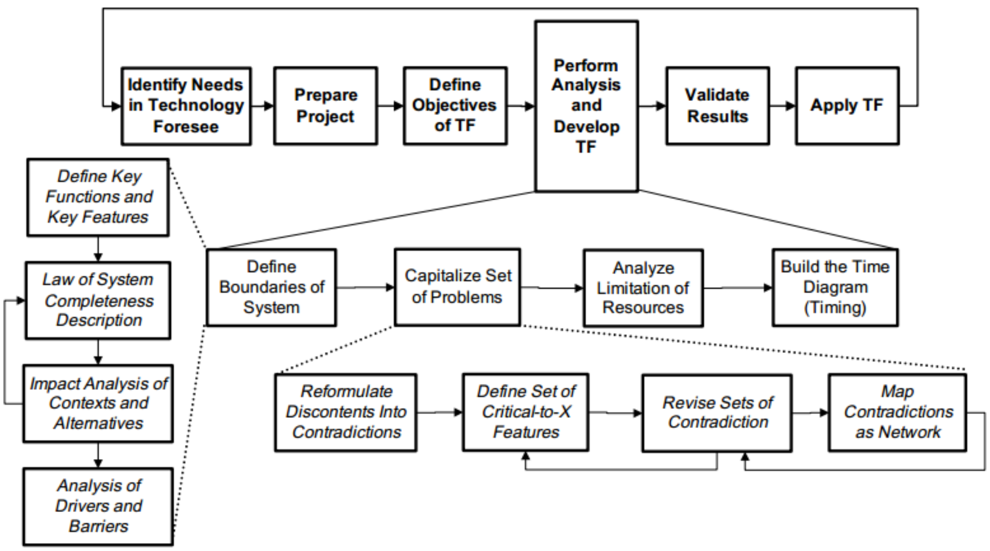


Figure 7 - Outline of some steps of the technology change and forecasting method

Proceeding and completing the whole procedure of the technology change and forecasting method for a real project, requires on average 10-12 sessions, each being 12 hours in length (FORMAT, 2015); it is not possible to apply it as comparable stimulus with respect to the two other previous developed stimuli. To develop a stimulus for the scope of this research, the main concepts are composed as a stimulus which can be followed in 30 minutes by an expert in the field. Analyses of the system's function, of the problems and solved problem, of the contradiction in the already not solved problems, and of the existing solutions and generating the new solutions, are the main concepts which are selected to develop a stimulus for the research.

4. Proposal to study R&D engineers' skills in designing the next generation of technical systems

The ultimate objective of the whole research is to develop a serious game for R&D engineers to support them in proposing the concept of the next generations of technical systems. Studying R&D engineers' skills are considered as the first step to approach this ultimate goal. Three complementary studies can be performed to highlight the target skills. While the 'used heuristics' by R&D engineers in the same task can be considered as their active skills, the effective skills can be clarified by assessing the 'degree of acceptability of their performance'. In addition, the 'effects of some stimuli' on the skills and performance of R&D engineers in the same task can highlight the effective skills.

Protocol analysis is one of the main tools used to capture design cognitions and consequently the requested skills. Protocol analysis is followed in two main phases; designing the protocol and investigating protocol. Protocol design is an activity to define the scope and condition of interested factors, according to the ultimate goal of the study, as well as developing the appropriate and representative coding scheme. Protocol investigation starts by transcribing the talks and speeches, and then follows by protocol segmentation, encoding the segmented sentences based on the developed coding scheme and revealing the patterns. In this section, the protocol developed for capturing R&D engineers' skills in designing the next generation of technical systems, is described.

4.1. Research question and the specific investigations

Two main research questions were defined for the whole research to develop a serious game for R&D engineers to support them in proposing the concept of the next generations of technical systems:
Research question # 1: How should the serious game for promoting R&D engineer's performance in designing the next generation of technical systems be structured?
Research question # 2: How effective is the developed serious game?
The first research question is studied and discussed in this Chapter, whilst the second question is explored further in Chapters 4. To approach the first question, the necessary skills of target players and the level of activeness of them must be clarified. In other words, in order to develop a serious game, the active and passive skills of target players in respect to the ultimate goal of the game must be considered; the elements of the game must also be developed in a way to improve the active skills and also transfer the passive ones to being active ones. Effective stimuli on the necessary skills of R&D engineers on the other hand, can help to design the elements of the games.
Although some general skills of target players are discussed in other researches, precise observation in respect to the exact ultimate goal of the game is necessary. Therefore, this main research question can be approached as the active and passive skills of R&D engineers in using effective heuristics for designing the next generation of technical systems. According to the patterns and strategies in design reviewed in the literature in Chapter 2, the set of criteria for assessing the acceptable candidate ideas for the next generation of technical systems among generated design proposals in section 1 of this chapter, the developed coding scheme for capturing the heuristics used by designers in the same task in section 2 of this chapter, and also the set of developed stimuli for promoting the skills and performances of R&D engineers in the same task in section 3 of this chapter, must still be checked. The following checks have therefore been identified:
Check #1: What are the average R&D engineers' performance in terms of the quantity of total generated ideas, the quantity of candidate ideas, the quantity of ideas with an acceptable degree of novelty, the quantity of ideas with an acceptable degree of technical plausibility, and the quantity of ideas with an acceptable degree of relevance?
Check #2: What are the effects of suggestive stimuli on R&D engineers' performance in terms of the same indexes mentioned in the previous check, whilst the suggestive stimuli are proposed according to the most effective stimuli of the quantity and quality of design sessions mentioned in literature?
Check #3: How many different heuristics are used by designers to propose next generation of the technical systems (skills)?
Check #4: Which heuristics are more used by designers to propose next generation of the technical systems (active skills)?
Check #5: Which heuristics used by designers are more effective than the others (effective skills)?
Check #6: What are the effects of suggestive stimuli on the heuristics used by R&D in proposing the next generation of technical systems?

4.2. Planned structure for the experiment

This study is an exploratory study to observe R&D engineers' performance and their skills in designing the next generation of technical systems. The experiment was scheduled to observe 12 teams of R&D engineers whereas participating in a design session for designing the next generation of a technical system. In order to study the effects of stimuli on the R&D engineers' performance, 2 design sessions were considered for each team; the first session for studying normal R&D engineers' performance and their active skills, and the second session for studying the effects of a different kind of stimuli on their performance and skills; the technical system as the design task was the same for both design sessions. To avoid cross-effect of different stimuli on the teams, every 3 teams were provided with one of the designed stimulus and the last 3 teams

which were not provided with any stimulus, were the control group. Time taken to participate in the whole experiment for each team was considered around 105 minutes; 5 minutes for the design brief, 45 minutes for the first design session, 10 minutes for a break, and 45 minutes for the second design session.
The participants were free to design, according to their normal behavior in the first and second design sessions, and apply any techniques they were used to, except in the second part for the teams which received the procedure as stimulus. It was expected that most teams proceed through brainstorming. Literature shows the preferred technique within industry for producing innovation is still traditional brainstorming in teams (Howard et al., 2010), despite the growing body of research identifying its limitations (Isaksen & Gaulin, 2005). Brainstorming is a group creativity technique pioneered by Alex Osborn (1953). Regardless some of its rules, such as not criticizing ideas during developing ideas, and also focusing more on the quantity of ideas than quality, it is expected that teams use this technique for proceeding in the design session.
The 45 minute-design session was proposed because researches show that the number of generated ideas in a brainstorming session decrease after half an hour, while the best ideas are generated in first 15 minutes (Howard et al., 2010). Additionally, some researchers suggested that 2-hour duration is an appropriate time period for investigation (Christiaans, 1992; Cross et al., 1996; Dorst, 1997) as the concentration level of most participants could be well maintained. Consequently, the duration for the total protocol is approximately around 1080 minutes (on average 90 minutes designing for 12 teams), which is a manageable size; most studies restricted their total size of protocols within 1000 minutes (Jiang & Yen, 2009). Stimuli was presented in the beginning of the second session, as previous researches show creativity or novelty of results are promoted by stimuli which are prepared and presented during the early design stages, or when the participant has been unable to solve the design problem for a difficult open-ended design problem (Tseng et al., 2008). Figure 8 shows the plan of experiment.

		Design brief (5min)	Design section Part 1 (45min)	Extra time (55min)	Break (10min)	Design section Part 2 (45min)	Extra time (55min)
Control group	T1						
	T4						
	T10						
Patent	T2						
	T5						
	T12						
Trends of evolution	T7						
	T8						
	T11						
Engineering procedure	T3						
	T6						
	T9						

Figure 8 - Planned protocol for studying R&D engineer performance and skills in designing the next generation of technical systems

The whole experiment for 12 teams were scheduled and performed in one week in the summer of 2014. The treatments were dedicated randomly to the teams in the second design session; therefore, the ordering in different groups is not according to the numbering of the teams.

4.3. Design brief

The task presented as an oral presentation in less than 5 minutes was as follows:
'In general the next generation of a technical system, can be considered as the version of that system which will be substituted the existing version providing at least the same task. Some researches show the next generation of technical systems can be classified in three classes; new version based on evolution in the applied technology in the system, new versions based on evolution in the meaning of the system and lastly new versions based on evolution in the design of the system. Transition from the white and black TV to color TV, transition of meaning of only showing time for watch to be as one of the accessories for people, and finally normal shape manual orange juice maker to spider shape one are the known examples for each

of these three kinds of evolution. Propose the next generation of home fridge including technological evolutions as its main evolution'.
The technical system used in this study is related to a product which is used by everyone in everyday life. This can facilitate utilization of prior knowledge and experience to generate and develop design ideas. In addition, all the participants are also familiar with the mechanism of cooling in a fridge, as it is taught within science lessons in high schools of the Iranian education system. The task is also considered as an open-ended task that the specific requirements are not provided. Such freedom is given in order to observe the natural behavior of participants while they generate ideas and develop them.

4.4. Participants and design teams

24 Iranian R&D engineers participated in the experiment as members of 12 teams (2 members in each team). The specific characteristics of the participants can be summarized as following:

- Gender: 75% male and 25% female (18 Men and 6 women);
- Ages: ranged from 28 to 40 years;
- Level of education: 12% PhD, 71% master and 17% bachelor;
- Engineering field: 37% industrial engineering, 21% mechanical engineering, 13% computer engineering, 13% electrical engineering, 8% design, 4% polymeric material engineering and 4% textile engineering;
- Experience in R&D units of Iranian companies: 67% (between 7-9 years), 16% (between 5-6 years) and 17% (between 3-4 years);
- Familiarity of technology forecasting methodologies: No one had any experiences in real technology forecasting projects, with 12% not even familiar with the related theories and methodologies, and 88% familiar with the theoretical part of the field;

As the participants are all from R&D units of Iranian companies, it is worth considering the situation of R&D and innovation in Iran based on world known rankings.

- Based on the Bloomberg report for 2014 (AS OF: January 7, 2014), with 110 countries participating in the ranking, Iran were positioned as followed:
    - R&D intensity: 39nd
    - Productivity: 56th
    - Researcher concentration: 49th
    - Manufacturing capability: 54th
    - Patent activity: 47nd
- Based on the Global Innovation Index 2014, the rankings of Iran in indexes related to innovation (100 as the upper limit) can be reported as following:
    - Global innovation index rankings: position of 120 by the score 26.14 of 100 while the first score is 64.78 for the first position;
    - Innovation input sub-index rankings: position of 107 by the score 33.24 of 100 while the first score is 73.60;
    - Innovation output sub-index rankings: position of 125 by the score 19.04 of 100 while the first score is 63.11.

4.5. Considered treatments

Given the discussion in Section 3 of this chapter, three different stimuli are developed as treatments for improving R&D engineer performances in designing the next generation of technical systems. Previous researches showed that 'combination of pictorial representation of examples with one form of structural representation of precedents', 'combination of novel artwork, previous solution and examples with more diversity and ambiguity' and 'composition of professional design procedure with the design strategies', are three potential forms of stimuli for the target of this research.

The first stimulus is defined as a combination of pictorial representation of examples with one form of structural representation of precedents; the evolution tree of the target system is based on TRIZ-based trends of evolution of technical systems which are considered as structural representations of precedents and templates describing an entire class of solutions. These examples are shown in Table 15.

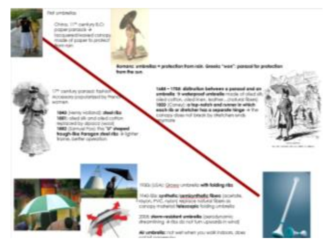
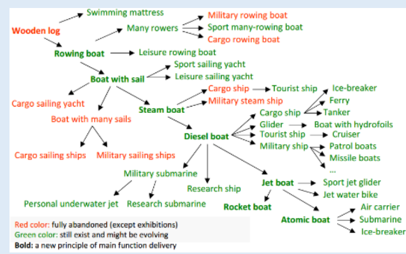
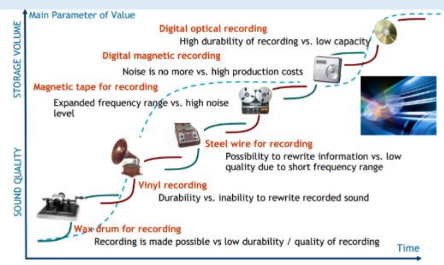
No.	Examples	Explanation	Picture
1	Eye glasses	To realize convenience and smartness through the following stages: 1. Two joint lenses 2. Two lenses with a handle 3. Normal glasses 4. Glasses front open 5. Google eye glasses * bring available technology into the field	
2	Umbrella	To realize better adaption to real conditions by solving the problems through new materials, fields and structures through the following stages: 1. Paper parasols 2. Ordinary umbrella 3. Non-symmetric umbrella 4. Big umbrella improved for wind 5. Air umbrella * bring available technology into the field	
3	Boat	To realize evolution in both various application and more efficient usage of energy sources through following stages: 1. Wooden log 2. Rowing boat 3. Sailing boat 4. Steam boat 5. Diesel boat 6. Jet boat 7. Atomic boat	
4	Voice recorder	To realize evolution on quality of object through following stages: 1. Wax drum 2. Vinyl recording 3. Steel wire 4. Magnetic tape 5. Digital magnetic recording 6. Digital optical recording * improving the technology	
5	Coffee maker	To realize evolution on quality of object, adding necessary and complementary processes to the system, and co-ordination with super-system through following stages: 1. Pot 2. Pot with handle 3. Kettle to brew coffee with boiled water 4. Kettle to brew coffee with steam 5. Electrical coffee maker 6. Capsules of different tastes of coffee 7. Device for one cup of coffee * bring available technology into the field	

Table 15 - Simple evolution path of five technical systems as the first form of stimulus for improving R&D engineer performance and skills in designing the next generation of technical systems

To prepare the first stimulus, a very simple and summarized evolution tree of 5 technical systems was plotted. 5 examples were prepared for this stimulus while there is no clear report about the effective number of examples in the literature. It is worth considering that the top designs are for the groups that chose to scrap their initial design and to start afresh with a new design concept as an alternative (Smith & Tjandra, 1998). Both generating few alternative concepts and generating a large number of alternatives, are equally weak strategies, leading to poor design solutions (Fricke, 1993; Fricke, 1996). This issue was also considered for preparing the second stimuli.

The second stimulus is defined as a combination of novel artwork, previous solution and examples with more diversity and ambiguity, while patents are considered as a representation of novel artworks. To prepare this stimulus, again the abstract of the 5 patents related to cooling were selected, while some of them are completely related to fridges and some others to other technical systems. The characteristics of the patents are described in Table 16.

No.	Patents titles	Publishing date	Explanation
1	Blast furnace cold-intensifying and heat avoiding type gradient brick distribution method	Sep 2013	– Similar system related to temperature with different materials – far field – combination of simple systems * new materials, fields, …
2	Ice cream maker	Sep 2012	– Similar system related to cooling – System combined of 2 function of cooling and processing food simultaneously – Systems before * adding necessary and complementary processes to the system * new application
3	Automated refrigerator opener	July 2012	– Family member/ industrial fridge – Related to sub-systems (improvements in sub-systems) – Related to less energy usage (hardware of technology) * convenience and smartness
4	Shelf life expiration date management	Nov 2012	– Family member/ industrial fridge – Related to sub-systems (improvements in sub-systems) – Related to smartness (software of technology instead of hardware) * convenience and smartness * consider quality of object
5	Customizable organizer assembly	Nov 2013	– Related to sub-systems (improvements in sub-systems) – Related to flexibility (hardware of technology) * to consider super-system * adaptation to real condition

Table 16 - Characteristics of five patents related to cooling for improving R&D engineer performance and skills in designing the next generation of technical systems

The third stimulus is defined as the combination of professional design procedure with design strategies. To develop a stimulus for the scope of the research, a TRIZ-based anticipatory method, a kind of design method composed as a procedure which can be followed in 30 minutes by an expert in the field, was used. The analysis of the system’s function, of the problems and solved problem, of the contradiction in the already not solved problems, and of existing solutions and generating the new solutions, are the main concepts which are selected to develop a stimulus for the research. The steps of the procedure are presented in Table 17.

No.	Main concept and steps	Guidelines
1	Define the function of system	1.1. Define the duty of system in the desire situation; 1.2. Define the object which receives the duty of system; 1.3. Redefine the duty of system according to the requirements of the object; 1.4. Reformulate the defined duty according to the pattern: <verb> + <subject/noun> + <additives/object..>
2	Define the technical problems which are solved to deliver the function	2.1. Define time period which this function was delivered from the past (Time of emergence of the system/ time of demise of previous version of system); 2.2. Analyze more details in 2 following points of time: ▪ Think about Sub-systems and super-systems in present; ▪ Think about sub-systems and super-systems in past; 2.3. Find the problems which are solved in transition from past to present: ▪ In sub-system level (among sub-systems of past & sub-systems of present); ▪ In super-system level (among super-systems of past & super-systems of present);
3	Define technical problems in the form of contradiction	3.1. Analyze the problems: ▪ Which technical improvements are seen in the system (improving parameters)? ▪ Which barriers didn't let the system to improve more (worsening parameters)? ▪ So which parameters were against which parameters? 3.2. Check the presence of above contradictions in transition between present to future. ▪ Are the same technical improvements needed? ▪ Are the previous barriers still active in transition from present to future?
4	Analyze the applied solutions for the contradictions	4.1. What was the main component in resolving the contradiction in transition from past to present: ▪ In sub-system level; ▪ In super-system level; ▪ In systems around; 4.2. What are the main physical effect and main material in resolving the contradiction? ▪ In sub-system level; ▪ In super-system level; ▪ In systems around;
5	Propose new solution for the contradictions	5.1. Resolve contradiction in transition from present to future: ▪ In higher performance compare to the current system; ▪ By merging to the super-system (or systems around); ▪ By applying new physical effects even if it pushes to change the sub-systems and their materials.

Table 17 - Five-step procedure for improving R&D engineer performance and skills in designing the next generation of technical systems

4.6. Data collection and coding procedure

The participants were asked to generate ideas through team working whilst talking loudly to make it possible to record the speeches, and to use the talk-aloud protocol analysis method for further analysis. In this method, the verbal speeches are used as the data for the analysis. The experiment was conducted in teams of two R&D engineers in a closed room, equipped with a video recording device to record the participants' speeches such as the verbal data. Markers, a pen and A3 paper, were provided for the participants. Figure 9 shows the setting of the experimental room.

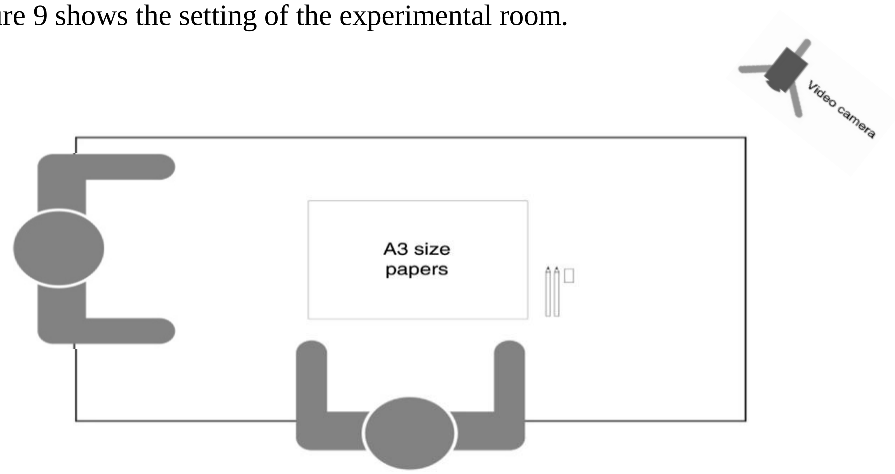


Figure 9 - Experimental setting

Different methods are seen within research for clarifying a cognitive act through verbal segments. Design move, design story and think flow are three concepts proposed to capture a cognitive act for more coherent studies. Design move is related to the beginnings and endings of coherent utterances which indicate a small step or an act which transforms the design situation (Goldschmidt, 1995). To parse design knowledge, the design story must conclude issues, concepts, and related forms (Oxman, 1994). A design issue refers to a particular point or a situation in a design problem. A concept is a solution which addresses an issue. It is realized as a specific artifact with a form. A design story is materialized whilst elaborating the linkages among these components. Think flow is similar to design story and combines verbal segments to make it possible to capture a single topic or a coherent perspective (Kim & Kim, 2015). A think flow embraces successive cognitive acts to understand the design problem and develop a solution with a coherent perspective. It is evident that granularity is different in these methods. In the scope of this research, the concept of design moves is used.

The verbal data collected as the talk-aloud protocol, was first transcribed into the text as 12 lines of speeches (see Appendix 1). At the same time with transcribing, the protocols were segmented based on verbal pauses when a design situation is transformed. While the duration of the design moves is in 10 to 60 second in the protocols, the average duration is around 18 seconds. The 12 lines of speeches were utilized as a main source of the analysis, supplemented by the A3 papers of each team, if the speeches were not obvious.

Encoding is a process which is considered to be as objective as possible. Based on the encoding procedure of previous studies (Gero & Mc Neill, 1998; Kim & Kim, 2015), this study focuses on defining each coding category precisely, and obtaining reliability through iterative encodings and arbitration. Primary encoding was done with the transcripts of 2 lines of speeches with the three-dimensional suggested coding scheme in 15 sub-categories (Tables 12, 13 & 14). During the primary encoding process, the definition of each sub-category was refined, and examples for each one was developed. The design moves were then decoded based on the provided coding scheme by a coder twice. There was at least a month between the first encoding and the second encoding. This time gap was intended to help the coder avoid becoming fixated on the first encoded result. It also helped to look over the definition of each category and enhance reliability. Figure 10 shows the procedure of data collection and coding.

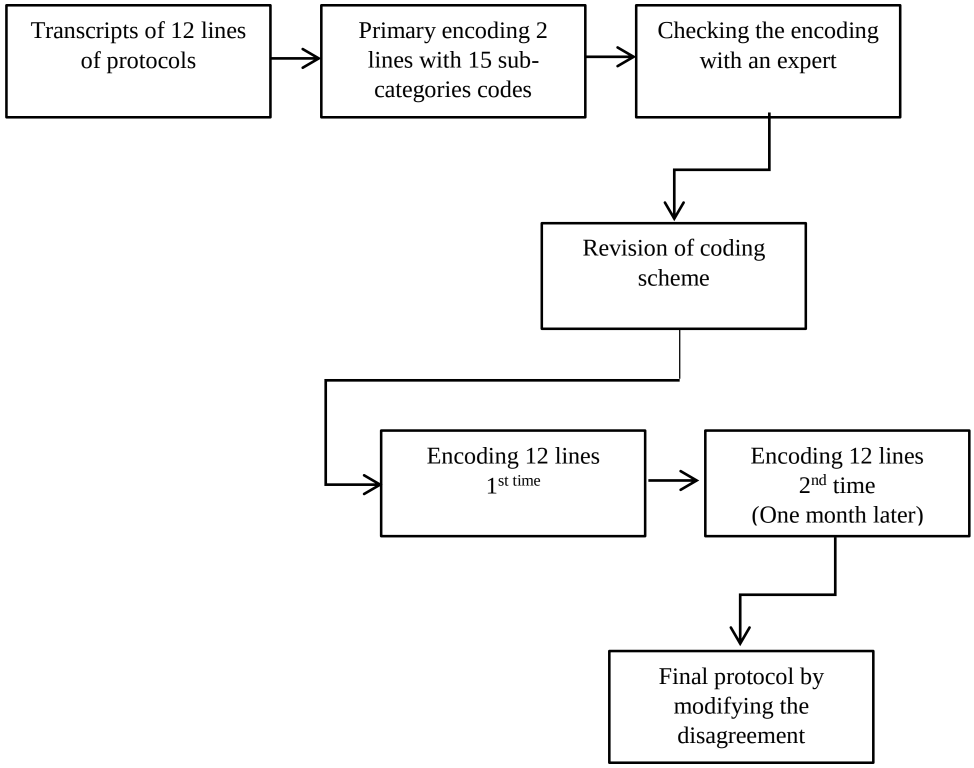


Figure 10 - Data collection and coding procedure

4.7. Quality of design sessions

To study the above mentioned checks, the protocol must be studied cognitively, with the quality of generated ideas in relation to the requested task considered. The quality of design sessions is considered as the productivity of acceptable ideas in respects to the requested task. Therefore, the parts of speeches encoded as the generated ideas were collected and then ranked by three experts (see Appendix 2).
Table 9 was used for ranking the ideas by three experts; each idea was ranked based on the three criteria of novelty, technical plausibility and relevance. All three criteria are prepared to be ranked in four levels, where only levels 3 and 4 on each of them would cover an acceptable quality of the next generation of technical systems. Table 18 shows the experts' agreement on the level of ideas on each criteria based on Kendall's tau. Kendall's tau is a statistic index used to measure the association between two measured quantities and it is used for ranking pairs by calculation of (#agree-#disagree)/(#total*(#total-1)/2) as its formula. If the agreement between the two rankings is perfect, the coefficient has value 1; in the case of complete disagreement, the coefficient has value −1. If the two rankings are independent, then it is expected that the coefficient would be approximately 0.

	Kendall's Tau		
	Agreement GC-NB	Agreement GC-DK	Agreement DK-NB
Novelty	-0.010486891	-0.010486891	-0.008489388
Technical plausibility	0.004494382	0.002996255	0.002996255
Relevance	-0.007490637	-0.008489388	-0.002996255

Table 18- Agreement of experts on level of ideas on each criterion

The table shows that for all criteria, the rankings by every couple, is independent. In other words, any complete agreement or disagreement cannot be reported. Therefore, ideas ranked 3 and 4 in all criteria by all experts were considered as acceptable ideas.

5. Data analysis and the effects of stimuli on team performance in designing the next generation of technical systems

Among the different checks considered for this study, the two following checks are related to R&D performances and the effects of developed stimuli on them.
Check #1: What are the average R&D engineers' performance in terms of the quantity of total generated ideas, the quantity of candidate ideas, the quantity of ideas with an acceptable degree of novelty, the quantity of ideas with an acceptable degree of technical plausibility, and the quantity of ideas with an acceptable degree of relevance?
Check #2: What are the effects of suggestive stimuli on R&D engineers' performance in terms of the same indexes mentioned in the previous check, whilst the suggestive stimuli are proposed according to the most effective stimuli of the quantity and quality of design sessions mentioned in literature?
In this section, these checks are studied in 7 parts. The first 6 parts discuss both the observed normal situation and also the influences of the suggested stimuli. In other words, both checks one and two are studied in each part. The final part discusses the findings together.

5.1. Influence of suggested stimuli on R&D engineers' performance in terms of dedicated time

Time dedicated by each team to the task is the first criterion to study the R&D engineers' performance. Figure 11 shows how the scheduled protocol happened in the real situation.

		Design brief (5min)	Design section Part 1 (45min)	Extra time (55min)	Break (10min)	Design section Part 2 (45min)	Extra time (55min)
Control group	T1		38.75			25.00	
	T4		32.00			27.00	
	T10		38.00			33.25	
Patent	T2		44.83			44.50	
	T5		45.00			31.00	
	T12		44.00			39.92	
Trends of evolution	T7		43.00			29.00	
	T8		36.00			38.00	
	T11		43.50			45.00	
Engineering procedure	T3		41.50				50.33
	T6			50.17			54.75
	T9			49.00			54.00

Figure 11 - Performed protocol according to the scheduled plan

As the figure shows despite the 45-minutes fix period proposed to the participants, each team dedicated different amount of time to finish the task. The teams dedicated between 32.00 to 50.17 minutes for performing the task in first session, and 25.00 to 54.75 minutes for the second session respectively. These tendencies can be used to estimate the necessary duration time, or tolerable time, for the serious game for R&D engineers with the same task and ultimate goal. Table 19 shows the dedicated times for each team.

Teams	Time	
	P1	P2
T1	38.75	25.00
T2	44.83	44.50
T3	41.50	50.33
T4	32.00	27.00
T5	45.00	31.00
T6	50.17	54.75
T7	43.00	29.00
T8	36.00	38.00
T9	49.00	54.00
T10	38.00	33.25
T11	43.50	45.00
T12	44.00	39.92
Average	42.15	39.31
STD	5.24	10.47

Table 19 - Dedicated time to each design session parts by different teams

Table 19 shows that in the first session, where there is no kind of intervention/treatment for the teams, 5 teams fulfilled the task in the suggested time (between 43 to 47 minutes), while 5 other teams dedicated less than 43 minutes to the task, and only 2 others asked for more time. In other words, 41.6% of teams ended the task in time, 41.6% ended sooner and only 16.8% of teams ended later. Based on this simple observation, it can be considered that R&D engineers prefer to spend their time in design sessions for 42 minutes on average, and they don't prefer to spend time continuously for developing the ideas in a design session more than this time. It is worth taking into account that this average decreases to 39 minutes in the second session.

Further studies on the dedicated time by teams can be pursued by the considering effects of different kinds of stimuli on the time dedicated to the design sessions. Table 20 shows the above data organized based on different kinds of stimuli.

Groups		Nothing			Patent			Trend			Engineering procedure		
Teams		**T1**	**T4**	**T10**	**T2**	**T5**	**T12**	**T7**	**T8**	**T11**	**T3**	**T6**	**T9**
P1	**Time (min)**	38.75	32.00	38.00	44.83	45.00	44.00	43.00	36.00	43.50	41.50	50.17	49.00
	Average		36.25			44.61			40.83			46.89	
	STD		3.70			0.54			4.19			4.70	
P2	**Time (min)**	25.00	27.00	33.25	44.50	31.00	39.92	29.00	38.00	45.00	50.33	54.75	54.00
	Average		28.42			38.47			37.33			53.03	
	STD		4.30			6.86			8.02			2.36	

Table 20 - Effects of different kinds of stimuli on the dedicated time for the task

The duration of design sessions decreased for all groups with different treatments, except for the teams in the group of engineering procedure. On average, the teams in the group with no treatment, tended to spend 21.61% less time in the second session than the first session. The groups which received patents and trends as stimuli, also tended to spend less time in the second session; on average, 13.76% and 8.57% respectively. The teams in the group receiving engineering procedure as stimuli, on average spent 13.09% more time to complete the task in the second session. Figure 12 graphically represents this comparison.

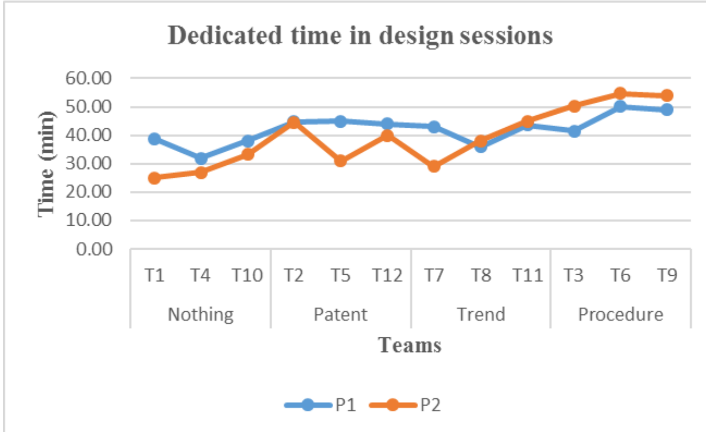


Figure 12- Dedicated time for performing the task in the first and second design sessions in respect to the kind of stimuli

The figure shows the control group and the group receiving patents tend to dedicate less time in the second session in comparison to the first session, but the groups received the engineering procedure and trend tend to dedicate more time. Considering the tendency of teams in the group with no treatment to spend less time in the second session, it can be supposed that the teams with the engineering procedure are forced to spend more time, and also that trends are more attractive to dedicate time.

5.2. Influence of suggested stimuli on R&D engineers' performance in terms of productivity

The number of generated ideas is used to study productivity if the duration of the design session is the same for all teams, the rate of idea generation in respects to the dedicated time is considered too. Table 21 shows the quantity of ideas generated and also the rate of idea generation for each team.

Teams	Time		Number of ideas		Rate of idea generation	
	P1	P2	P1	P2	P1	P2
T1	38.75	25.00	24	17	0.62	0.68
T2	44.83	44.50	24	21	0.54	0.47
T3	41.50	50.33	21	3	0.51	0.06
T4	32.00	27.00	29	8	0.91	0.30
T5	45.00	31.00	30	8	0.67	0.26
T6	50.17	54.75	15	3	0.30	0.05
T7	43.00	29.00	30	19	0.70	0.66
T8	36.00	38.00	25	19	0.69	0.50
T9	49.00	54.00	27	1	0.55	0.02
T10	38.00	33.25	30	14	0.79	0.42
T11	43.50	45.00	13	11	0.30	0.24
T12	44.00	39.92	39	31	0.89	0.78
Average	42.15	39.31	25.58	12.92	0.62	0.37
STD	5.24	10.47	7.06	8.92	0.20	0.26
Sum	505.75	471.75	307	155		

Table 21 - Productivity of the teams in protocol

In total, 462 ideas were generated in both the first and second design sessions by all teams; 307 of them were generated in the first design session and the other 155 were generated in the second design session. The table shows that approximately all the teams together generated half the number of ideas in the second session compared to the first session that can be observed for each individually; the average number of generated ideas for each team is 25 ideas for the first session and 13 ideas for the second session. In the first session with no stimuli, the teams generated and developed at least 13 ideas, while in the highest case, the total number of ideas is 39. It is worth mentioning that the ideas which are counted for the analysis are not completely separate from each other, and any amendment for an idea is counted as a new idea. Considering the first session without any treatment, it can be highlighted that on average, in a 42 minute-design session, 25.5 ideas are generated and developed by R&D engineers. This observation can also be considered as part of the expectations of serious game for supporting R&D engineers in producing new concepts for the next generation of systems.

Respectively, the rate of idea generation decreases for almost all teams in the second session compared to the first session. The average rate of idea generation in the first session is 0.62, while this average decreases to 0.37 for the second session. Figure 13 shows the time of appearance of ideas and the total number of generated ideas for each point of time cumulatively.

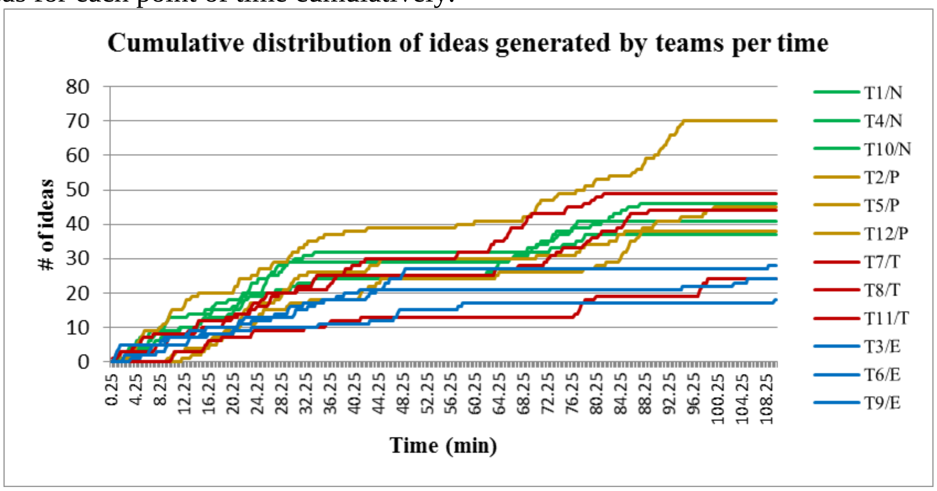


Figure 13 - Cumulative distribution of ideas generated in the first and second design sessions

The figure shows the total number of ideas for teams at the end of the second session is among 18 to 70 ideas with 52 differences. These amounts are 13, 39 and 26 respectively for the first session. Further studies on team productivity can be pursued by considering the effects of different kinds of treatments on a team's performance.

Table 22 shows the above data organized based on different kinds of stimuli. Through the information presented in the table, it can be discussed that the generated ideas and rate of idea generation decreased for all groups. For the teams in the groups which received patents and trends as stimuli, the amount of reduction is less than the group with no treatment. In other words, despite reduction in the performance of all teams in generating ideas, the teams received patents and trends show less reduction than the other teams. Overall, the teams that received trends and patents show better productivity sequentially.

Groups		Nothing			Patent			Trend			Engineering procedure		
Teams		T1	T4	T10	T2	T5	T12	T7	T8	T11	T3	T6	T9
P1	Time (min)	38.75	32.00	38.00	44.83	45.00	44.00	43.00	36.00	43.50	41.50	50.17	49.00
	Average		36.25			44.61			40.83			46.89	
	STD		3.70			0.54			4.19			4.70	
P2	Time (min)	25.00	27.00	33.25	44.50	31.00	39.92	29.00	38.00	45.00	50.33	54.75	54.00
	Average		28.42			38.47			37.33			53.03	
	STD		4.30			6.86			8.02			2.36	
(P2-P1)/P1	%		-21.61			-13.76			-8.57			13.09	
P1	# Ideas	24	29	30	24	30	39	30	25	13	21	15	27
	Average		27.67			31.00			22.67			21.00	
	STD		3.21			7.55			8.74			6.00	
P2	# Ideas	17	8	14	21	8	31	19	19	11	3	3	1
	Average		13.00			20.00			16.33			2.33	
	STD		4.58			11.53			4.62			1.15	
(P2-P1)/P1	%		-53.01			-35.48			-27.94			-88.89	
P1	Rate of idea generation	0.62	0.91	0.79	0.54	0.67	0.89	0.70	0.69	0.30	0.51	0.30	0.55
	Average		0.77			0.70			0.56			0.45	
	STD		0.14			0.18			0.23			0.13	
P2	Rate of idea generation	0.68	0.30	0.42	0.47	0.26	0.78	0.66	0.50	0.24	0.06	0.05	0.02
	Average		0.47			0.50			0.47			0.04	
	STD		0.20			0.26			0.21			0.02	
(P2-P1)/P1	%		-39.64			-27.86			-17.23			-90.20	

Table 22 - Effects of different kinds of stimuli on the indexes of productivity

Figure 14 shows these comparisons graphically.

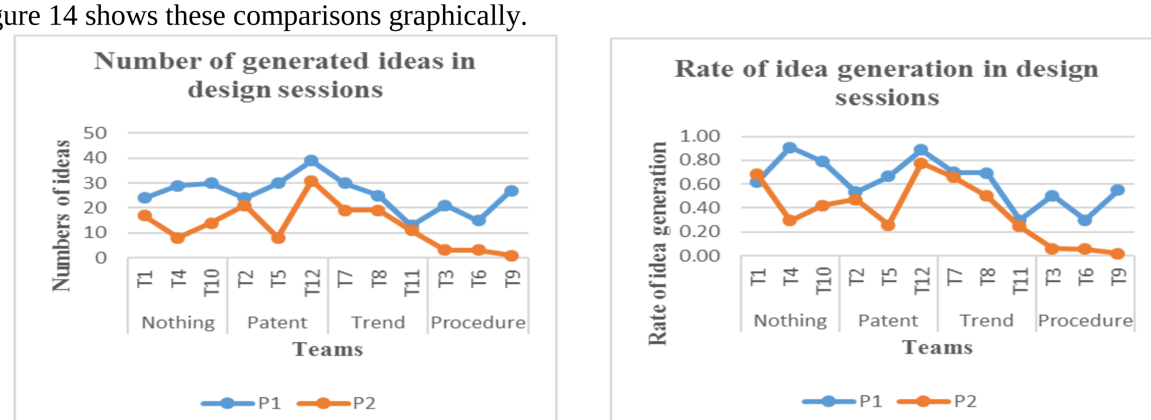


Figure 14 - Comparison of team productivity in the first and second design sessions with respects to the kind of stimuli

The figure shows that the number of generated ideas reduces for all teams in all groups and the rate of idea generation reduces for almost all teams in all groups. The amount of reduction is highest for the group with the engineering procedure and then the control group. Among the two other groups, the amount of reduction is less for the teams in the group that received trends. In other words, the groups that received trends and patents seem more productive sequentially in the second session compared to the control group.

5.3. Influence of the suggested stimuli on R&D engineers' performance in terms of quantity of candidate ideas for the next generation of technical systems

Further studies can be followed by looking on quality and quantity together. As mentioned all the ideas ranked respectively novelty, technical plausibility and relevance by three experts, and the ideas which passed the least desired degree by all experts, were considered as candidate ideas for the next generation of technical systems. Table 23 shows the results of ranking ideas on each criterion based on these levels.

		Novelty		Technical plausibility		Relevance	
Experts' ranking		Part 1	Part 2	Part 1	Part 2	Part 1	Part 2
all 4	Number	11	2	163	81	130	46
	Percentage	2.38%	0.43%	35.28%	17.53%	28.14%	9.96%
all 3&4	Number	30	23	61	36	98	52
	Percentage	6.49%	4.98%	13.20%	7.79%	21.21%	11.26%
2 of 3, 3&4	Number	99	61	43	14	50	28
	Percentage	21.43%	13.20%	9.31%	3.03%	10.82%	6.06%
others	Number	167	69	40	24	29	29
	Percentage	36.15%	14.94%	8.66%	5.19%	6.28%	6.28%
sum	Number	307	155	307	155	307	155
		462		462		462	
	Percentage	66.45	33.55	66.45	33.55	66.45	33.55
		100.00%		100.00%		100.00%	

Table 23 - Ranking of generated ideas by experts

The table shows 36.15% of ideas (respect to the whole ideas) in the first session and 14.94% of ideas in second session could not receive 3 and 4 by at least 2 experts on the novelty criterion, which means that around 51% of ideas are not distinguished as novel by at least 2 experts. The corresponding numbers on the two other criteria are less than 15%. In other words, just around 14% and 12% of generated ideas are not distinguished as plausible and relevant. Therefore, it can be discussed that R&D engineers are more capable to propose plausible and relevant ideas, than novel ideas, even when they are asked to propose the next generation of technical systems.

A candidate idea for the next generation of technical systems, must receive a value of 3 or 4 on all 3 criteria by all 3 experts. Only 16 ideas out of 462 generated ideas (3.46% of ideas) are ranked as candidate ideas. Table 24 shows the realized candidate ideas and their appearance on the protocol.

No.	**Idea**	**Team**	**Time** (min)
1	changing the mechanism of cooling by finding an organic element that absorbs heat for its metabolism	4	4.25
2	the size of fridge changes according to new place when we move our house	6	7.67
		5	15.17
		12	20.75
		12	21.17
		5	32.75
		9	45.25
		10	79.5
		10	81.17
3	the fridge shows the characteristics of food such as ingredients, calories, its healthiness …	8	15.25
		10	26.25
		12	60.17
4	fridge that listens to our talks and act as a friend	2	17.83
		7	77.17
5	fridge that accept orders one day before and it give us the fruit or vegetables in the right time according to the seeds it has	2	21.83
6	using the heat of condenser to melting ice to have purified and drinking water instead of using filter	5	44.5

Table 24 - Appearance of candidate ideas in design sessions

The table shows that some of the 16 candidate ideas are the same and there are only 6 non-repeated candidate ideas. Only 4 of the 16 points of appearance of candidate ideas (25%) are in the second session, which were generated by other teams in the first session. In other words, all candidate ideas were generated at least once without any treatment. Distribution of candidate ideas are presented graphically in Figure 15.

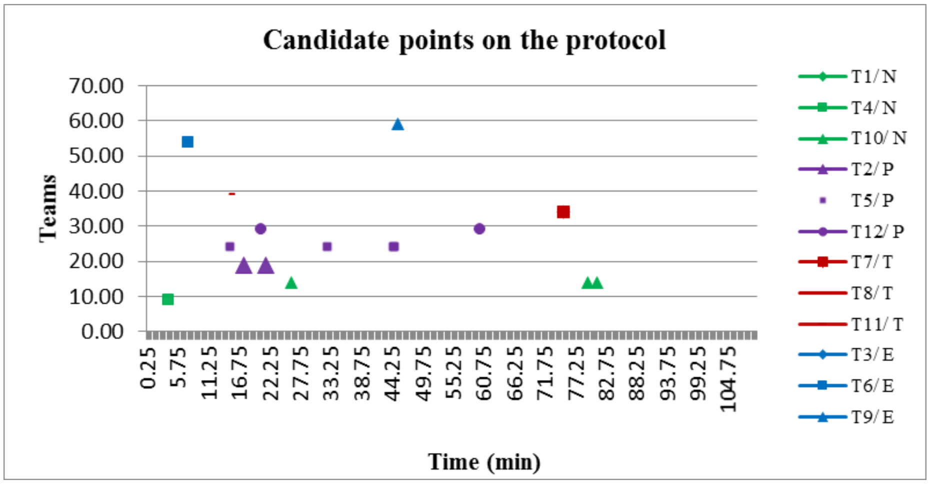


Figure 15 - Distribution of candidate ideas in protocol

Figure 15 shows 3 teams did not generate any candidate idea while the maximum quantity of candidate ideas is 3 for 3 teams. The number of candidate ideas in the second session is less than the first session. Table 25 shows the changes in the quantity of candidate ideas in the second session compared to the first session for different treatments.

		Candidate ideas for next generation of the technical systems					
		# P1	# P2	(P2-P1)/P1	# P1	# P2	(P2-P1)/P1
Nothing (control groups)	T1	0	0	-	2	2	0
	T4	1	0	1			
	T10	1	2	-1			
Patents	T2	2	0	2	7	1	0.86
	T5	3	0	3			
	T12	2	1	1.5			
Trends	T7	0	1	-	1	1	0
	T8	1	0	1			
	T11	0	0	-			
Engineering procedure	T3	0	0	-	2	0	-1
	T6	1	0	1			
	T9	1	0	1			
Average		1.00	0.33				
STD		0.95	0.65				

-: not possible to compute the rang of changes in second session respect to the first session

Table 25 - Effects of different stimuli on the quantity of generated candidate ideas

None of the treatments are effective in increasing the quantity of candidate ideas for next generation of technical systems; given this, further studies can be followed to highlight the effects of each kind of stimuli on each criterion individually. In other words, further studies can be pursued for each novelty, technical plausibility and relevance criteria individually.

5.4. Influence of the suggested stimuli on R&D engineers' performance in terms of the quantity of ideas with the least expectation of novelty degree

Novelty is the first criterion in the set to realize the candidate ideas for the next generation of technical systems. In the scope of this research, 'novel feature or trait' and 'existing feature or trait in other fields of application never applied to the domain of this product' are considered as novelty levels 4 and 3 respectively. Table 26 shows the quantity of ideas ranked 3 or 4 by agreements among all or two out of three experts.

	all 4			all 3&4			2 of 3, 3&4			others		
	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100
T1	0	0	-	1	1	0.00	5	12	-140.00	18	4	77.78
T2	1	0	100.00	3	5	-66.67	6	4	33.33	14	12	14.29
T3	3	0	100.00	2	0	100.00	1	0	100.00	15	3	80.00
T4	0	0	-	2	2	0.00	15	1	93.33	12	5	58.33
T5	2	0	100.00	4	3	25.00	4	0	100.00	20	5	75.00
T6	1	0	100.00	1	1	0.00	5	1	80.00	8	1	87.50
T7	0	0	-	5	4	20.00	11	7	36.36	14	8	42.86
T8	0	0	-	5	2	60.00	5	9	-80.00	15	8	46.67
T9	2	0	100.00	3	0	100.00	13	1	92.31	9	0	100.00
T10	0	2	-	1	2	-100.00	7	5	28.57	22	5	77.27
T11	0	0	-	1	2	-100.00	4	7	-75.00	8	2	75.00
T12	2	0	100.00	2	1	50.00	23	14	39.13	12	16	-33.33
Average	0.92	0.17	-	2.50	1.92	7.36	8.25	5.08	25.67	13.92	5.75	58.45
STD	1.08	0.58	-	1.51	1.51	68.04	6.18	4.80	80.98	4.50	4.63	37.01
sum	11	2	81.82	30	23	23.33	99	61	38.38	167	69	58.68
% of total (462)	2.38	0.43		6.49	4.98		21.43	13.20		36.15	14.94	

-: not possible to compute the rang of changes in second session respect to the first session

Table 26 - Teams' Performance in respect to the novelty criterion

As the table shows, in total, out of 462 ideas, 13 ideas (around 3%) were ranked 4 by all experts, 53 ideas (around 11.5%) were ranked 3 and 4 by all experts, 160 ideas (around 34.5%) were ranked 3 and 4 only by 2 out of 3 experts, and finally 236 ideas (around 51%) received less degrees. The numbers show that in total, without and with different stimuli, the most percentage of ideas generated by R&D engineers are ranked in the last column, while the least percentage are ranked in the first and second columns. On average, the numbers of ideas receiving 4 by all experts decreased, with this reduction being seen for all teams. Also on average, the numbers of ideas receiving 3 and 4 by all experts decreased, with this reduction not being seen in all teams, and inversely, increased for three teams. Respectively the reductions are seen for two remained columns too.

The effects of stimuli can be discussed by looking at the numbers of ideas receiving each 4 target levels cumulatively for the 3 teams in each group of different stimuli. Table 27 shows the numbers of ranked ideas in 4 levels cumulatively for different stimuli.

	all 4			all 3&4			2 of 3, 3&4			others		
	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100
Nothing	0	2	-	4	5	25.00	27	18	-33.33	52	14	-73.08
Patent	5	0	-100.00	9	9	0.00	33	18	-45.45	46	33	-28.26
Trend	0	0	-	11	8	-27.27	20	23	15.00	37	18	-51.35
Engineering procedure	6	0	-100.00	6	1	-83.33	19	2	-89.47	32	4	-87.50

-: not possible to compute the rang of changes in second session respect to the first session

Table 27- Effects of the different stimuli on the quantity of novel ideas

As the table shows, none of the stimuli compared to control group are effective in increasing the percentage of ideas ranked 4 by all experts. Also, for the ideas receiving 3 and 4 by all experts, none of the stimuli are more effective in increasing the percentage of ideas in the second session compared to the control group. The reduction percentage is higher for the group receiving the engineering procedure, then trend, and finally patent. Just in the third column for the ideas receiving 3 and 4 by 2 experts, the effect of trend is more than control group. In other words, the stimuli are not effective in increasing the quantity of very novel ideas. Trend shows effectiveness upon increasing the quantity of novel ideas, of which are agreed in levels 3 and 4, by 2 out of 3 experts. Graphical studies can be used for better studying the effects of different stimuli on the novelty of ideas. Figure 15 shows the surface of different target levels of novelty for teams. To compare the effects of stimuli, the value of surfaces can be studied.

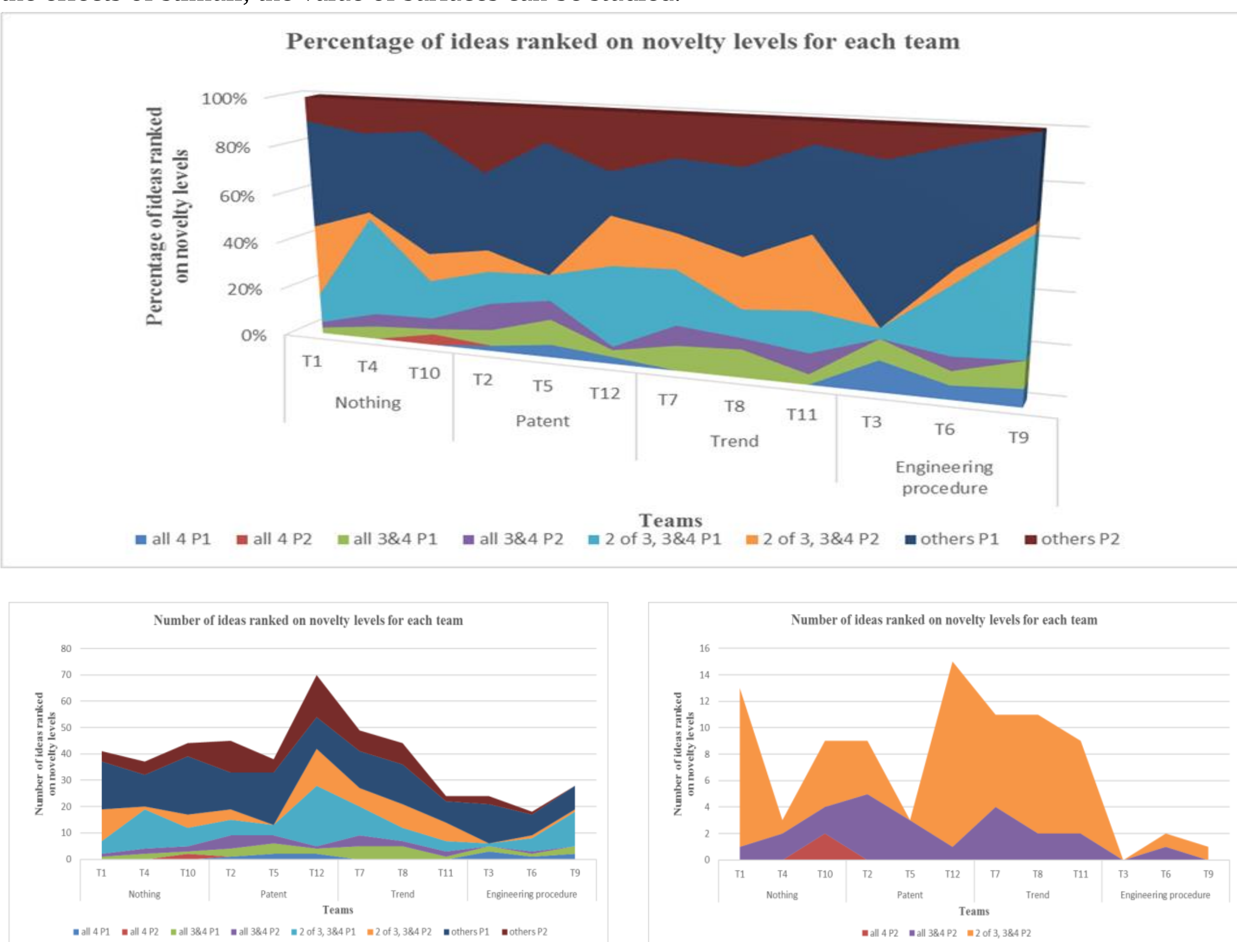


Figure 16 - Percentage of ideas ranked on novelty levels in the first and second design sessions

The red, purple and orange color surfaces are the surfaces for the second session for the target novelty levels. The surface of the orange color is the highest for the group receiving trend and it is more than the control group. Furthermore, the surface of the purple colors for the group receiving trend is more or less similar to the control group. In other words, trend seems to be more effective than other stimuli in increasing the number of novel ideas.
Respectively, the surface analysis can be discussed for the group with patent. Although the patent does not increase the number of novel ideas on the target level, the value of surfaces is more or less close to the control group.

5.5. Influence of the suggested stimuli on R&D engineers' performance in terms of the quantity of ideas with the least expectation of technical plausibility degree

Technical plausibility is the second criterion in the set to realize the candidate ideas for the next generation of technical systems. In the scope of this research, 'traits sound feasible with current knowledge' and 'traits sound infeasible with current knowledge but presumably achievable with further research in the field' were considered as technical plausibility levels 4 and 3 respectively. Table 28 shows the quantity of ideas ranked 3 or 4 by agreements among all or 2 out of 3 experts.

	all 4			all 3&4			2 of 3, 3&4			others		
	P1	**P2**	**(P1-P2)/P1*100**	**P1**	**P2**	**(P1-P2)/P1*100**	**P1**	**P2**	**(P1-P2)/P1*100**	**P1**	**P2**	**(P1-P2)/P1*100**
T1	23	9	60.87	0	1	-	0	1	-	1	6	-500.00
T2	10	7	30.00	6	9	-50.00	4	0	100.00	4	5	-25.00
T3	11	3	72.73	4	0	100.00	2	0	100.00	4	0	100.00
T4	13	5	61.54	10	1	90.00	3	0	100.00	3	2	33.33
T5	18	6	66.67	8	1	87.50	4	1	75.00	0	0	-
T6	8	2	75.00	3	1	66.67	1	0	100.00	3	0	100.00
T7	17	12	29.41	6	3	50.00	6	4	33.33	1	0	100.00
T8	15	15	0.00	6	4	33.33	4	0	100.00	0	0	-
T9	6	1	83.33	6	0	100.00	8	0	100.00	7	0	100.00
T10	17	6	64.71	7	6	14.29	6	1	83.33	0	1	-
T11	10	5	50.00	0	2	-	1	3	-200.00	2	1	50.00
T12	15	10	33.33	5	8	-60.00	4	4	0.00	15	9	40.00
Average	13.58	6.75	52.30	5.08	3.00	-	3.58	1.17	-	3.33	2.00	-
STD	4.83	4.14	24.38	2.97	3.10	-	2.35	1.59	-	4.23	3.02	-
sum	163	81	50.31	61	36	40.98	43	14	67.44	40	24	40.00
% of total (462)	35.28	17.53		13.20	7.79		9.31	3.03		8.66	5.19	

-: not possible to compute the rang of changes in second session respect to the first session

Table 28 - Teams' Performance with respect to the Technical plausibility criterion

The table shows that in total, out of 462 ideas, 244 ideas (around 52.81%) were ranked 4 by all experts, 97 ideas (around 21%) were ranked 3 and 4 by all experts, 57 ideas (around 12.34%) were ranked 3 and only by 2 of 3 experts, and finally 64 ideas (around 13.85%) received less degrees. The numbers show that in total, without and with different stimuli, the most percentage of ideas generated by R&D engineers, are ranked in the first column.
The effects of stimuli can be discussed by looking at the numbers of ideas receiving each 4 target levels of technical plausibility cumulatively for the 3 teams in each group of different stimuli. Table 29 shows the quantity of ranked ideas in 4 levels cumulatively for different stimuli.

	all 4			all 3&4			2 of 3, 3&4			others		
	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100
Nothing	53	20	-62.26	17	8	-52.94	9	2	-77.78	4	9	125.00
Patent	43	23	-46.51	19	18	-5.26	12	5	-58.33	19	14	-26.32
Trend	42	32	-23.81	12	9	-25.00	11	7	-36.36	3	1	-66.67
Engineering procedure	25	6	-76.00	13	1	-92.31	11	0	-100.00	14	0	-100.00

Table 29 - Effects of the different stimuli on the quantity of plausible ideas

As the table shows, patent and trend groups in comparison to the control group are more effective in increasing the percentage of ideas ranked 4 by all experts, and 3 and 4 by all experts in technical plausibility; while the effect of trend is higher than patent.
Graphical studies show the positive effects of trend and patent upon increasing the technical plausibility of ideas. Figure 17 shows the surface of the different target level of technical plausibility for teams.

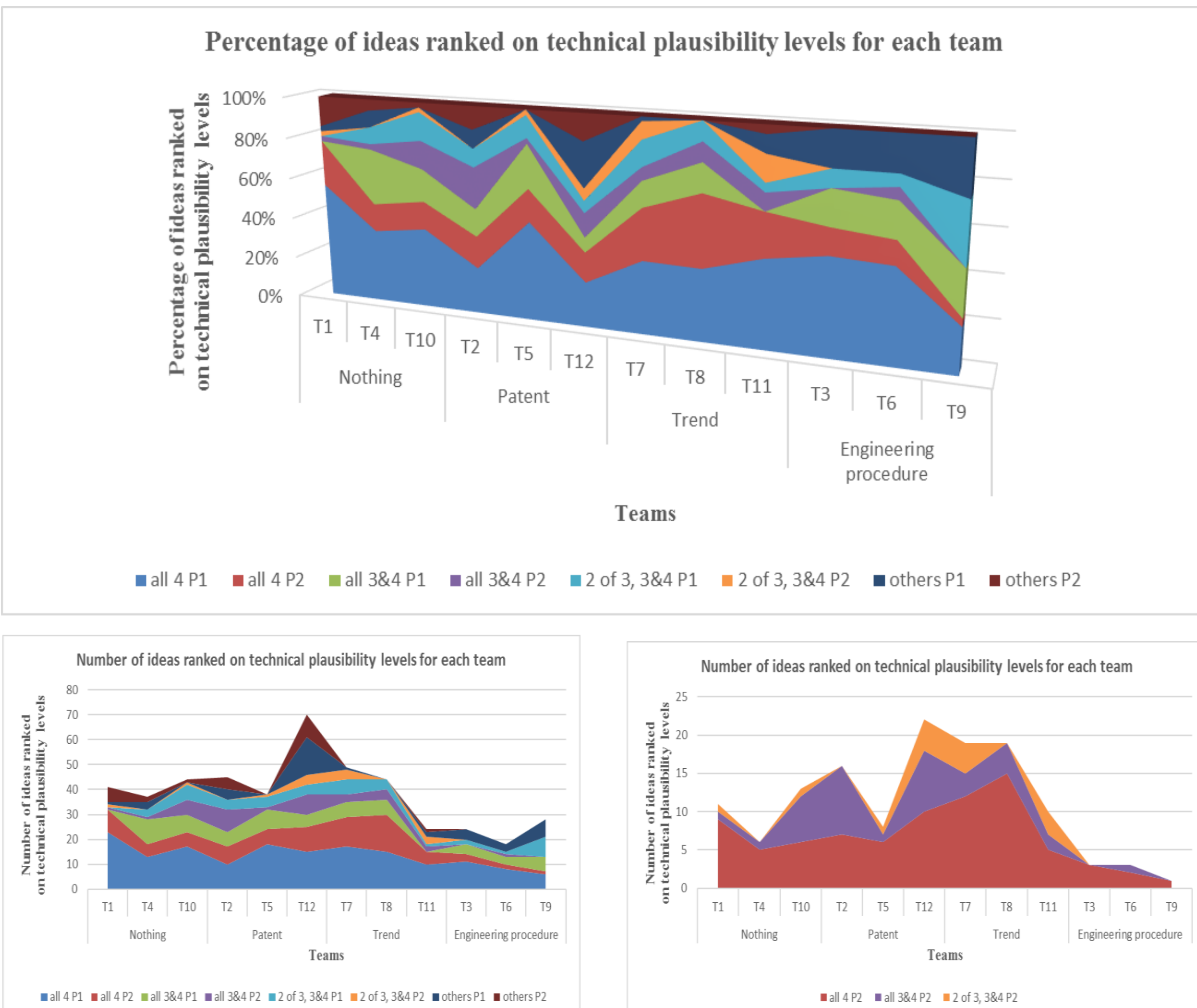


Figure 17 - Percentage of ideas ranked on technical plausibility levels in the first and second design sessions

The red, purple and orange color surfaces are the surfaces for the second session for the target technical plausibility levels. As the figure shows, the surface of all of them, are highest for the groups receiving trend and patent.

5.6. Influence of suggested stimuli on R&D engineers' performance in terms of the quantity of ideas with the least expectation of relevance degree

Relevance is the third criterion in the set to realize the candidate ideas for the next generation of technical systems. In the scope of this research, 'traits which have benefits also for the current society' and 'traits which have no benefit for the current usage of the system in the current society but potential benefits (interpretation) perceived for different usage in a future society' were considered as relevance levels 4 and 3 respectively. Table 30 shows the quantity of ideas ranked 3 or 4 by agreements among all or 2 out of 3 experts.

	all 4			all 3&4			2 of 3, 3&4			others		
	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100
T1	14	5	64.29	5	6	-20.00	5	3	40.00	0	3	-
T2	8	4	50.00	9	7	22.22	4	2	50.00	3	8	-166.67
T3	12	1	91.67	4	1	75.00	4	0	100.00	1	1	0.00
T4	9	5	44.44	14	2	85.71	5	0	100.00	1	1	0.00
T5	17	6	64.71	11	1	90.91	2	1	50.00	0	0	-
T6	6	2	66.67	3	0	100.00	6	1	83.33	0	0	-
T7	12	5	58.33	8	7	12.50	6	4	33.33	4	3	25.00
T8	14	6	57.14	5	4	20.00	5	3	40.00	1	6	-500.00
T9	7	0	100.00	13	0	100.00	2	1	50.00	5	0	100.00
T10	16	1	93.75	4	6	-50.00	5	7	-40.00	5	0	100.00
T11	7	4	42.86	0	4	-!	2	2	0.00	4	1	75.00
T12	8	7	12.50	22	14	36.36	4	4	0.00	5	6	-20.00
Average	10.83	3.83	62.20	8.17	4.33	-	4.17	2.33	42.22	2.42	2.42	-
STD	3.81	2.29	24.63	6.07	4.03	-	1.47	2.02	41.52	2.11	2.81	-
sum	130	46	64.62	98	52	46.94	50	28	44.00	29	29	0.00
% of total (462)	28.14	9.96		21.21	11.26		10.82	6.06		6.28	6.28	

-: not possible to compute the rang of changes in second session respect to the first session

Table 30 - Teams' Performances in respect to the relevance criterion

As the table shows, in total, out of 462 ideas, 176 ideas (around 38%) were ranked 4 by all experts, 150 ideas (around 32.5%) were ranked 3 and 4 by all experts, 78 ideas (around 16.8%) were ranked 3 and only by 2 of 3 experts, and finally 58 ideas (around 12.5%) received less degrees. The numbers show that in total, without and with different stimuli, the most percentage of ideas generated by R&D engineers, are ranked in the first and second columns.
The effects of stimuli can be discussed by looking at the numbers of ideas receiving each 4 target levels cumulatively for the 3 teams in each group of different stimuli. Table 31 shows the numbers of ranked ideas in 4 levels cumulatively for different stimuli.

	all 4			all 3&4			2 of 3, 3&4			others		
	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100	P1	P2	(P1-P2)/P1*100
Nothing	39	11	-71.79	23	14	-39.13	15	10	-33.33	6	4	-33.33
Patent	33	17	-48.48	42	22	-47.62	10	7	-30.00	8	14	75.00
Trend	33	15	-54.55	13	15	15.38	13	9	-30.7692	9	10	11.11
Engineering procedure	25	3	-88	20	1	-95.00	12	2	-83.33	6	1	-83.33

Table 31 - Effects of the different stimuli on the quantity of relevance ideas

As the table shows, patent and trend groups compared to the control group are more effective in increasing the percentage of ideas ranked 4 by all experts, and 3 and 4 by all experts in relevance, while the effect of trend is higher than patent.

Graphical studies can be used for better studying the effects of different stimuli on the relevance of ideas. Figure 18 shows the surface of different target level of relevance for teams. To compare the effects of stimuli, the value of surfaces can be studied.

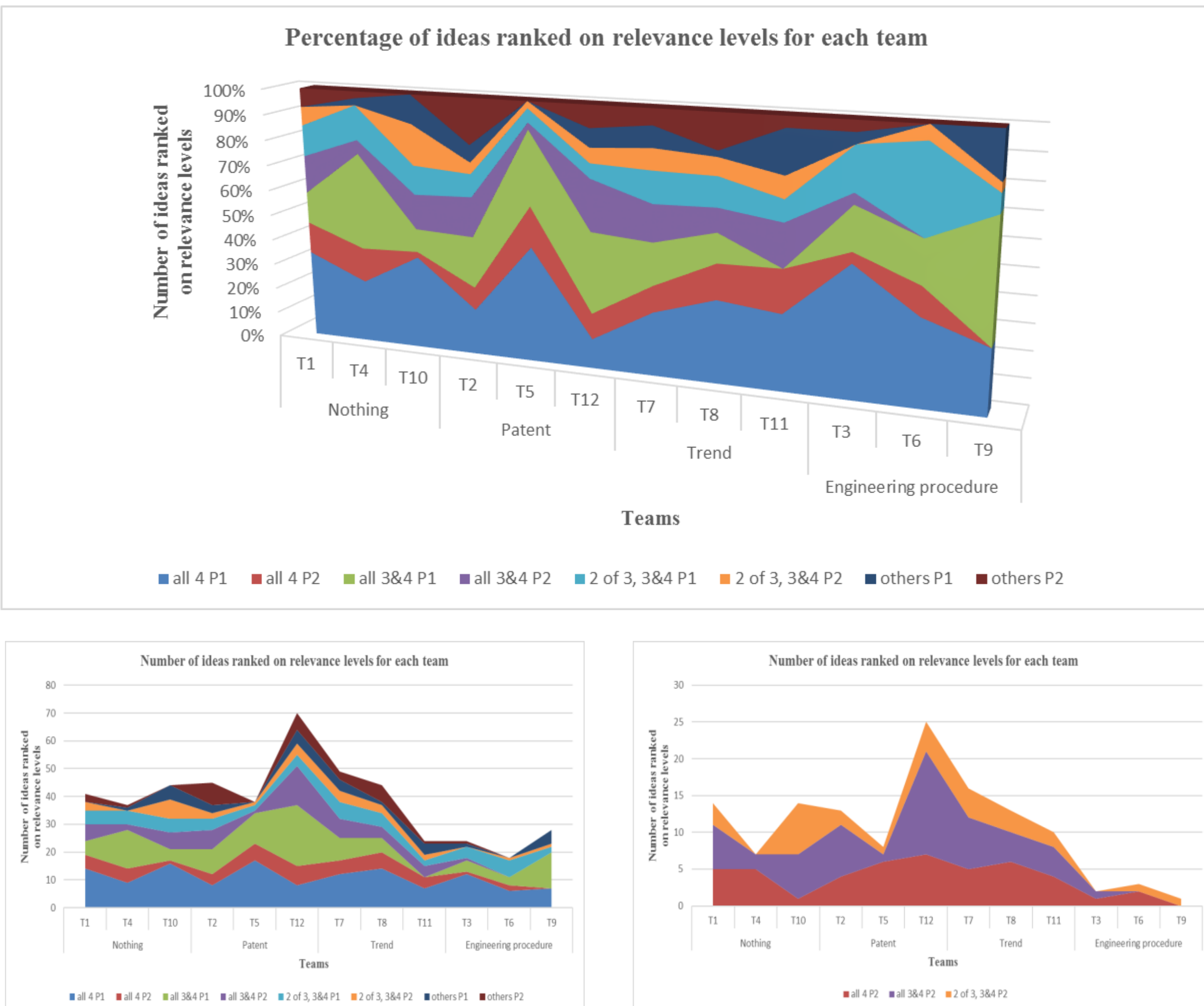


Figure 18 - Percentage of ideas ranked on relevance levels in first and second design sessions

The red, purple and orange color surfaces are the surfaces for the second session for the target relevance levels. As the figure shows the surface of all of them are highest for the groups received trend and patent sequentially.

5.7. Findings together; discussion and conclusion

In the scope of this research, the average R&D engineers' performance in designing the next generation of technical systems and the effects of some promising stimuli on their performance are studied; these were the issues related to checks #1 and #2 of the research. In this section, this research is situated in respects to previous researches in this field, with the mentioned checks being stated. There is no related information in the literature about R&D engineer performance in the design process for the next generation of technical systems; the effects of different kinds and forms of stimuli on the quantity and novelty of design proposals are also studied. Therefore, the result of this research can be discussed in respect to the previous researches in these two characteristics in the field.

Examples of simple and summarized evolution trees of 5 technical systems (called trend), abstracts of the 5 patents related to cooling or any part of a fridge (called patent), and an engineering procedure were considered as the proposed stimuli for the experiment. As mentioned, the effects of these stimuli were studied in respects to a control group.

Trend is a form for composition of three effective stimuli in increasing some characteristics of performance of designers; examples, pictorial representation of examples, structural representation of precedents. Among the different forms of stimuli, examples are used more as stimuli and it can be applied for increasing the ideas for next generation of the technical systems. The studies show despite some doubts about the positive effects of examples on the quantity and novelty of design proposals (rows 7, 8, 16 & 20 of Table 4 in Chapter 2), they are positively effective (rows 12,13,14,15 & 17 of Table 4 in Chapter 2). On the other hand, examples are a kind of singular representation of precedents; it can be suggested and studied that using examples for some structural representation forms of precedents can be more effective, as structural representations seem more effective in increasing both quantity and quality. Additionally, pictorial representation of the precedents is positively effective in increasing novelty (row 17 of Table 4 in Chapter 2).

Patent is a form for composition of novel artwork, previous solution, and examples with more diversity and ambiguity that previous researches show they are effective in increasing novelty of design proposals. Previous solutions are a form of precedents that studies show this form of precedents are also effective in increasing novelty and diversity, if they are presented with more diversity and ambiguity (rows 4, 12 & 34 of Table 4 in Chapter 2). There are some doubts about any influence of them on novelty or even reducing novelty (rows 22, 23 & 24 of Table 4 in Chapter 2). Also it is discussed that novel artworks are positive in increasing novelty (row 13 of Table 4 in Chapter 2).

The engineering procedure included the functional and structural analysis of target system and its relevant hierarchical systems, and their future problems to generate new ideas.

The effects of the stimuli were studied in the second session of the experiment. The percentage of changes of all teams of each group in the second session compared to the first session compared together was then examined.

No.	Performance characteristics	Orders of influence			
		Stimulus 1	Stimulus 2	Stimulus 3	Stimulus 4
1	Quantity of ideas	Trend	Patent	Control group	Procedure
2	Novelty of ideas	Control group	Trend	Patent	Procedure

Table 32 - The influence of different stimuli in order in the second session

Table 32 shows the results of all the experienced stimuli on the two target characteristics of design proposals. The results demonstrate that trend and patent are effective in increasing the quantity of ideas in respects to the control group in the second session. This observation proves the previous researches that precedents increase the quantity (rows 1-6 of Table 4 in Chapter 2) despite some doubts about the positive effects of examples on the quantity (rows 7 and 8 of Table 4 in Chapter 2). The results also show that the effect of trend and patent on the novelty of design proposals is not positive, compared to the control group; while the effect of trend is more than patent. Previous researches show that examples increase novelty (rows 12,13,14,15 & 17 of Table 4 in Chapter 2), and previous solutions also increase novelty if they were presented with more diversity and ambiguity (rows 4, 12 & 34 of Table 4 in Chapter 2) while there are some doubts about any influence of them on novelty, or even reducing novelty (rows 22, 23 & 24 of Table 4 in Chapter 2). As trend and patent are not effective in increasing novelty in the scope of this research, it can be stated that the acceptable degree of novelty is considered higher than in previous researches, or the three experts are not in agreement on the level of novelty of the generated ideas.

Considering the above discussion about the similarities and differences among the observation of this research compared to previous researches, it is worth looking at the normal behaviors of R&D engineers in designing the next generation of technical systems, and the effects of the developed stimuli on them. R&D engineers' average performance on the characteristics of design proposals in designing the next generation of technical systems can be concluded in dedicated time, the quantity of ideas, the quantity of candidate ideas, the quantity of ideas with an acceptable degree of novelty, the quantity of ideas with an acceptable degree of technical plausibility, and finally the quantity of ideas with an acceptable degree of relevance. These observations can also be considered as part of the expectations of the serious game for supporting R&D engineers in producing new concepts for the next generation of systems.

On average, around 83% of R&D engineers tended to finish the design session on time or less than the suggested time of 45 minutes. On average, in a 42 minute-design session, 25.5 ideas are generated and developed by R&D engineers, while the minimum and maximum quantities of generated ideas are 13 and 39 ideas respectively. In other words, team productivity can be reported as 0.62 on average with 0.2 STD. It means every minute, 0.62 ideas are generated by the teams. Consequently, on average, the teams generated 1 candidate with 0.95 STD, which means in total, 12 candidate ideas are generated by all the teams. 12 candidate ideas are 3.9% of the total ideas generated in the first session. It is worth mentioning that these 12 candidate ideas are only 6 separate ideas. 9 out of the 12 selected ideas are generated in the first 30 minutes and 8 of them (89%) are generated before 22.5 minutes, which is the half of the considered time for a design session. This means that around 22.5 minutes can be enough for generating appropriate ideas. Further studies show that 0.87 (266 out of 307) of ideas in first session are not ranked 3 and 4 by all 3 experts. This means that R&D engineers are unsuccessful in designing the next generation of technical systems or the experts are not agreed on the novelty of ideas. Inversely around 75% of ideas are assessed as being plausible and relevant by all 3 experts, meaning that R&D engineers are successful in generating plausible and relevant ideas, or that the experts agreed on the degree of plausibility and relevance of ideas. This observation shows that the serious game must concentrate on promoting R&D engineers' performances in terms of novelty, more so than the two other characteristics effective in the next generation of technical systems.

To proceed the study, the changes of performance of all teams of each group in second session respect to the first session are compared together. Table 33 shows the results of all the experienced stimuli on the target characteristics of design proposals.

No.	Performance characteristics	Orders of influence			
		Stimulus 1	**Stimulus 2**	**Stimulus 3**	**Stimulus 4**
1	**Quantity of ideas**	Trend	Patent	Control group	Procedure
2	**Quantity of candidate ideas**	Patent	Trend/ Control group		Procedure
3	**Quantity of ideas with acceptable level of novelty**	Control group	Trend	Patent	Procedure
4	**Quantity of ideas with acceptable level of technical plausibility**	Trend	Patent	Control group	Procedure
5	**Quantity of ideas with acceptable level of relevance**	Trend	Patent	Control group	Procedure

Table 33 - The influence of different stimuli in order in the second session

The results show that in total, trend is more effective in increasing almost all design proposal characteristics in respects to other stimuli. In other words, while none of stimuli are effective in increasing the quantity of ideas in the second session in relation to the performances of the same teams in the first session, the drop

of reduction in the total quantity of ideas is less for the teams that received trend, and then patents, as the stimuli in comparison to the control group. The results also show that the group receiving patent are more effective in both quantity and percentage of candidate ideas, while the results for the group that received trend, is equal with the control group, while there are no percentages of any changes.
The results show that none of the stimuli are effective in increasing the quantity of ideas with an acceptable degree of novelty (novelty levels 3&4) by all 3 experts, while the drop is less in the group that received trend, than patent and procedure sequentially. Inversely, for the two other characteristics of technical plausibility and relevance, the results show that the group that received trend and patent respectively are more effective than the control group.
Overall, both trend and patent can be applied for designing the target serious game. On the other hand, both trend and patent, are representative for three factors effective in novelty, so each of the factors such as examples, structural representation of precedents, pictorial representation of precedents, and previous solutions with ambiguity and diversity, can be considered for proposing the elements of the serious game.

6. Data analysis and the heuristics applied by R&D engineers in designing the next generation of technical systems

Among the different checks which are considered for this study, the four following checks are related to the heuristics applied by R&D engineers in designing the next generation of technical systems and the effects of developed stimuli on them.
Check #3: How many different heuristics are used by designers to propose the next generation of technical systems (skills)?
Check #4: Which heuristics are more used by designers to propose the next generation of technical systems (active skills)?
Check #5: Which heuristics used by designers are more effective than the others (effective skills)?
Check #6: What are the effects of suggestive stimuli on the heuristics used by R&D in proposing the next generation of technical systems?
In this section, these checks are studied.

6.1. Reliability of segmentation

The reliability of segmentation of protocols is an issue and a concern in protocol analysis before performing the main analysis. In the scope of this research, the reliability of segmentation is checked by studying the coherence of the performed segmentation with general results of another valid research in the field. The selected research discusses the productivity of design projects in real situations within industries, while brainstorming is used as the technique of generating ideas and solving design problems in the teams. The selected research claims some findings about the productivity of design projects in terms of both total generated ideas and selected ideas as the appropriate ones at the end of the projects. It is obvious that the ultimate goals and the structure of experiments of this research, and the selected research are different, but for valid comparison to check the coherence, the least similarities can be discussed. The structure of the two experiments and the coherence of the findings are summarized in Table 34.

<table>
<tr><th colspan="2">To check coherency with
Howard, et al., 2010, The Use of Creative Stimuli at Early Stages of Industrial Product Innovation</th></tr>
<tr><th>Literature</th><th>Recent research</th></tr>
<tr><th colspan="2">Structure of the experiment</th></tr>
<tr><td>- 5 real projects in a real company (8 members in each team);
- First 30 min for communicating the project brief to the team members;
- Followed by a free thinking brainstorming session lasting between 30 and 70 min;
- Followed by brainstorming session with creative stimuli for roughly 40 min;
- Followed by 1-week period to produce six ideas by each team members individually;</td><td>- 12 teams (2 members for each team, randomly matched from different companies);
- Less than 5 minutes to explain the task to the team members;
- Followed by the first part of design session for 45 min (which some teams leave it after 32 min and some other followed up to 50 min);
- Followed by 10 min break;
-Followed by the second part of design session with creative stimuli for roughly 45 min;</td></tr>
<tr><th colspan="2">Selection of ideas</th></tr>
<tr><td>- Reviewed and selected in a meeting after 1 week when the ideas of brainstorming sessions and also the ideas generated by each team member individually are shared and combined;</td><td>- Reviewed by 3 experts according to the set of criteria and sub-criteria provided by researchers for potential candidate ideas of the next generation of technical systems;</td></tr>
<tr><th colspan="2">Relevant findings according to the least similarities of structures of two researches</th></tr>
<tr><th colspan="2">Some issues to consider for comparison</th></tr>
<tr><td colspan="2">- In both experiments team members generated ideas continuously for 30 minutes mostly by using brain storming rules and the results of these 30 minutes can be compared.
- As there was a 30-minutes design brief session in the selected research from the literature, and there was not such a session in the recent research, it is expected that ideas are generated later in recent research.
- Numbers of team members are significantly different so it is expected that the rate of idea generation for the recent research be less than was observed in the literature.</td></tr>
<tr><th colspan="2">The similarity in rate of idea generation as the first similarity in the results</th></tr>
<tr><td>The rate of idea generation remained relatively constant throughout the first 30 minutes of each session where a normal distribution was observed; there was shown to be no significant difference between the teams.
After 30 minutes, this rate began to drop, where in team 5 (the control team) using a Mann–Whitney test, the average ideas per minute changed from 1.2 ideas per minute in first half an hour, to 0.7 ideas per minute after the first half hour (statistically significant to $p = 0.05$) supporting previous findings (Helquist et al. 2007). Therefore, the ratio of average rate of idea generation after and before 30 min is 0.58.</td><td>The rate of idea generation in general for first design session changes from 0.3 to 0.91 for all teams. This rate changes from 0.3 to 1.03 for the first half an hour for all teams, while this rate changes from 0.0 to 0.83 after minute 30. The ratio of average rate of idea generation after and before 30 min is 0.66. Using a T-test, there is a significant difference among the mean of rate of idea generation for teams before and after 30 minutes by 95% confidence level (P-Value = 0.021). The ratio of these rates is approximately close to the ratio which is declared by the literature (0.66 for recent research respect to 0.58 for the literature), therefore it can be considered that segmentation and sentences coded as ideas are reliable.</td></tr>
<tr><th colspan="2">The similarity in rate of appropriate ideas as the second similarity in the results</th></tr>
<tr><td>75% of the appropriate ideas in the first 30 min occurred before 15 min. Using a paired t-test, this showed to have a two-tailed significance value of $p = .162$. It must be considered that 15 min is the half of 30 min which was common time among 5 projects.</td><td>9 out of 16 selected ideas are generated in first 30 minutes and 6 of them (67%) are generated around 20 first min (the half of the part 1 of the design session) or 8 of them (89%) are generated before 22.5 min which is the half of the considered time for design session. Using T-test shows significance value of $p=0.9$ among rate of selected ideas before and after minute 22.5 in the 95% confidence level. Also using a Z-test for show significance difference among portion of selected ideas before and after 22.5 min (Z-Value = 1.15 P-Value = 0.125).</td></tr>
</table>

Table 34 - Checking the reliability of segmentation and coding

As the table shows, the segmentation and coding can be considered valid because the rate of idea generation and the proportion of acceptable ideas are close to the corresponding amounts in the literature. Therefore, further studies for each investigation can be undertaken.

6.2. General thinking characteristics of R&D engineers in designing the next generation of technical systems

As mentioned, to cover the goals of the research, a two part-design session is performed. As some treatments were used in the second part of design session, only the first session is used for capturing the general thinking characteristics of R&D engineers in designing the next generation of technical systems. Table 35 shows the time dedicated to sub-classes of three considered scopes in the first part of design session which took 505.75 minutes for all teams together. The time dedicated to the *, shows the time the R&D engineers talked about some issues completely out of the scope, like greetings.

Time (min)		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	AVE	STD
Total time		38.75	44.83	41.50	32.00	45.00	50.17	43.00	36.00	49.00	38.00	43.50	44.00	42.15	5.02
Speech nature	*	4.42	2.08	0.17	0.00	1.42	0.83	0.00	0.00	3.75	0.00	4.58	1.42	1.56	1.70
	Semantic precedent	19.08	25.67	19.58	11.75	19.67	31.58	18.75	17.83	22.25	19.00	24.25	18.67	20.67	4.67
	Episodic precedent	5.83	5.92	9.58	7.33	11.67	8.67	11.58	7.58	8.92	4.50	8.75	9.00	8.28	2.09
	Given interpreter	0.00	0.00	1.17	0.42	0.92	0.75	0.25	1.25	1.00	1.58	0.83	0.00	0.68	0.52
	Found interpreter	0.17	1.08	0.67	0.67	4.25	3.50	1.67	1.58	5.17	3.08	1.92	2.83	2.22	1.49
	Idea	9.25	10.08	10.33	11.83	7.08	4.83	10.75	7.75	7.92	9.83	3.17	12.08	8.74	2.60
Time horizon	*	4.42	2.08	0.17	0.00	1.42	0.83	0.00	0.00	3.75	0.00	4.58	1.42	1.56	1.70
	Past	0.00	0.00	2.75	0.00	1.17	1.08	2.17	3.92	3.83	0.17	1.17	2.67	1.58	1.40
	Present	9.42	25.42	16.83	10.25	26.75	25.25	20.58	15.00	13.83	18.92	19.58	23.17	18.75	5.59
	Future	24.92	17.33	21.75	21.75	15.67	23.00	20.25	17.08	27.58	18.92	18.17	16.75	20.26	3.48
System hierarchy	*	4.42	2.08	0.17	0.00	1.42	0.83	0.00	0.00	3.75	0.00	4.58	1.42	1.56	1.70
	Sub-system	24.67	15.08	23.00	21.58	30.58	25.33	35.00	20.67	26.67	25.00	26.00	31.33	25.41	5.05
	Object	3.50	7.67	4.92	4.75	1.42	5.42	0.92	2.33	3.25	8.83	0.67	1.50	3.76	2.53
	User	0.67	10.92	1.25	1.67	3.58	6.17	4.50	3.17	3.92	1.08	4.08	2.75	3.65	2.68
	Co-system	2.42	2.58	6.17	2.42	3.50	7.75	1.67	2.42	3.83	0.17	1.75	1.00	2.97	2.04
	Analogous system	2.33	4.92	4.25	1.58	4.50	4.08	0.92	7.42	3.00	2.33	6.42	4.75	3.88	1.85
	Alternative system	0.75	1.58	1.75	0.00	0.00	0.58	0.00	0.00	2.58	0.58	0.00	1.25	0.76	0.83

Table 35 - Time dedicated to sub-classes of coding scheme

The scope of speech nature is divided to five sub-classes. Although the idea description is divided into initial and developed ideas in the coding scheme for another further study, this classification cannot be considered as real sub-classes in the type of modification. Among these five sub-classes, semantic precedent is the most applied one. While on average, the teams spent around 42 minutes designing the next generation of technical systems, they spent on average 20.67 minutes; this means around 50% of the time was used to analyze the promising spaces through generalization and typification. After semantic precedent, idea description and episodic precedent are equally used more than other codes by R&D engineers. The time horizon scope is divided to three sub-classes, where around half of the total time was dedicated equally to thinking about present and future. Finally, the system hierarchy scope is divided into six sub-classes and among them the sub-class of sub-system individually dedicated the most of the time to itself.

To study further the general characteristics, it is worth considering the proportion of the dedicated time to each code, instead of looking at the duration. Figure 19 shows the portion of the time to the main sub-classes of each dimension of coding scheme for each team.

Figure 19 - The portion of the design session dedicated to the main sub-classes of coding scheme for each team

As the figure shows, around 70% of the time, the teams applied precedents and only less than 10% of the time is dedicated to interpreters. Furthermore, for around 70% of the time, the speeches are about the system, while the super-system and similar system had approximately 15 % of the time each dedicated to them. Respectively, on the time horizon scope, the figure shows that less than 10% of the time is dedicated to the past by designers, while the 90% of the time is dedicated equally to the present and future. Further studies can be undertaken for the sub-classes, which dedicated most of the time to itself. Figure 20 presents the distribution of the proportion of the time dedicated to two kinds of precedents.

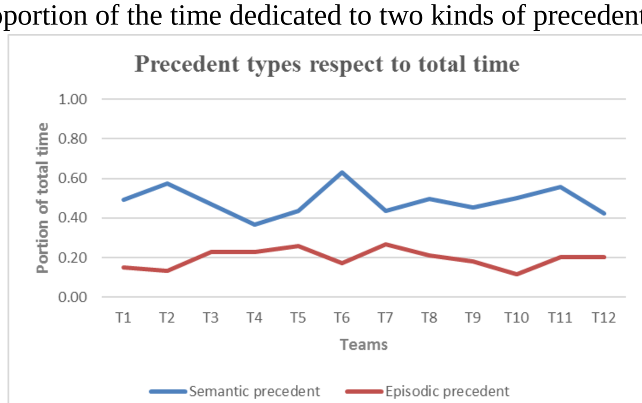


Figure 20 - The portion of the time to semantic and episodic precedents

The graph shows almost the time dedicated to semantic precedents compared to episodic precedent is twice for the most of the teams, while the rate is more for other teams. In other words, half the time is enough for searching for promising information, while twice as much is used for modifying them to the new requirements of the new design.
Further studies can be followed for the sub-classes of system hierarchy too. Figure 21 shows the proportion of the time dedicated to the codes of system hierarchy.

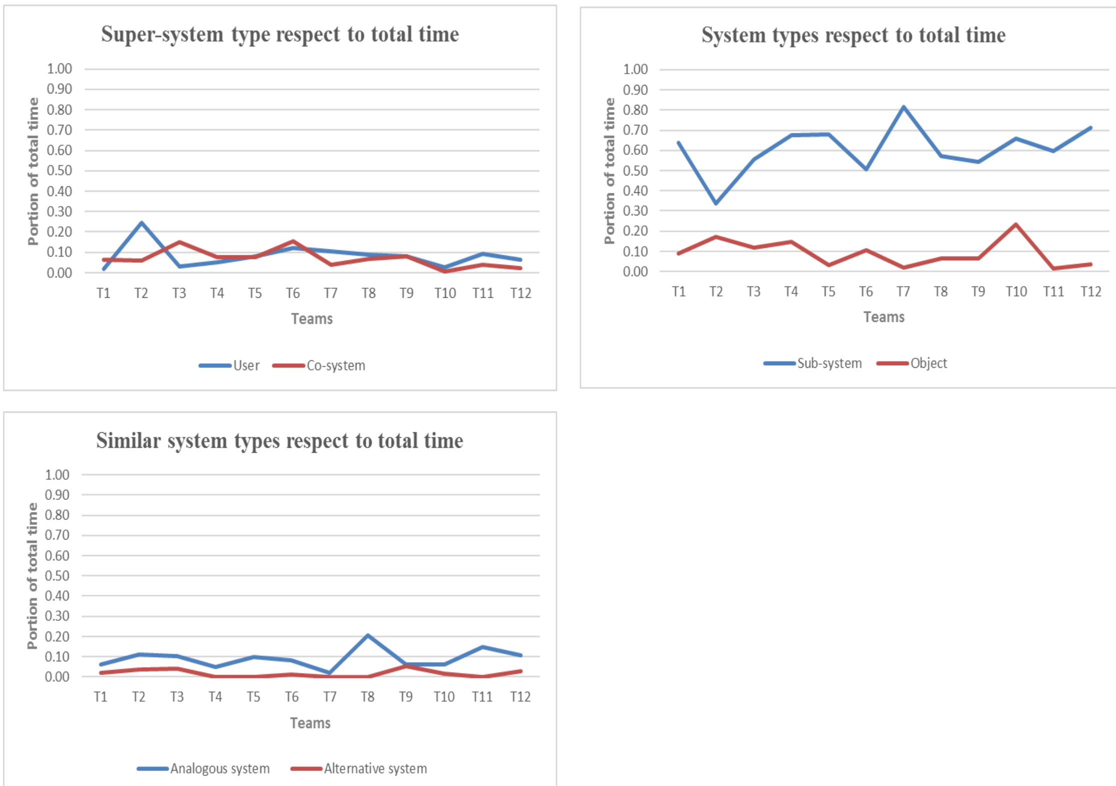


Figure 21 - The portion of the design session dedicated to the sub-classes of system hierarchy

The figure shows that while R&D designers dedicated 70% of the time to system, most of this portion is spent in talking about sub-systems, and around 15% is spent on talking about the object. Respectively, the figure shows the time dedicated to the super-system is spent similarly to talking about users and co-systems. Furthermore, it also shows that most of the time dedicated to similar systems was dedicated to analogous systems, and the time dedicated to alternative systems was very low. Despite considering the effectiveness of observed thinking characteristics of R&D engineers, it can be concluded that the speeches of R&D engineers are compositions of semantic precedent, sub-system, and present and future.

6.3. Heuristics used by R&D engineers in designing the next generation of technical systems

According to the sub-classes of three dimensions of the developed coding scheme, 90 combinations can be developed as heuristics; 5 moods for speech nature, 6 moods for system hierarchy and 3 moods for time horizon. To proceed the study in a manageable scope, it is worth reducing the number of combinations based on the initial observation of general characteristics. It is expected that heuristics show the promising spaces for searching novel feasible traits and how to modify them for the target system.
The general characteristics show the dominant appearance of some codes on the dimensions of speech nature and system hierarchy, without considering their effectiveness; therefore, it is difficult to discard the

other codes. On the other hand, the initial observation on the dimension of time horizon shows that less than 10% of time, the speeches are about the past, and almost the whole time is dedicated to present and future equally. Therefore, it can be considered logical to remove time horizon in further studies for realizing the applied couples of nature speech and system hierarchy by R&D engineers. When composing the heuristics, the effective couples can be completed by adding present and future as the time horizon. By discarding the sub-classes of time horizon in further studies, 30 possible couples of moods of nature speech, and system hierarchy, can be studied. Table 36 shows the most used couples of speech nature and system hierarchy by R&D engineers in designing the next generation of technical systems.

No.	Heuristics	Time (min)													%	Ordering of usage
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	Sum		
-	*,*	4.42	2.08	0.17	0.00	1.42	0.83	0.00	0.00	5.75	0.00	4.58	1.42	20.67	4.09	-
1	se,co	0.92	1.58	3.42	0.25	0.75	6.08	0.17	0.50	1.83	0.17	0.67	0.58	16.92	3.34	9
2	se,user	0.67	7.58	0.00	1.50	2.75	4.83	3.58	2.00	1.75	0.75	4.08	1.00	30.50	6.03	4
3	se,sub	14.67	7.75	9.83	8.75	15.50	15.42	14.67	10.75	14.00	11.33	16.67	13.50	152.83	30.22	1
4	se,obj	2.67	4.25	4.00	0.75	0.67	3.75	0.00	1.17	1.42	5.42	0.00	0.42	24.50	4.84	6
5	se,an	0.17	2.92	1.58	0.50	0.00	1.50	0.33	3.42	0.58	1.33	2.83	2.25	17.42	3.44	8
6	se,alt	0.00	1.58	0.75	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.92	3.92	0.77	
7	ep,co	0.83	0.58	1.50	0.00	1.92	0.25	0.00	0.17	0.42	0.00	0.00	0.00	5.67	1.12	14
8	ep,user	0.00	3.17	1.25	0.00	0.50	0.92	0.33	0.83	1.33	0.33	0.00	1.17	9.83	1.94	12
9	ep,sub	3.25	0.00	3.00	3.17	4.75	3.92	10.67	2.33	2.58	1.75	5.17	5.17	45.75	9.05	3
10	ep,obj	0.00	0.33	0.17	3.08	0.00	0.42	0.00	0.25	0.25	0.83	0.00	0.00	5.33	1.05	15
11	ep,an	1.75	1.83	2.67	1.08	4.50	2.58	0.58	4.00	2.42	1.00	3.58	2.50	28.50	5.64	5
12	ep,alt	0.00	0.00	1.00	0.00	0.00	0.58	0.00	0.00	1.92	0.58	0.00	0.17	4.25	0.84	
13	f,co	0.00	0.00	0.00	0.00	0.25	0.67	0.00	0.25	0.00	0.00	0.00	0.42	1.58	0.31	
14	f,user	0.00	0.00	0.00	0.00	0.33	0.42	0.00	0.17	0.83	0.00	0.00	0.00	1.75	0.35	
15	f,sub	0.17	0.50	0.67	0.67	3.67	2.00	1.67	1.00	3.50	1.75	1.92	2.42	19.92	3.94	7
16	f,obj	0.00	0.42	0.00	0.00	0.00	0.42	0.00	0.17	0.83	1.33	0.00	0.00	3.17	0.63	
17	f,an	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.03	
18	f,alt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
19	g,co	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
20	g,user	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
21	g,sub	0.00	0.00	1.17	0.42	0.92	0.75	0.25	1.25	1.00	1.58	0.83	0.00	8.17	1.61	13
22	g,obj	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
23	g,an	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
24	g,alt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
25	id,co	0.67	0.42	1.25	2.17	0.58	0.75	1.50	1.50	1.58	0.00	1.08	0.00	11.50	2.27	11
26	id,user	0.00	0.17	0.00	0.17	0.00	0.00	0.58	0.17	0.00	0.00	0.00	0.58	1.67	0.33	
27	id,sub	6.58	6.83	8.33	8.58	5.75	3.25	7.75	5.33	5.58	8.58	1.42	10.25	78.25	15.47	2
28	id,obj	0.83	2.67	0.75	0.92	0.75	0.83	0.92	0.75	0.75	1.25	0.67	1.08	12.17	2.41	10
29	id,an	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.08	
30	id,alt	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.92	0.18	
	sum	38.75	44.83	41.50	32.00	45.00	50.17	43.00	36.00	49.00	38.00	43.50	44.00	505.75		

Table 36 - Time dedicated to couples of sub-classes of speech nature and system hierarchy of the coding scheme

The table shows the time dedicated to each code by every team, in addition to the total time dedicated to each code by all the teams. 30 options of possible couples are presented; only 15 of them could dedicate to

themselves in total by all the teams more than 5 minutes (more than 1%), while designing the next generation of technical systems. Respectively it can be seen that only 3 codes occupied the time around 10% or more. The last column shows the orders of usage of these 15 codes by R&D engineers.
Further studies show that the most used codes by all the teams together are seen as the most used codes for each team individually. Figure 22 demonstrates the distribution of time for designing by each team in relation to the coupled codes.

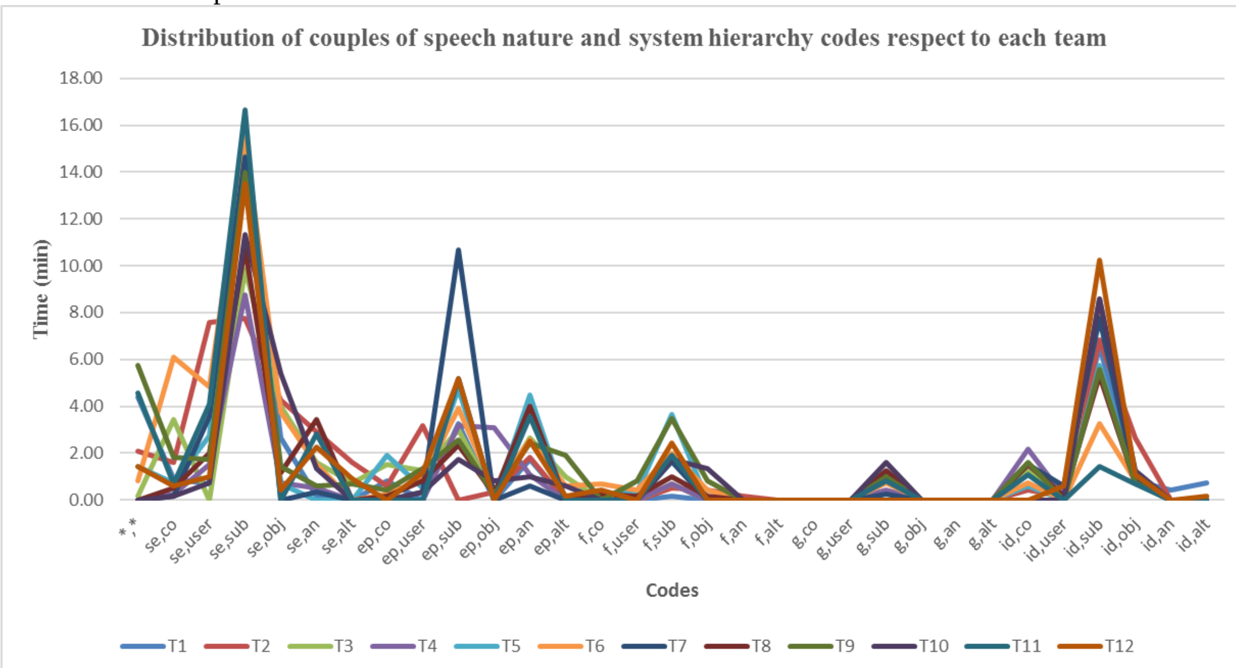


Figure 22 - Codes observed in teams' protocols in designing the next generation of technical systems (classified by first code of each couple)

The graph shows some very sharp picks in the codes "se,sub", "id,sub" and "ep,sub" which the teams spent 23.99 (STD: 37.47), 12.28 (STD: 19.27) and 7.18 (STD: 11.44) minutes on them respectively on average. There are two other sharp picks on codes "ep,an" and "f,sub" with an average occupied time of 4.47 (STD: 7.06) and 3.13 (STD: 4.98) minutes respectively. In-between, there are two hidden picks on codes "se,user" and "se,obj" with an average occupied time of 4.79 (STD: 7.72) and 3.85 (STD: 6.24) minutes respectively. To consider the most used codes, it is worth considering also the two other codes of "se, an" and "se,co" which are hidden picks, but at least occupied more than 3% of total time with an average occupied time of 2.73 (STD: 4.39) and 2.66 (STD: 4.44) minutes respectively.

6.4. Heuristics more effective in designing the next generation of technical systems

While the most used couple codes can be considered as representative for normal skills of R&D engineers in designing the next generation of technical systems, highlighting effective skills, is the ultimate aim of this research. It is expected that the serious game will activate those skills in the target players. Therefore, in following the whole speeches of each protocol, the corresponding ones to the candidate ideas which are ranked by experts, are studied as effective skills. Corresponding speeches were highlighted by researcher by considering the keywords of the candidate idea, its relevant problem and other solutions. As mentioned before in section 5.3 of this chapter, 16 ideas out of 462 generated ideas are ranked as candidate ideas, of which they are 6 separated ideas in total. 12 of candidate ideas are generated in first design session and therefore the corresponding speeches can be pursued before these 12 candidate ideas. Table 37 presents the time dedicated to each coupled codes before the generation of candidate ideas in the corresponding protocols.

Candidate idea	1	2	3	4	5						6		Sum	Most effective codes	Most used codes
Team	T2	T2	T4	T5	T5	T5	T6	T9	T12	T12	T8	T10			
Time of appearance	21.83	17.83	4.25	44.5	15.17	32.75	7.67	45.25	20.75	21.17	15.25	26.25			
# sections of related speech	1	2	1	2	2	3	2	5	3	3	1	4			
time between related speeches	0.00	13.25	0.00	13.17	1.25	17.92	1.42	34.33	14.83	14.83	0.00	14.50			
# moves	11	12	11	46	6	10	11	36	20	23	25	21			
# previous related ideas	0	0	4	4	1	3	1	2	7	8	1	6			
time duration of related speech	2.67	3.58	3.58	11.08	1.5	2.5	3.58	8.42	5.17	5.75	8.08	7.00	62.92		
,	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50		
se,co	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.58	0.58	0.00	0.00	2.42	8	9
se,user	0.00	1.67	0.00	0.00	0.00	0.00	0.92	0.33	0.00	0.00	0.00	0.33	3.25	6	4
se,sub	0.67	0.33	0.00	1.50	0.92	1.42	0.17	2.00	0.67	0.67	1.75	0.17	10.25	2	1
se,obj	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	1.17	1.83	9	6
se,an	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	2.67	0.00	2.92	7	8
se,alt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
ep,co	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.50		14
ep,user	0.00	1.17	0.00	0.00	0.00	0.00	0.25	0.17	0.00	0.00	0.00	0.00	1.58	10	12
ep,sub	0.00	0.00	1.17	1.58	0.00	0.25	0.75	1.50	0.75	0.75	0.00	0.00	6.75	5	3
ep,obj	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		15
ep,an	0.33	0.00	0.00	4.50	0.00	0.00	0.00	0.58	0.00	0.00	2.17	0.67	8.25	3	5
ep,alt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
f,co	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.17	0.17	0.00	0.00	1.00	13	
f,user	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
f,sub	0.00	0.00	0.67	1.42	0.00	0.00	0.50	1.75	1.17	1.42	0.00	0.67	7.58	4	7
f,obj	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	1.33	1.50	11	
f,an	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
f,alt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
g,co	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
g,user	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
g,sub	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17		13
g,obj	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
g,an	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
g,alt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
id,co	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.92		11
id,user	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17		
id,sub	0.50	0.00	1.58	1.33	0.58	0.83	0.33	0.25	1.83	2.17	0.92	1.92	12.25	1	2
id,obj	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.75	1.08	12	10
id,an	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
id,alt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		

Table 37 - Time dedicated to couples of sub-classes of speech nature and system hierarchy of the coding scheme that are effective on the candidate ideas

The first 6 rows show some information about the position of candidate ideas in the protocols. For example, the third row shows the number of relevant parts of speeches in the corresponding protocol for each candidate idea for each team. Among the 12 candidate ideas, 3 of them were generated in one part of the speech, 4 of them were generated after once again coming back to the issue, 3 of them after 2 times coming back to the issue, 1 after 3 times, and finally 1 after 4 times of coming back to the issue. Also the fifth row shows the number of design moves effective for each candidate idea, which differs from 6 to 46.
Only the time dedicated to 13 codes of 30 possible codes are at least more than 1 minute, and the 5 first codes occupy around 75% time dedicated to the effective codes. Furthermore, the table shows the effective couple codes are the same codes which are used most by R&D engineers in protocols with different sequences and orderings. For example, the code "ep,sub" which is the third most used code is the fifth effective code in generating candidate ideas for the next generation of technical systems. Figure 23 shows the relations of the most used and most effective codes in designing the next generation of technical systems.

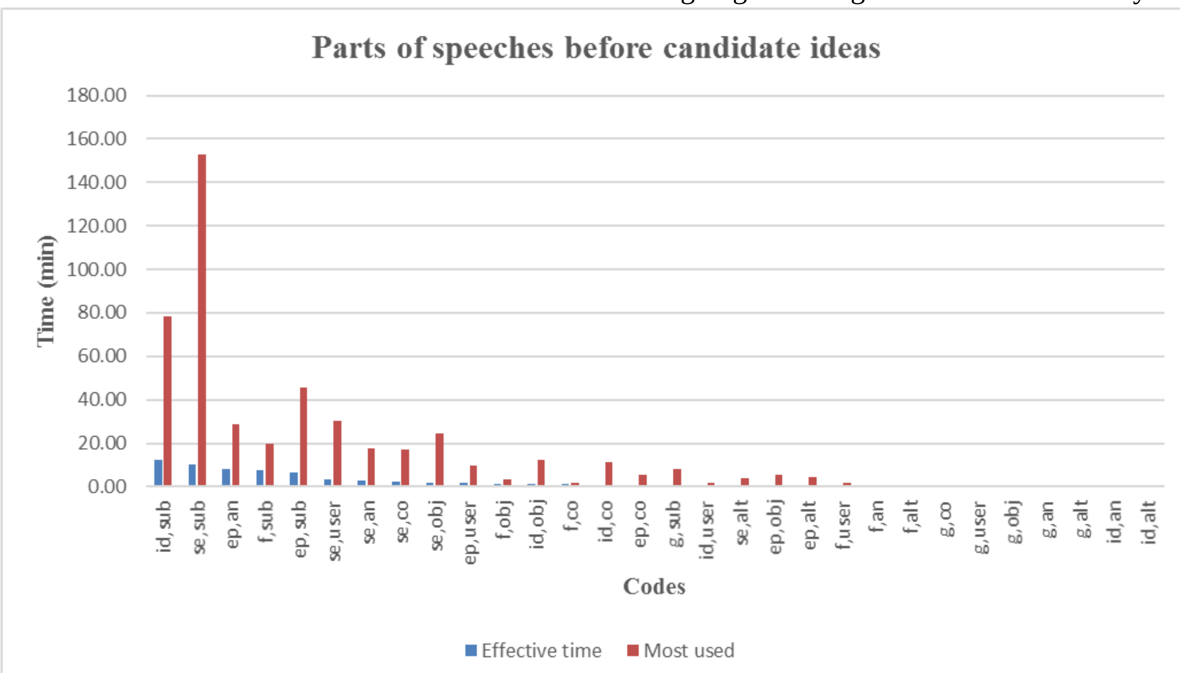


Figure 23 - The time of most observed codes in related speeches for generating candidate ideas in relation to the total time dedicated to each code in whole protocols

The figure shows that the order of most used codes and effective codes are different, while they are still similar. In other words, the 9 first most used codes and 9 first most effective codes are the same, though their orderings in usage is different. Therefore, it is logical to consider them for developing a serious game for supporting R&D engineers in designing the next generation of technical systems.
It is worth reminding that each coupled codes shows the nature of speech and the hierarchy of systems. In other words, these codes are representative for searching the promising spaces for picking up some novel traits and efforts to generate solution based on them. The usage of these this codes for proposing the heuristics used for the game are discussed more precisely in Chapter 4.

6.5. Influence of some stimuli on the heuristics used by R&D engineers in designing the next generation of technical systems

As mentioned, activating the necessary skills in R&D engineers through a serious game is the ultimate goal of the research and it is worth studying the effects of some stimuli on the required skills. In the scope of this research, the most used heuristics are considered as the active skills, while the effective heuristics are considered as necessary skills. Table 38 shows the effects of the applied stimuli on increasing the dedicating time to the most used effective heuristics.

No.	Effective codes on candidate ideas	Stimuli effective in increasing the corresponding codes	
1	id,sub	_	_
2	se,sub	Nothing	Engineering procedure
3	f,sub	Engineering procedure	_
4	ep,an	_	_
5	ep,sub	Engineering procedure	_
6	se,user	Nothing	Engineering procedure
7	se,an	Trend	_
8	ep,user	Nothing	_
9	se,obj	Trend	_
10	f,obj	_	_
11	f,co	Engineering procedure	Trend
12	ep,co	Engineering procedure	_

Table 38 - The Positive effects of some stimuli on increasing the codes effective in candidate ideas

Among the three different stimuli and no treatment, only two of them in highest case increased the dedicated time to each heuristic. For example "no treatment" and "engineering procedure" increased the "se,sub" code sequentially, while "trend" and "patent" were not effective in increasing the time dedicated to this code. The table shows that mostly engineering procedure is effective in increasing the time dedicated to the most effective codes. This observation is strange; previous studies show that engineering procedure as stimuli is not effective in increasing R&D engineers' performance in generating candidate ideas or ideas with an acceptable degree of novelty, technical plausibility and relevance.

6.6. Findings together; discussion and conclusion

In the scope of this research, normal behavior and skills of R&D engineers during designing the next generation of technical systems and the effects of some promising stimuli on their skills, are studied; these are the issues of checks #3, #4, #5 and #6 of the research. To cover the goals of the research, the two part-design session is performed. The normal behaviors and thinking path of R&D engineers (their skills) are studied in the first session through highlighting the applied heuristics. The effects of suggested stimuli on R&D engineers' skills were studied in the second session.

In relation to the previous researches about the next generation of technical systems discussed in the literature (Table 2), their characteristics were summarized as the added novel feasible technological or functional traits in the technical systems, which are brought in the set from already established elements of available systems and technologies. Therefore, it is expected that R&D engineers could search and add these traits to the target system. To study the corresponding skills in R&D engineers, a content-oriented coding scheme was developed. For the most part, content-oriented coding schemes separate the sentences related to an idea from the discussions that support that idea. An idea is classified and studied through the corresponding problem, suggested concept and suggested form. The supportive discussion also is classified as the parts related to the requested requirements by design task, the potential appropriate knowledge and previous experiences for formulating and solving the problems (episodic knowledge), and the analysis of the appropriateness of the suggested knowledge (semantic knowledge). On the other hand, the most promising spaces for creative problem-solving is described by the multi-screen model, also known as the system operator model and powerful thinking schema (Altshuller, 1988). This model is established based on the three dimensions of system hierarchy, time, and interfaces of anti-systems for describing the promising spaces (Khomenko & Ashtiani, 2007). Therefore, an appropriate coding scheme was developed by considering multi-screen thinking and general characteristics of content-oriented coding schemes. Nature of speech with five sub-classes, time horizon with three sub-classes, and system hierarchy with six sub-classes, are the dimensions of the developed coding scheme for clarifying the precedent-based heuristics applied by R&D engineers in designing the next generation of technical systems. According to the sub-classes of these dimensions of the developed coding scheme, 90 combinations can be developed as heuristics.

As reviewed in Chapter 2, knowledge of different time scopes of the target system or the hierarchy of related system to the target system (Pasman, 2003; Lawson, 2004; Eilouti, 2009) are parts of the precedents; while the knowledge of any other system (Marslen-Wilson & Tyler, 1980; Jansson & Smith, 1991; Purcell & Gero, 1992; Smith et al., 1993; Dunbar, 1997; Benami & Jin, 2002; Nijstad et al., 2002, Tseng et al., 2008; Mak & Shu, 2008; Helms et al., 2009; Weisberg, 2009; Linsey et al., 2010; Chan et al. 2011; Fu et al., 2013; Gonçalves et al., 2013; Moreno et al., 2014) and also knowledge of design methods and tools (Archer, 1968; Booz et al., 1968; Radcliffe & Lee, 1989; Fricke, 1993; Fricke, 1996; Basadur et al., 2000; Shneiderman, 2000; Kryssanov et al., 2001; Howard et al., 2008) are the other parts of the precedents. These observations are almost seen in the current research too. Time horizon, system hierarchy and any other systems are among the developed coding scheme and the results show that R&D engineers search these codes as promising spaces. Studies show in the scope of nature of speech, within 70% of the time, the teams applied precedents while only dedicated less than 10% of the time to interpreters and around 20% to describing their ideas. Further studies show the teams spent around 50% of the time analyzing the promising spaces through generalization and typification, which is clarified by semantic precedent. After semantic precedent, the idea description and episodic precedent are equally used more than other codes by R&D engineers. In the scope of time horizon, the teams dedicated almost all the time to present and future equally. In the scope of system hierarchy, 70% of the time, the speeches are about the system, while the super-system and similar system dedicated approximately the same portion of around 15%. At a more detailed level, the sub-system individually dedicated most of the time to itself in the scope of the system hierarchy. In addition, the time dedicated to the super-system is divided similarly to talking about users and co-systems, while most of the dedicated time to similar systems is spent on analogous systems, with the dedicated time to alternative systems is so low. Considering these initial observations, it can be concluded that most R&D engineer speeches are a combination of semantic precedent, sub-system, and present and future.

As the dedicated time to the present and future in the scope of time horizon, are equal and almost half of the whole time, this dimension can be considered natural in the heuristic combinations. By discarding the sub-classes of time horizon in further studies, 30 possible couples of moods of nature speech and system hierarchy can be studied. Among 30 options of possible couples, only 15 of them dedicated in total more than 5 minutes (more than 1%) to themselves by all the teams. Respectively only 3 codes occupied the time around 10% or more. "se,sub", "id,sub" and "ep,sub" are the first three mostly used heuristics with around 30%, 15% and 9% of spent time respectively. "ep,an", "f,sub", "se,user" and "se,obj" are the four similar other used codes, with each one being dedicated around 4% to 6% of the spent time. To consider the most used codes, it is worth considering also two other codes of "se, an" and "se,co" which are hidden picks but at least occupied more than 3% of total time. The studies show the effective couple codes are the same codes which are used most by R&D engineers in protocols with different sequences and orderings. In other words, the 9 first most used codes and 9 first most effective codes are the same, where their orderings in usage is different.

As mentioned, activating the required skills in R&D engineers through a serious game is the ultimate goal of the research; therefore, the effects of some stimuli on the required skills were also studied in the second design session. The observations show that mostly engineering procedure is effective in increasing the time dedicated to the most effective codes. This observation is strange as previous studies show that engineering procedure as stimuli is not effective in increasing the R&D engineers' performance in generating candidate ideas or ideas with an acceptable degree of novelty, technical plausibility and relevance. It can be stated that the engineering procedure guides R&D engineers to the promising spaces but it is not successful in supporting them for requested final results. After engineering procedure, trend also seems effective. As trend was effective in increasing the R&D engineers' performance in general, it can be suggested to benefit trend while leading R&D engineers applying the 9 most used codes in the serious game.

While some design heuristics are composed based on finding design strategies, design precedents and design models, the heuristics are mostly highlighted and discussed in the literature through studying the characteristics of design proposals. There is too few information in the literature about the degree of appropriateness of coding schemes in highlighting precedent-based heuristics. It is worth mentioning that the developed coding scheme in the scope of this research was easy to apply and effective in clarifying some heuristics. As the results show some majority for some of the codes, it can therefore be considered that maybe more precise codes and divisions of moods are more effective in highlighting heuristics; changing the perspective of time, from passing time to the sequential functional relations of systems (such as systems before and after the target system), or even changing from passing time to the period of working time of target system (such as working time, not working time, time of repairment, time of production, and time of recycling) can be more representative for the generated ideas.

Chapter 4

Methodological proposal and research contribution for promoting R&D engineers' skills and performance in designing the next generation of technical systems through a developed serious game

The balance point between active and non-active skills of target players of any serious game is one of the most crucial issues in designing them. The balance point refers to the point in which although the player is losing some points, he believes that he can win in the next steps by more iteration and so forth, hence he continues to play. To clarify the required skills, both active and non-active, literature was reviewed and empirical studies performed in the current research, with the results presented in Chapters 2 and 3.

This chapter reports the third and fourth phases of the current research based on the DRM framework which are discussed in Chapter 1; Prescriptive study and Descriptor study II. Therefore, respectively this chapter is written in 2 main sections dedicated to each phase. In the first section, after summarizing the relevant literature which are reviewed in Chapter 2 and the findings of the phase of Descriptor study I which are studied in Chapter 3, the target serious game is developed. In the second section, the effects of the developed game in respect to various conditions is studied and discussed through a set of empirical studies.

1. A Serious game for designing the next generation of technical systems

Designing a serious game is a multi-disciplinary task that requires the collaboration of experts in different fields (Zarraonandia et al., 2012). Content, theory and game design are considered as the three kernels of serious games; content includes subjects, theory includes the concepts of pedagogy, cognition, learning, psychology, flow, perception and behavior, and game design includes technologies of Artificial Intelligence (AI), Human-Computer Interaction (HCI), networking, computer graphics and architecture, signal processing and web-distributed computing (Greitzer et al., 2007). Therefore, when designing a successful serious game, the three kernels must be considered simultaneously. In the scope of this research, the next generation of technical systems is considered as the target content. Required skills and thinking paths, and active and non-active skills of R&D engineers, are considered as pedagogy, cognition and theory. Finally, a board game is considered as the general picture of game design.

To design a serious game, content and theory must be first highlighted as list of required skills of target players with their values before and after playing the game, and also the list of other general characteristics of the target players. Then the listed characteristics and skills must be interwoven in the forms of game mechanics such as theme, story, objects, subjects, characters, rules, choices, chances, and assessments & feedbacks. Therefore, in following, in the first section, after summarizing and clarifying both general skills (literature reviewed in Chapter 2) and the specific required skills (findings of studies in Chapter 3), the target serious game designed and presented in the form of set of game mechanics.

1.1. General characteristics of target players

The general characteristics of target players are discussed in Chapter 3. The characteristics are considered as:

- Professional: R&D engineers, designers and in wider perspective, engineers interested in novelty, invention and innovation;
- Pre-requisite knowledge and experiences: All engineering majors at any educational level (PhD, Masters and Bachelors), no need to be familiar with theories of innovation, technology forecasting and problem solving methodologies;
- Gender: male and female;
- Age: ranged from 28 to 40 years;
- Other characteristics related to the content:
    - Mostly working in firms;
    - Challenging for main classes of R&D tasks; New Product Research, New Product Development, Existing Product Updates, Quality Checks, and Innovation;
    - Members of the taskforce teams which are organized to focus on future key technologies by keeping recent technology developments under surveillance; knowledge sharing and unlearning are considered as some of the aims of these teams. Knowledge typically resides in the minds of workgroup members and is only invoked during use; knowledge sharing enables the sharing of relevant experiences and information between workgroup members; and unlearning facilitates the ability to adapt to a new environment and produce innovations, through two important dimensions: discarding routines and beliefs, and applying forgotten slacks.

1.2. Requested characteristics of the target serious game

After reviewing the general characteristics of the target players (section 1.1), it is worth considering the general expected characteristics of the target serious game according to the both characteristics of target players and the characteristics of their professional jobs. Some of the main requested characteristics of a serious game for R&D engineers can be clarified as:

1. To promote R&D engineers' performance in designing the next generation of technical systems:
- To be confidence in generating ideas and developing them;
- To be both productive and qualitative.

2. To be played at work easily:
- Time: around 1 hour;
- Technology: no need to spend for technology (specific technology for playing the game).

3. To be seemed specific for R&D engineers:
- To be motivated to play;
- To be familiar to them;
- To be serious during playing.

4. To promote team working:
- To be collaborative instead of competitive;
- To improve social skills;
- To improve knowledge sharing.

1.3. Required skills for target players

Required skills must be clarified in the beginning before designing the target serious game. It is worth remembering that for the target task such as design, all required knowledge must be transferred to the skills; otherwise the ultimate goal will not be achieved. In the scope of this research, the required skills can be summarized in at least two groups; general skills of designers, and required specific skills in designing the next generation of technical systems. The second group is considered the main group of skills for designing the target game to increase the probability to achieve the ultimate goal. The first group is considered as the group of the base-line skills to make the game specialized and familiar for designers. Therefore, in this section, the previous researches reviewed in Chapter 2 and new finding in Chapter 2 are categorized and presented under these two kind of skills.

1.3.1. General skills of designers

Design is a dynamic process of transforming prior experience and knowledge into a form of design knowledge through generalization and typification of precedents, according to required situations, constraints, and goals to embody the knowledge across different domains (Oxman, 1990). As reviewed in the Chapter 2, the general skills of designers can be summarized as the design precedents and design strategies they are used to apply during designing. The design precedents and design strategies are mostly highlighted and clarified based on the results on professional designers. Target players are considered R&D engineers who are not necessarily professional designers. Therefore, the general skills of professional designers, in using design precedents and strategies, can be considered as part of the required skills for target players. On the other hand, in the case of professional target players, the skills related to using design precedents and strategies are considered as familiar elements in the target game for target players.

Design strategies are defined as sequences of activities and moves in the design process related to problem formulation and solution generation phases, and the dedication of time to them. Table 39 summarizes the seven dominant strategies discussed in the literature.

No.	Dominant strategies mentioned in the literature	Summarized concepts of strategies	Abstract view of strategies
1	Considering design problems as ill-defined problems (Akin, 1978; Thomas & Carroll, 1979) that can perhaps never be converted to well-defined problems, so proceeding to find a satisfactory solution rather than an optimum (Cross, 2001)	Considering the design problem as ill-defined problem	Guiding designers to start designing
2	Co-evolving the problem and solution until reaching a matching problem-solution pair through iterative cycles (Conradi, 1999); undertaken through exploring partial structure of design space and solution space, generating some initial ideas in the form of a design concept (Cross & Dorst, 1998), and bridging these two partial models through the articulation of the concept which enables the models to be mapped onto each other (Cross, 1997)	Co-evolving the problem and solution	
3	Starting design by using previous solutions as starting points to create designs with new goals, extra functions, and substructures inspired by previous designs (Pugh & Clausing, 1996; Howard et al., 2008)	Starting design by using previous solutions	
4	Framing a problematic design situation by setting the boundaries, selecting particular things for attention, and imposing on the situation a coherence that guides subsequent moves (Schön, 1988). Only some constraints are given in a design problem; other constraints are introduced by the designer from domain knowledge, and/or are derived by the designer during the exploration of particular solution concepts (Ullman et al., 1990)	Framing a problematic design situation by setting boundaries	
5	Scrapping initial design ideas and starting afresh with new design concepts and a suitable amount of alternatives (Smith & Tjandra, 1998); a dominant influence is seen by initial design ideas on subsequent co-evolving problem and solution, even when severe problems are encountered and despite changes in the framing of the design situation (Rowe, 1987; Ullman et al., 1990)	Scrapping initial design ideas and starting afresh with new design concepts as suitable amount of alternatives	Supporting designers to pursue designing
6	Framing five times sequentially while it is done dominantly at the beginning of the design task and reoccurs periodically throughout the task (Goel & Pirolli's, 1992); it is seldom done in one burst at the beginning of a design process (Schön, 1988)	Framing five times sequentially predominantly undertaken at the beginning of the design task and reoccurring periodically throughout the task	
7	Rapid alternation of activities, which they measured as transitions between design actions and moves (Atman et al., 1999)	Rapid alternation of activities among the problem	

Table 39- The general skills of designers in applying design strategies

The first column of the Table 39, summarizes the previous researches on strategies in the field of design cognition. The two last columns summarize and classify the abstract concepts of corresponding researches in first column. Therefore, in an abstract level, considering the design problem as ill-defined problem, co-evolving the problem and solution, starting design by using previous solutions, and framing a problematic design situation by setting boundaries are the four main findings which guide designers to start designing. Scrapping initial design ideas and starting afresh with new design concepts as suitable amount of alternatives, framing five times sequentially predominantly undertaken at the beginning of the design task and reoccurring periodically throughout the task, and rapid alternation of activities among the problemare the strategies supporting designers to pursue designing.

Precedents in design are defined as prior knowledge and experiences used in designing (Jones & Thornley, 1963; Tulving, 1991; Visser, 1995; Eckert & Stacey, 2000; Pasman, 2003; Lawson, 2004; Dix, 2004). Understanding the design creative process will give insight into where and when resources should be focused in order to enhance creative performance and quality of the product designed (Howard et al., 2008). Episodic precedents represent knowledge retrieved from episodic memory, which have specific contexts and a direct relationship with personal experience. Semantic precedents are composed of two different types of semantic memory; theoretical knowledge that participants have learnt or studied, and created knowledge by participants through inference and generalizations of episodic knowledge. Table 40 summarizes the type and form of precedents which are observed in design or their effects are studied on design.

Precedent form referred in literature	Reference	Effects on design proposal	Abstract view of position of studied precedents on multi-screen model	Precedent type
Previous solution	Jansson & Smith, 1991	Reduce novelty	Knowledge of the different time scopes of the target system	Episodic
	Smith et al., 1993	Reduce novelty		
	Pasman, 2003	-		
	Lawson, 2004	-		
	Eilouti, 2009	Generate new ideas		
ideas of other group members	Nijstad et al., 2002	Increase quantity		
Examples	Jansson & Smith, 1991	Reduce quantity	Knowledge of any other systems	
	Purcell & Gero, 1992	Reduce quantity		
	Smith et al., 1993	Reduce quantity		
More ambiguous examples	Benami & Jin, 2002	Increase diversity		
More variety examples	Nijstad et al., 2002	Increase creativity		
Novel artworks	Ishibashi, 2006	Increase creativity		
Cross-domain examples	Mak & Shu, 2008	Lead to fixation		
	Helms et al., 2009	Lead to fixation		
Far-field examples	Dunbar, 1997	Increase inventions and discoveries		
	Tseng et al., 2008	Increase novelty		
	Weisberg, 2009	Increase inventions and discoveries		
	Linsey et al., 2010	Increase novelty		
	Chan et al. 2011	Increase novelty		
	Fu et al., 2013	Increase novelty		

	Gonçalves et al., 2013	Increase novelty		
	Moreno et al., 2014	Increase novelty		
templates for entire class of solutions	Senbel et al., 2013	-	**Knowledge of analogy based on any classification on characteristics of solutions**	**Semantic**
Dissimilarity of design examples	Marslen-Wilson & Tyler, 1980	Increase creativity		
Similarities of examples	Marslen-Wilson & Tyler, 1980	Reduce diversity		
FBS framework classified examples	Benami & Jin, 2002	-		
Functional classified examples	Nijstad et al., 2002	-		
functional and behavioral classified examples	Doboli & Umbarkar, 2014	-		
Considering requirements	Downing, 2003	-	**Knowledge of analogy based on any classification on characteristics of problems**	
general	Suwa & Tversky, 1997	-	**Knowledge of analogy based on any classification on domain closeness**	
close-domain/ previous solutions	Jansson & Smith, 1991	Reduce novelty		
	Smith et al., 1993	Reduce novelty		
	Nijstad et al., 2002	Increase quantity		
	Pasman, 2003	-		
	Lawson, 2004	-		
	Eckert et al., 2005	-		
	Eilouti, 2009	Help to find new ideas		
cross-domain	asakin & Goldschmidt, 1999	-		
	Leclercq & Heylighen, 2002	-		
	Mak & Shu, 2008	Lead to fixation		
	Helms et al., 2009	Lead to fixation		
	Christensen & Schunn, 2007	-		
far-field	Gick & Holyoak, 1980	-		
	Casakin & Goldschmidt, 1999	-		
	Dunbar, 1997	Increase inventions and discoveries		
	Tseng et al., 2008	Increase novelty		
	Weisberg, 2009	Increase inventions and discoveries		
	Linsey et al., 2010	Increase novelty		
	Chan et al. 2011	Increase novelty		
	Fu et al., 2013	Increase novelty		

	Gonçalves et al., 2013	Increase novelty		
	Moreno et al., 2014	Increase novelty		
	Blanchette & Dunbar, 2001	-	**Knowledge of analogy based on analogy's principles**	
	Leclercq & Heylighen, 2002	-		
	Ball et al., 2004	-		
	Eckert et al., 2005	-		
	Christensen & Schunn, 2007	-		

Table 40- The general skills of designers in applying episodic and semantic precedents

Table 40 is another presentation for the information mentioned in the Table 4. The three first columns of the Table 40, summarizes the previous researches on precedents in the field of design cognition. The two last columns summarize and classify the abstract concepts and type of corresponding researches in first three columns. Therefore, in an abstract level, applying knowledge of the different time scopes of the target system, and knowledge of any other systems are the two dominant skills of designers in using episodic precedents. And in addition, ability to analyze the episodic precedents and applying analogy for design respect to characteristics of solutions, characteristics of problems, distance of analogy domain to the target field and context, and analogy's principles are the four observed or expected skills of designers for applying semantic precedents. In other words, the dominant behavior of designers in designing is design based on analogy or they are capable to design based on analogy.
According to the above summarized results of previous research, the target serious game can benefit from the seven dominant strategies used by professional designers and the designers' skills in applying episodic and semantic knowledge.

1.3.2. Specific required skills

Specific required skills of R&D engineers in designing the next generation of technical systems are dependent to the characteristics of the next generation of technical systems. in the scope of the current research after developing set of criteria for distinguishing the next generation of technical systems, the applied skills by R&D engineers for covering the required levels for the all criteria, are studied in Chapter 2 and Chapter 3. In this section, these studies are summarized briefly to be clarified for designing the target serious game.
As reviewed in Table 2 of Chapter 2, the next generation of a technical system is a kind of breakthrough innovation (Geels, 2004), which is defined by overlapped characteristics between the outcomes of the technology-push innovation (Dosi, 1982) and design-driven innovation (Verganti, 2008). In other words, the next generation of a technical system is the version of the system consisting of radical technological change, and radical meaning change of the system, for existing or new customers. Radical novelty, which is at the core of the next generation of technical systems, is achieved through re-combining already established elements (Fleming, 2001), or by introducing and bringing in an established element into a new setting (Hargadon & Sutton, 1997; Van de Poel, 2003). It provides a new technological trajectory for solving the system's problems (Dosi, 1982). Radical novelty is a result of resolving a contradiction (Altshuller, 1988). In Chapter 3, the mentioned characteristics were covered by developed set of criteria for designing the next generation of technical systems; novelty, technical plausibility, and relevance (Table 9). These three criteria are the common concepts for covering the desired characteristics of quality of a design proposal. In the scope of this research, their corresponding sub-criteria are defined in four levels, with the first level showing the lowest degree and the fourth level the highest degree of target criteria. A potential candidate idea must receive 3 or 4 on all the criteria related to the quality.

The specific required skills were studied through clarifying the applied design strategies and precedents for designing the next generation of technical systems. Reviewed literature in Chapter 2 showed that despite much research in design precedents, strategies and models in the field of design cognition, there are no specific researches to discuss these issues in designing the next generation of technical systems. Applying a special coding scheme developed for studying the speeches of R&D engineers during designing the next generation of a technical system showed that 12 combinations of codes among 90 possible combinations, are more effective respect to the ultimate aim. The applied coding scheme was developed to highlight the type and positions of used precedents respect to the multi-screen thinking model (Chapter 3) to observe the skills of R&D engineers in searching the effective scopes of time and space for acceptable novel feasible traits and also customizing them to come in to the target system by exploiting the available knowledge and experiences. Table 42 shows the effective heuristics in order.

No.	Effective codes on candidates	Heuristics
1	id,sub	Generating ideas for improving sub-systems in the target system
2	se,sub	Pattern searching and generalizing the problems and evolution path of sub-systems in the target system
3	f,sub	Defining new requirement for sub-systems in the target system
4	ep,an	Searching and analyzing similar systems for novel traits (the domain and subject of the similarity is free)
5	ep,sub	Searching and analyzing sub-systems in the target system
6	se,user	Pattern searching and generalizing the users' characteristics, behavior and requirements
7	se,an	Pattern searching and generalizing the novel traits of similar systems for customizing in the target system
8	ep,user	Searching and analyzing the users' behavior and requirements
9	se,obj	Pattern searching and generalizing the objects' characteristics, behavior and requirements
10	f,obj	Defining new requirement for objects of the target system
11	f,co	Defining new requirement for the co-systems of the target system
12	ep,co	Searching and analyzing co-systems of the target systems

Table 41 - The effective heuristics in designing the next generation of technical systems

According to the code definitions in Chapter 3, the heuristics corresponding to each code is defined in the third column. For example, the first effective heuristic is defined by code "id,sub", meaning 'Generating ideas for improving sub-systems in the target system' in their present condition or for their future version. It is expected that the target serious game will lead R&D engineers to generate candidate ideas for the next generation of technical systems, by applying the 12 mentioned heuristics.

In addition, as mentioned in Chapter 3, in the scope of this research, the effects of some precedents on R&D engineers' performance were studied to be applied for designing the serious game. The suggestive precedents were developed respect to the findings of previous researches and positive effects of precedents on quantity and novelty of design proposals (Table 4). Examples of simple and summarized evolution trees of 5 technical systems (called trend), abstracts of the 5 patents related to cooling or any part of a target system (called patent), and an engineering procedure were considered as the proposed stimuli for the experiment. The effects of these stimuli were studied in respects to a control group. Trend is a form for composition of examples, pictorial representation of examples, and structural representation of precedents as three before studied effective stimuli in increasing some characteristics of performance of designers. Patent is a form for composition of novel artwork, previous solution, and examples with more diversity and ambiguity that previous researches show they are effective in increasing novelty of design proposals. The engineering procedure included the functional and structural analysis of target system and its relevant hierarchical systems, and their future problems to generate new ideas. The results show that (i) trend and patent in order are more effective than nothing (the control group) and the engineering procedure in increasing R&D engineers' performance in terms of quantity of total ideas; (ii) they are more effective in increasing the novelty of ideas than engineering procedure, while their effectiveness in novelty is less than the control group; and (iii) in order, trend and patent are more effective in increasing the technical plausibility and relevance of ideas. In other words, in total, R&D engineers are more influenced by trends of evolution path of some other technical systems respect to the ultimate aim of this research. Therefore, it seems logical to apply it directly or its main components such as entire class of solutions, examples of other systems for each class of solution and pictorial representation of examples, in designing the target serious game.

1.4. Common behavior in target players

The performed protocol analysis for revealing the heuristics used by R&D engineers, clarify some common characteristics of R&D engineers' performance; the time dedicated to each sub-class of nature of speech, the quantity of generated ideas, and the quantity of candidate ideas for the next generation of technical system. It is worth to mention again here some of these common characteristics which are supportive for designing the target serious game.

No.	Characteristics		Average	STD
1	Dedicated time (min)	Total	42.15	5.24
		Episodic speeches	8.28	2.09
		Semantic speeches	20.67	4.67
		Describing ideas	8.74	2.60
		Interpreter speeches	2.90	2.01
2	# generated ideas		25.58	7.06
3	# candidates		1.00	0.95
4	% candidates respect to total ideas		3.91	-

Table 42 - The common behaviors of target players based on the results of protocol analysis of their performances in designing the next generation of technical systems

Table 43 demonstrates the corresponding observed information. It shows R&D engineers dedicate around 8 minutes for searching their useful experiences and knowledge to help with the task (episodic speeches); however, they dedicate around 20 minutes for generalizing and customizing them to the target system and around 8 minutes for describing their ideas. In other words, for designing the target serious game, around 8 minutes can be considered for searching for knowledge, and around 28 minutes can be considered for idea generation. Additionally, it is expected that the target serious game can motivate the players to generate more than 1 candidate idea.

1.5. Techno-shift; developed serious game

Serious games demonstrate the transfer of learning (to be 'serious'), whilst also remaining engaging and entertaining (to be 'games'). The balance between fun and educational measures, and the balance between active and non-active skills, are the biggest issues with educational games pursued through adequate integration of educational and game design principles. As mentioned above, content, theory and game design are considered as the three kernels of serious games. Two approaches are seen in literature for developing initial methods for serious game design: a focus on some serious game descriptors which are claimed as more effective on a serious game's success, and a focus on serious game mechanics. These two approaches are not completely separate as serious games mechanics are among serious games' descriptors.

In a successful serious game, high level pedagogical intents are translated and implemented through low-level game mechanics.

The LM-GM (learning mechanics-game mechanics) is a model focused on mechanics, and includes a set of pre-defined game mechanics and pedagogical elements that are abstracted from literature on game studies and learning theories. In this model, the Serious Game Mechanic (SGM) is defined as the design decision and the set of goals and rules that concretely realizes the transition of a learning practice/goal into a mechanical element of game-play directly perceivable by a player's actions, for the sole purpose of play and fun (Arnab et al., 2015). Respect to the literature reviewed in Chapter 2, the following serious games mechanics and effective descriptors should be considered when designing a successful serious game: market, purpose, application domain, pedagogy level, skills, learning outcomes, assessment, social involvement, gameplay, deployment, target players, game components, reality, activity, modality, environment and interaction style.

In the scope of this research, skills are considered as the starting point, as precise research highlighted that most games adequately meet the two primary elements of clear goal and feedback; however, balancing game challenges and player skill is often lacking (Broin, 2011). Themes and name, technology, story, space, characters, subjects, objects, choices, chances, rules and guidance, assessment and feedback, and social involvement are then designed simultaneously based on the above summarized characteristics of target players, their required skills and the requested characteristics of target serious game. Table 44 shows the transfer of skills as a result of content and pedagogy to the elements of the serious game based on LM-GM model.

Learning Mechanics		Game Mechanics	
Requested characteristics of target serious game	To support R&D engineers in designing the next generation of technical systems	Techno-shift Game	**Name**
Requested characteristics of target serious game	To be played at work easily	Board game (Size of A2) with game piece and a die	**Technology**
Requested characteristics of target serious game	To be seen as specific for R&D engineers	I am a champion R&D engineers working collaboratively with my colleagues to save the company in the market through proposing the next generation of company products.	**Theme**
Requested characteristics of target serious game	To promote team working	1. Collaborative game, makes players know the skills of each other and improve their friendships 2. Possibility to compare the results of different groups and organize competition within the company	**Social involvement**
General characteristics of target players	R&D engineers working in the R&D department; the task is related to improving and controlling product. Therefore, they are in relations with production line and workshops	The company loses market share unless R&D department proposes innovative idea to compensate the lost opportunities	**Story**
General characteristics of target players	R&D engineers working in the R&D department; the task is related to improving and controlling product. Therefore, they are in relations with production line and workshops	R&D department of a company	**Space**
General characteristics of target players	Any technical system	Target system	**Object**
Required skills for target players	General Strategies: Start designing: - co-evolving problem & solution - using previous solutions -reframing the problem by resetting the boundaries Pursue designing: - scrapping initial solutions -reframing five times periodically	Co-systems (super-system, systems before, system after); Similar systems; Table of resources	**Subject**

		-rapid alternation in design moves			
	Precedents	Episodic/ Searching knowledge of: - different time scope of target system - any other system Semantic/ Analyzing, generalizing & performing analogy for searched episodic knowledge: - based on characteristics of problems - based on characteristics of solutions - based on domain distance of analogy	Systems around		
Specific	Precedents	- structural representation of precedents (templates describing entire class of solutions) - pictorial representation of examples - Some tricks for resolving contradictions	Think stations Examples	Line of idea generation	
Specific	Heuristics	- analyzing the requirements of users & objects - searching co-systems & similar systems for novel traits - Pattern searching and generalizing the novel traits of other systems for customizing in the target system	Tips & tricks	Line of idea generation	
		Group of R&D engineers together	Group of players		**Characters**
		The observation on R&D engineers' performance: Total time Average time for episodic, semantic, ideas and interpreters Expected average # of ideas & The observation on effective heuristics	Higher level: 1. Total time of the game 2. Starting by table of resources 3. Co-following table of resources and line of idea generation 4. Assessing criteria and final score Lower level: 1. Managing time for each station and among table of resources and line of idea generation 2. Using opportunity of #1 on die for going to more effective station 3. Using opportunity of #6 on die for using a trick card		**Rules & guidance**
		Design moves and actions in the form of heuristics and strategies	Applying subjects on objects according to the higher and lower levels of rules		**Choices**

	Interest on fun and entertainment based on chances	1. Using die to go through stations which are normal and more effective 2. Using opportunity of #1 on die for going to more effective station 3. Using opportunity of #6 on die for using a trick card	**Chances**
	According to the content	Idea card: Self-evaluating of quality of ideas through the ideation card Score card: Self-evaluating time managing through score card	**Assessment & feedback**

Table 43 - The big picture of designed serious game according to LM-GM model

The table shows the developed concepts for the mechanics of the target serious game. In following each mechanic is presented in more detail level.

1.5.1. Subjects of the Techno-shift game

As the game supports R&D engineers for generating the next generation of technical systems, the board is designed as representative for the production line organized in different workstations. Idea generation is going to be triggered in virtual think stations in an imaginary idea generation line of an R&D department. The think stations are the evolution stages for systems that the R&D engineers are trying to improve, through these unwritten stations in reality.
The main subjects of the Techno-shift game are: 'Table of resources', 'Idea generation line', 'Think stations and design heuristics', 'Examples for creativity stimulation', 'Tips & tricks', 'Idea cards with ranking criteria' and 'Score card'. Altogether, they lead players to generate ideas for the next generation of the target system. Most of these elements are composed based on the required skills for target players.

1.5.1.1. Table of resources

Table of resources is one of the main elements of the Techno-shift game. Table of resources is a common table for each work station at work, and as the game mimics the production line of industries, this table is considered as an element of the game. The table of resources is composed according to the following results in relevant researches:

- General design strategies: Literature shows problem formulation and the resetting of a system's boundaries and requirements is one of the main issues of design strategies, which co-evolves with solution generation. In addition, literature shows despite co-evolving problem and solution during the design session, at the beginning of design session, time is mostly dedicated to problem formulation by designers (Table 39).
- Specific design heuristics for designing the next generation of technical systems: Results of the empirical study revealed the effective heuristics used by R&D engineers in designing the next generation of technical systems (Table 42), and showed that R&D engineers search for novel ideas in different spaces including users' requirements, co-systems, similar systems and also sub-systems.

- Time for episodic speeches: According to Table 43, R&D engineers dedicated on average around 8 minutes for searching useful knowledge and experiences.

Based on the above three issues, the table of resources is prepared to be performed at the beginning of the play in around 10 minutes. To guide the players to more effectively search the systems mentioned, the searching spaces are divided to sub-classes; for example, super-system, systems before and systems after are substituted to co-systems. Literature also shows that the multi-screen thinking model is an appropriate structural model for classifying and searching the resources; the overall picture of a table of resources (figure 24) is designed based on the multi-screen model.

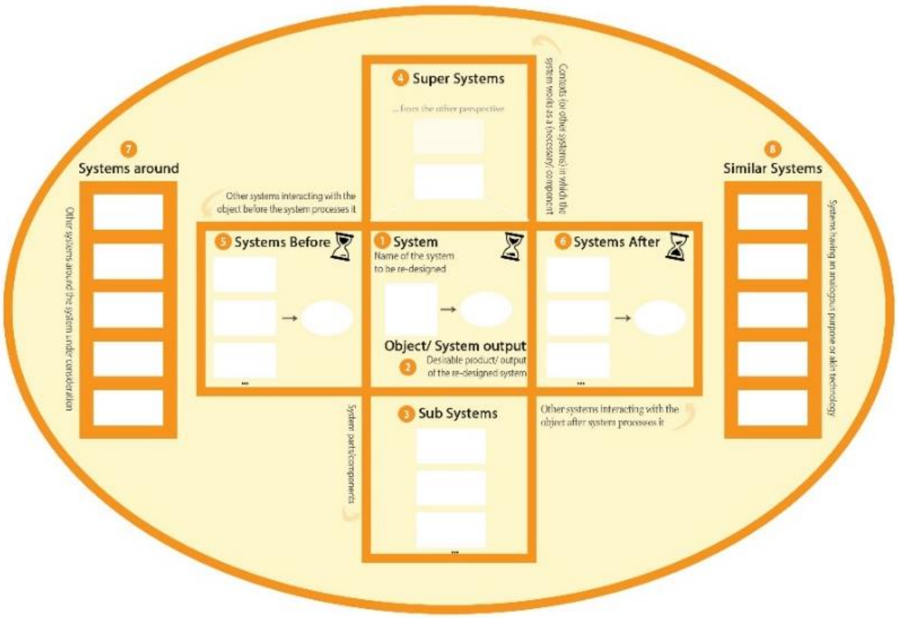


Figure 24 - The image of table of resources in the Techno-shift game

There is a brief description for each part of the system hierarchy in the table of resources:

1. System: Name of the system to be re-designed
2. Object/System output: Desirable product/output of the re-designed system
3. Sub-systems: System parts/components
4. Super-systems: Contexts (or other systems) in which the system works as a (necessary) component
5. Systems before: Other systems interacting with the object before the system processes it
6. Systems after: Other systems interacting with the object after the system processes it
7. Systems around: Other systems around the system under consideration
8. Similar Systems: Systems having an analogous purpose or akin to technology

The bigger picture of this table is presented in Appendix 3.

1.5.1.2. Idea generation line

The idea generation line is another main element of the Techno-shift game. It mimics the production line in the industries. Think stations are the main parts of idea generation line, where example cards and tips & tricks cards are complementary elements for each think station. Each of these elements is presented in more detail in the following sections. The whole picture of the idea generation line is designed to be structural representations of the effective heuristics used in designing the next generation of technical systems. Think stations are considered imaginary evolution stages for the target system that R&D engineers are trying to improve, through these unwritten stations in reality. According to Table 43, around 30 minutes is considered for the line of idea generation; it is expected that around 20 minutes will be dedicated for semantic speeches and thinking about the heuristics, and around 8 minutes for idea descriptions.

1.5.1.3. Think stations

Think stations are mostly composed based on used effective heuristics by R&D engineers in designing the next generation of technical systems. Among the 30 possible combinations of sub-codes of nature of speeches and system hierarchy, 9 codes are used more, which the further studies show they are the more effective ones too (Figure 23). Table 42 shows these 9 heuristics with 3 more heuristics to consider as the concept of think stations. It is worth remembering that the used spaces in the scope of sub-codes of system hierarchy are used to compose the table of resources.
To compose the think station based on the heuristics clarified in Table 42, similar heuristics were merged in one hand, and on the other hand, some very general heuristics were divided into some sub-heuristics to lead R&D engineers to pursue them more easily. Table 45 details these changes.

System hierarchy (Similarities)	Heuristics	Sub-heuristics
Sub-system	**id,sub:** Generating ideas for improving sub-systems in the target system **f,sub:** Defining new requirement for sub-systems in the target system **se,sub:** Pattern searching and generalizing the problems and evolution path of sub-systems in the target system **ep,sub:** Searching and analyzing sub-systems in the target system	Pattern searching and generalizing the problems and evolution path of sub-systems in the target system: • less undesired side effects (undesired effects on user, other systems, environment, …) • lower consumption of resources • higher performance and efficiency (system working with a different principle or technology) • merging all or some of its components into a simpler system without performance losses • improving based on conditions of different phases of its lifecycle (manufacturing, installation, management, recycling, …)
User	**se,user:** Pattern searching and generalizing the users' characteristics, behavior and requirements **ep,user:** Searching and analyzing the users' behavior and requirements	Pattern searching and generalizing the users' characteristics, behavior and requirements: • improved usability, comfort, controllability, accessibility, … • less human involvement or easier to use (common usage, maintenance, feedback, ...) • better addressing future users' needs and environment conditions
Object	**f,obj:** Defining new requirement for objects of the target system **se,obj:** Pattern searching and generalizing the objects' characteristics, behavior and requirements	Pattern searching and generalizing the objects' characteristics, behavior and requirements: • higher flexibility to answer demands for varying quality of the object • higher flexibility to answer demands for varying quantity of the object
Co-system	**f,co:** Defining new requirement for the co-systems of the target system **ep,co:** Searching and analyzing co-systems of the target systems	Pattern searching and generalizing the concept of co-working; • harmonization and integration with systems around • harmonization and integration with systems commonly used just before or after
Similar system	**se,an:** Pattern searching and generalizing the novel traits of similar systems for customizing in the target system **ep,an:** Searching and analyzing similar systems for novel traits (the domain and subject of the similarity is free)	Pattern searching and generalizing the novel traits of similar systems for customizing in the target system to be used for all above related idea generation

Table 44 - Sub-heuristics to be used for the Techno-shift game

The third column of the table shows some sub-heuristics to be used for the Techno-shift game's think stations. These sub-heuristics are presented based on some of the TRIZ-based laws and trends of evolution (Figure 5). To organize the sub-heuristics in an imaginary line of idea generation, these heuristics are ordered in a logical order of the stages for technical system evolutions. Table 46 demonstrates the suggestive orders of the think stations in the Techno-shift game.

No.	Think stations	Input stations	Output stations
0	Old and current version of system performing the task expected by the user (delivering the function)	-	1
1	System evolving towards improved usability, comfort, controllability, accessibility , …	0	2
2	System evolving to a higher flexibility to answer demands for varying quality of the object	1	3
3	System evolving towards harmonization and integration with systems around	2	4, 5, 6, 7
4	System evolving towards harmonization and integration with systems commonly used just before/after	3	8, 10
5	System evolving to reduce human involvement or easier to use (common usage, maintenance, feedback, ...)	3	8, 10
6	System evolving towards less undesired side effects (undesired effects on user, other systems, environment, …)	3	8, 10
7	System evolving towards lower consumption of resources	3	8, 10
8	System evolving towards better addressing future users' needs and environment conditions (first, figure out which needs and conditions)	4, 5, 6, 7	9
9	System working with a different principle or technology (higher performance and efficiency)	8	1, 00
10	System evolving to a higher flexibility to answer demands for varying quantity (of the object)	4, 5, 6, 7	8, 11, 12
11	System evolving towards merging all or some of its components into a simpler system without performance losses	10	-
12	System evolving through improving different phases of its lifecycle (manufacturing, installation, management, recycling,..)	10	-
00	Object evolving so that the system becomes unnecessary	9	-

Table 45 - Orders of heuristics as think stations on the line of idea generation

In total, 14 think stations are developed for the game. Think station #0 is the starting point (the current target system version) and think station #00 is the ideal version of the system, which is usually out of the scope of the research for the next generation of technical systems, given it is not technically plausible with available technologies. Figure 25 shows the image of these think stations in the line of idea generation on the board; however, a larger version of the image is presented in Appendix 3.

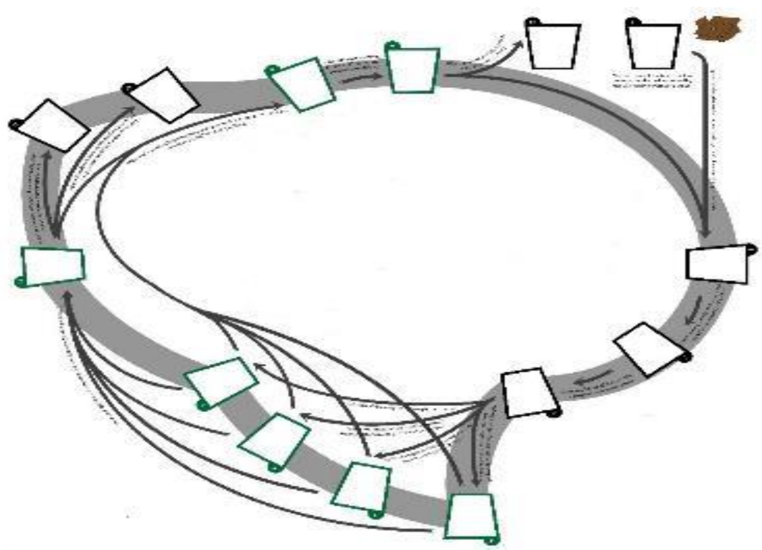


Figure 25 - The organizations of think station in the line of idea generation in the Techno-shift game

As the picture shows, the line of idea generation is organized as circular. This circular organization of the think stations lets the game continue among the think stations, during the time considered for the game.

1.5.1.4. Example cards

Literature shows that pictorial representations of examples increase the quantity and novelty of proposals; this was studied as part of one of the stimuli effective in increasing R&D engineers' performance in designing the next generation of technical systems (Chapter 3). The results of protocol analysis showed the trends, which include pictorial representations of evolutions of five other technical systems, are effective in increasing R&D engineers' performance in designing the next generation of technical systems. According to these observations, example cards are considered as an element of the target game.
Example cards are considered as a complementary element for think stations. For each think station, five examples are prepared. In other words, in total, five technical systems are chosen and the corresponding version with respect to each think station were searched or generated. In total, 66 examples were prepared for the game. Figure 26 shows one of these examples for think station #2 (all examples are presented in Appendix 3).

Figure 26 - Front and back information of one of the example cards

There is information on the front and back of each example card. On the front side there is the picture of the selected version of the selected technical system. On the reverse, there is a brief description of the relation of the selected example with the corresponding think station.

1.5.1.5. Tips & tricks cards

Tips and tricks cards are designed as another element of the target serious game. These cards include some heuristics for removing fixations and also some heuristics for resolving contradictions. These cards are developed based on some precedents mentioned in the literature which are effective on novelty of ideas or the ideas related to the kind of innovation reviewed in Chapter 2. In total, 9 concepts are prepared as 9 tips and tricks card. Figure 27 is an example of one of these cards; see Appendix 3 for all cards.

Figure 27 - Front and back information of one of the tips & tricks cards

The information is only presented on the front side of the card. The following concepts are included in the cards:

Think of…

1. …you and your relatives' future needs.
2. …other systems that could share one of their components with the system. What evolution might they have?
3. …potentialities of new or future manufacturing systems (such as diffusion, adoption, manufacturing processes).
4. …trimming some of the system components and transferring their performance to something else
5. …splitting contradictory performances, desires of users, desired quality or quantity of the object, …and address them one by one through the different system parts (Splitting system to its components or even each component to smaller parts).
6. …splitting contradictory performance, desires of users, desired quality or quantity of the object and trying to address them during different time fractions (within the system working time).
7. …splitting contradictory performance, desires of users, quality or quantity of the object, …and trying to address them by designing a system that works with improved versatility in different conditions.
8. …defining two contradictory requirements of the system and trying to address them so that the whole system addresses one of them and one of the system components addresses the second one.
9. … splitting one of the user conditions, object or environment in two conditions while each one need one contradictory requirements in respect to other parts and trying to cover by adjusting the system for both.

1.5.2. Assessment and feedback inside the Techno-shift game

Assessment can be performed by one's own players or by external experts. Self-assessing is more convenience as it can give the feedback to the players. The assessment can be done once or more times according to the stages of the game.

Generating more candidate ideas for the next generation of technical systems by R&D engineers is the ultimate goal of the Techno-shift game. Therefore, it is expected that the assessment structure highlights the candidate ideas among the total generated ideas. Self-assessing in flexible times of assessing is considered for the Techno-shift game. Idea cards and the score card are two elements of the game which are developed for self-assessing and feedback.

1.5.2.1. Idea cards

The idea card is an element of the Techno-shift game for self-assessing the generated ideas by one's own players. The idea card includes the set of criteria, developed and used for assessing the candidate ideas for the next generation of technical systems (Chapter 3). Novelty, technical plausibility and relevance are the three criteria which together highlight the candidate ideas for the next generation of technical systems. For each idea, one idea card must be filled. The players can improve their ideas according to the ranking levels of each criterion, if they complete the idea card whenever they generate an idea. Each criterion is divided into four levels and the candidate ideas must receive 3 or 4 on all the three criteria. Figure 28 displays an idea card; see Appendix 3.

Techno-Shift Game	Group No. ………… Idea No. …………… Station No. ………. Idea description ……………………………… ……………………………… ……………………………… ……………………………… ……………………………… ……………	Criterion	Level	Description
		Novelty	1	Existing in the market/Already in use
			2	Existing concept, not available on the market
			3	**Existing feature or trait in other fields of application never applied to the domain of this product**
			4	**Novel feature or trait**
		Technical plausibility	1	Against laws of physics
			2	Not against laws of physics, but it sounds infeasible
			3	**It sounds infeasible with current knowledge but presumably achievable with further research in the field**
			4	**It sounds feasible with current knowledge**
		Relevance	1	No benefits foresee neither for the current usage of the system nor potential interpretations for the future society
			2	No benefits foresee for the current usage of the system in the current society, but potential relevance in specific (narrow) niches of members of future society
			3	**No benefit for the current usage of the system in the current society but potential benefits (interpretation) perceived for different usage in a future society**
			4	**Benefits also for the current society**

Figure 28 - Idea card of the Techno-shift game

As the picture shows the idea card is designed as the table so all the ranking levels can be described on it. Players highlight the levels on each criterion by a circle. For more convenience, the acceptable levels are in bold on the cards.

1.5.2.2. Score card

The final evaluation is considered more than number of candidate ideas. As the game can be played by both novices and professionals, it is expected that the game motivates both groups by considering quantity and quality of ideas together. To motivate the players to go from quantity through to quality, a formula is developed by combining lost opportunity of time passing, the worth of the total generated ideas and the worth of the candidate ideas. In other words, the final assessment is based upon the quantity and quality of all generated ideas, through the time dedicated to lead them towards managing their time for more qualitative ideas. Figure 29 shows the score card; a clearer version is presented in Appendix 3.

Techno-Shift Game

Group No.: ……………………………………………………………………
Number of players: ……………………………………………………………………
Name of system: ……………………………………………………………………
Time dedicated to table of resources: ……………………………………………………………………
Time dedicated to line of idea generation: ……………………………………………………………………
No. of think stations passed: ……………………………………………………………………
No. of ideas generated: ……………………………………………………………………
Time dedicated to complete score card: ……………………………………………………………………
Final score: ……………………………………………………………………

Idea No.	Idea	Station No.	Idea score			candidates
			Novelty	Technical plausibility	Relevance	
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						

Final score formula:
-15 (corresponding to the factory lost opportunities in 30 minutes) + total numbers of idea + 2 * number of candidates (for radical shift)

Figure 29 - Score card of the Techno-shift game

As shown in Figure 28, the worth of each candidate idea is 3 times more of a normal idea. For every 2 units of time, the company loses 1 unit of market share, therefore for 30 minutes of playing time, -15 is considered as the lost market share that can be compensated by 15 normal ideas or 5 candidate ideas, or a combination of both, which worth 15 units. The players must try not only to compensate the -15 units of lost market share, but also gain positive units.

1.5.3. Rules and Guidance of the Techno-shift game

The rules are designed to lead the target players to the ultimate goal. The players become familiar with the rules through guidance and instruction of the game. These two mechanics are described in the following sections.

1.5.3.1. Rules of the Techno-shift game

The rules of the game for all phases are defined as higher and lower level rules. Higher level rules are the definite rules that lead the game through its ultimate goal; in the Techno-shift game, these consist of total game time, starting the game with the table of resources, the possibility of co-following the table of resources and idea generation line, and assessing the criteria and final scores. The lower level rules give players freedom to manage the choices (acting of different characters with their corresponding subjects on the objects) to reach the goal. In the Techno-shift game, these lower level rules include the possibility for managing the time for each think station, the time among table of resources and line of idea generation, the time for filling the idea cards and computing the final score, using the opportunity of #1 on die for going to a more effective station, and using the opportunity of #6 on die for using a trick card. The choices developed in the Techno-shift game, let players apply the appropriate combination of characters and subjects to improve the object towards the next generation of target technical system. The players improve their choices by self-assessing through idea cards and score cards.

1.5.3.2. Guidance of the Techno-shift game

The Techno-shift game includes all three phases of taking on the board, playing on the board and taking off the board, such as the professional serious games. The instruction and guidance of the game tells the players how to go through these phases with the elements of the game. The following was the prepared instruction for Techno-shift game:

1. Your role in company's share market

- You hold the position of an R&D engineer.
- The mission of your company's R&D department concerns proposing candidates for the next generation of technical systems (radical shift ideas) to protect or increase your company's market share.
- Every 2 units of time, the company loses 1 unit of market share, unless the R&D department proposes an innovative idea to compensate the lost opportunities. Candidate ideas for the next generation of the technical systems gain 3 units of market share.
- You work collaboratively in teams to propose candidate ideas for the next generation of the technical systems.

2. Adjust yourself for playing your role (To be ready to perform your role)

- Candidate ideas for the next generation of the technical systems let the company run R&D projects to be technically prepared for them.
- To propose candidate ideas for the next generation of the technical systems, your role is 'to generate plausible ideas for technical novelties that can provide significant benefits for the users'.
- The board aims at supporting you in your role. It supports you by the 'Table of resources', the 'Idea generation line', the 'Think stations and design heuristics', the 'Examples for creativity stimulation', the 'Tips & tricks', the 'Idea cards with ranking criteria' and the 'Score card' (Figure 30).
- The game starts with the 'Table of resources' and then follows through the 'Idea generation line' where the player can propose new idea by means of the 'Think stations and design heuristics', the 'Tips and tricks', the 'Examples for creativity stimulation' and the 'Idea cards'. Eventually, the game finishes by summarizing and assessing the results through completing the 'Score card'.
- Trust the platform prepared for you, and follow your tasks as much as possible precisely to gain desire result.

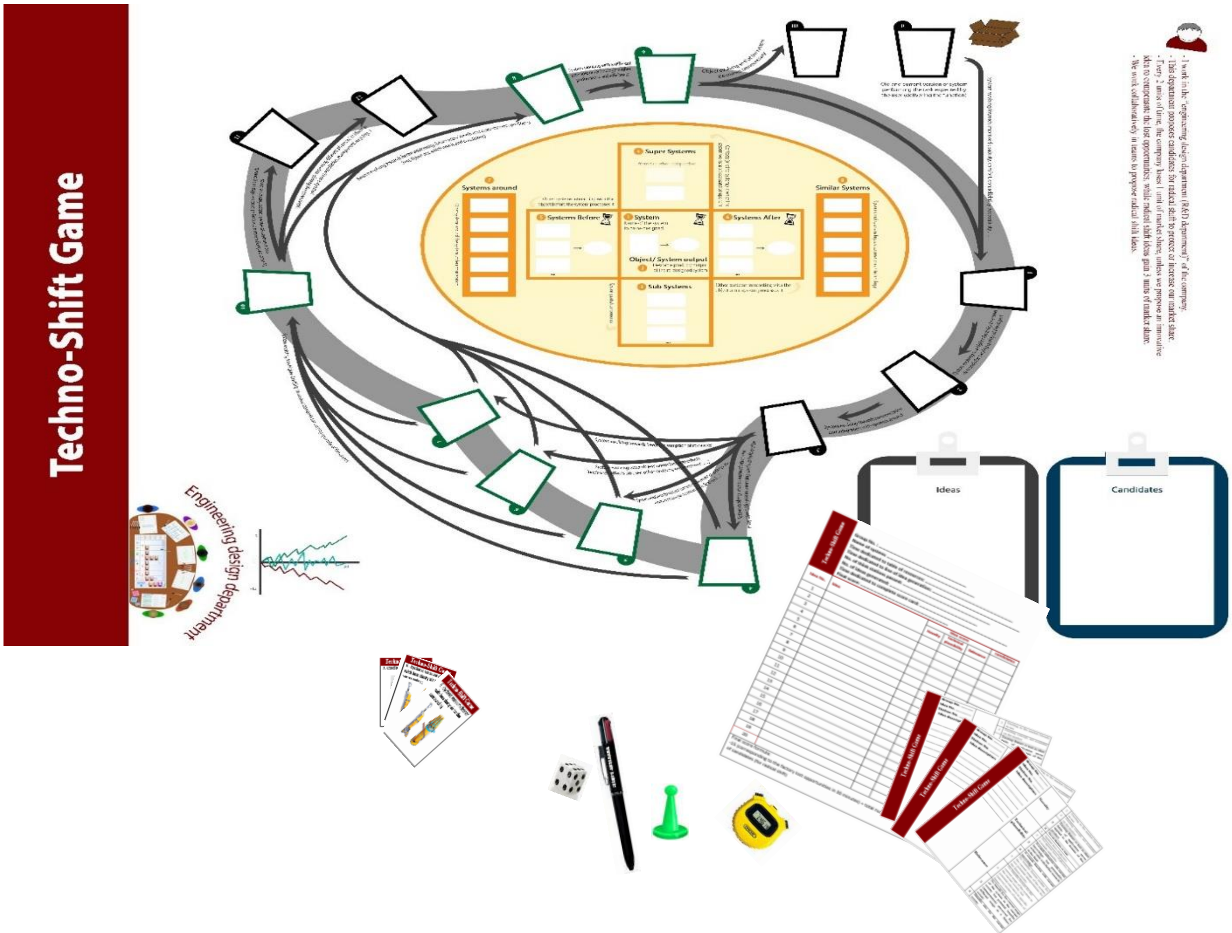


Figure 30 - The elements of the Techno-shift game together

3. Play your role

1. Position the board ready for starting the game:
   - Separate the cards of each think station by their numbers on their back side, shuffle them and put the piles on each related think station with the back side on top;
   - Shuffle the cards of tips & tricks and put the pile with the back side on top;
   - Put the Piece in the 'think station 0';
   - Be sure you have the pile of idea cards and a pen close to yourself;
2. Adjust the table of resources for yourself in 10-15 minutes. The table of resources is full of blank boxes and some guidelines for you to fill them. You start by choosing the system you want to improve and proceed by filling the spaces around it concerning the other resources. The numbers on the 'Table of resources' suggest a more convenient ordering to fill the blank boxes. Such collection of resources opens your mind and lets you generate ideas beyond them. You can add new items to the table of resources even in the middle of the 'idea generation line'.
3. Generate ideas through the 'Idea generation line' for 30-45 minutes:
   - Throw the die to start the game;
   - Move ahead with your game piece according to the number of steps shown on top of the die. (Each think station represents one step ahead);

- Generate as many ideas as possible. Be inspired by the design heuristics you find on the board before the think station. Draw also 2 cards from the pile on top of the think station to be inspired by some examples of the abstract heuristic described before the think station;
- Fill the idea cards for each idea, rank them according to the provided ranking criteria, then put them on the board of ideas (lower right corner of the border);
- Put the examples you've just used out of board;
- Continue throwing die, moving forward by your piece on 'idea generation line';
    - If you get 6 on top of the die, whatever its distance is, you can go directly to the nearest green think station. These stations should be more effective in stimulating the generation of radical shift ideas;
    - If you get 1 on the top of the die, you can take one of the cards of tips and tricks. Once you've used it, put it back on the pile as the last card;
- Continuing moving forward on the line of idea generation, you can also back to the table of resources and think about the new resources to use in each think station;

4. Evaluate your effort in 10 minutes or less, to highlight your efforts through following steps:
    1. Select the ideas that scored 3 or 4 on all the three criteria: novelty, technical plausibility and relevance. Put the related idea cards in the board of candidates for the next generation of technical systems;
    2. Fill in the score table and compute your result by the proposed formula;

4. Improve your role

- It is suggested to play the game to improve your thinking, imagination and social networking abilities:
    - Once a week by some R&D engineers;
    - Before starting some design sessions;
    - When you stock in generation of ideas and solving problems;
    - With different colleagues;
    - With lead customers and suppliers.

2. Proposal for studying the application of developed serious game on R&D engineers' skills and performance

The ultimate objective of the whole research is to improve R&D engineers' performance in designing the next generation of technical systems through developing a specific serious game. In this section, the usability, robustness and effectiveness of the Techno-shift game in respect to some other kind of stimulation of designers in the same task must be studied. Usability measures the possibility and ease of use of the game in the early stages of playing; robustness checks the sensitivity of the system's stability and performance to parameter variations; and effectiveness studies the capability of producing a desired result. The techno-shift game is developed based on the results of previous researches in the literature, with some new studies on the required skills, active and non-active skills, of R&D engineers in designing the next generation of technical systems, and some general characteristics of target players and the expectation of a professional game for them. In other words, some parts of the Techno-shift game were developed based on results of empirical studies, while R&D engineers were proposing their ideas for the next generation of a fridge as a concrete technical system. In addition, as mentioned in Chapter 3, some combinations of stimuli were developed based on the literature and the effects of them were studied on the R&D engineers' performances while designing for the next generation of fridges. According to the results, some of these combinations are used for composing the Techno-shift game. Therefore, to approach the usability, effectiveness and robustness of the developed serious game, some concerns must be studied. Usability, effectiveness and robustness of a full or partial version of the game must be studied in respects to the different spectrum of target players and target systems. Table 47 presents some of necessary and possible tests to study these three factors respect to a base condition.

<table>
<tr><th>Checking factor</th><th>Participant</th><th>Target system</th><th>Game structure</th></tr>
<tr><td>(Base conditions respect to preliminary studies in chapter 3)</td><td>Base:
- R&D engineers
- 3-9-years experiences in R&D departments
- No experiences in serious TF & PS projects</td><td>Base:
fridge</td><td>Base:
Full version</td></tr>
<tr><td rowspan="4">Usability</td><td>Same participants in profile</td><td>Same target system</td><td>Same version of the game</td></tr>
<tr><td>Same participants in profile</td><td>Free target system</td><td>Same version of the game</td></tr>
<tr><td>More professional participants in TF & PS projects</td><td>Another target system</td><td>Same version of the game</td></tr>
<tr><td>Less professional participants (engineering master students)</td><td>Another target system</td><td>Same version of the game</td></tr>
<tr><td rowspan="5">Effectiveness</td><td>Same participants in profiles</td><td>Same target system</td><td>Same version of the game</td></tr>
<tr><td>Same participants in profile</td><td>Free target system</td><td>Same version of the game</td></tr>
<tr><td>More professional participants in TF & PS projects</td><td>Another target system</td><td>Same version of the game</td></tr>
<tr><td>Less professional participants (engineering master students)</td><td>Another target system</td><td>Same version of the game</td></tr>
<tr><td>New participants in profile</td><td>Another target system</td><td>Various versions of the game:
- without table of resources
- without examples
- without heuristics</td></tr>
<tr><td>Robustness</td><td>New participants in profile</td><td>Another target system</td><td>Various versions of the game:
- without table of resources
- without examples
- without heuristics</td></tr>
</table>

Table 46 - Least concern for checking the usability, effectiveness and robustness of the Techno-shift game

As Table 47 shows to detail the least checks for studying usability, effectiveness and robustness, different conditions of participants, target system and game structure are considered.
In the following section, after discussing the research question and its corresponding specific investigations in relation to Table 47, a set of empirical studies to approach the checks are developed.

2.1. Research question and the specific investigations

As mentioned in Chapters 1 and 3, two main research questions were defined for the whole research to develop a serious game for R&D engineers to support them in proposing a concept of the next generation of technical systems:
Research question #1: How should the serious game for promoting R&D engineer's performance in designing the next generation of technical systems be structured?
Research question #2: How effective is the developed serious game?

The first research question was studied and discussed in Chapter 3, while the second question is studied further in this chapter. To approach the second research question given the details in Table 47, the following checks must be performed:
Check #7: Does the developed game work with less elements than configured?
Check #8: Is the developed game more effective than design sessions with the same task?
Check #9: Does the developed game work the same for the same technical system?
Check #10: Does the developed game work the same for any technical system?
Check #11: Does the developed game work the same for different kind of players?

2.2. Planned structure for the empirical study

In total, 3 experiments are developed to approach Checks #7 to #11; Table 48 details these experiments.

No. Experiment	No. Rounds	Changing factors	Checking criteria	# of related checks
Experiment #1	Round 1	Same participants in profile Same target system Full version of game	Usability Effectiveness	9 8
	Round 2	Same participants in profile Free target systems Full version of game	Usability Effectiveness	10 8
Experiment #2	Round 1	More professional participants in profile One another target system Full version of game	Usability Usability Effectiveness	10 11 8
Experiment #3	Round 1	Less professional participants in profile Two other target systems Four different versions of game	Usability Usability Robustness	10 11 7

Table 47- Relation of the experiments and the checks for the second research question of the whole research

In the next section, the performed experiments and their results are discussed.

3. Effects of developed and applied serious game on R&D engineers' skills and performance

Three experiments are designed to study the usability, effectiveness and robustness of the developed game together. Robustness and usability are fundamental for presenting scientific approaches in developing the game, whereas effectiveness is critical for consequent industrial usage. Each experiment and the corresponding checks for usability, effectiveness and robustness are discussed below.

3.1. Experiment #1: Usability and effectiveness of the Techno-shift game for the same target players in same and free target systems

Experiment #1 is the main designed experiment for studying the usability and effectiveness of the Techno-shift game. With the same target players and participants and the same target system, the usability and effectiveness of Techno-shift in very similar conditions are studied. By changing the target system while the target players are the same, the usability and effectiveness in different conditions are studied too.

3.1.1. Specific investigations

Experiment #1 is designed to study the following checks:
Check #8: Is the developed game more effective than design sessions with the same task?
Check #9: Does the developed game work the same for the same technical system?
Check #10: Does the developed game work the same for any technical system?
Usability for Checks #9 and #10 are approached by looking at the time dedicated to the game, the quantity of generated ideas, the relations of generated ideas with think stations, and the quantity of generated candidates. Effectiveness for Check #8 is studied by comparing the quantity of total generated ideas and the quantity of candidate ideas in the two conditions of normal design sessions and using the Techno-shift game.

3.1.2. Planned structure for the experiment

Experiment #1 checks both usability and effectiveness of the Techno-shift game in respect to the normal design sessions with the same target players in profiles for the same task. Table 49 shows the planned structure for this experiment; it consists of 3 parts. Part 3 is the control group for this empirical study. Both usability and effectiveness of Parts 1 and 2 are studied in relation to Part 3.

Part 1. Techno-shift/ first round playing	Part 2. Techno-shift/ Second round playing
Target players: 12 teams of R&D engineers **Time:** 45-60 min **Task:** next generation of **fridge**	**Target players:** 12 teams of R&D engineers **Time:** 45-60 min **Task:** next generation of **any free technical system**
Part 3. Normal design session	
Participants: 12 teams of R&D engineers **Time:** 45-60 min **Task:** next generation of **fridge**	

Table 48 - The planned structure for the Experiment #1

It is worth mentioning that given the existing limitations in the scope of this research, Part 3 is not performed newly and the first part of the previous empirical study for revealing the heuristics through protocol study (Chapter 3), is considered as Part 3.

3.1.3. Participants and design teams

Same as the participants in the protocol study for revealing heuristics used by R&D engineers in designing the next generation of technical systems, 24 Iranian R&D engineers were involved in the experiment (12 teams of 2 members). The specific characteristics of the players are summarized in Table 50.

Participants' profiles	Different parts of experiment #1	
	Part 3	Parts 1 & 2
Gender	75% male and 25% female (18 Men and 6 women)	75% male and 25% female (18 Men and 6 women)
Age	28 to 40 years	25 to 53 years
Education	12% PhD, 71% master and 17% bachelor	20.83% PhD, 70.83% master and 8.33% bachelor
Engineering field	37% industrial engineering, 21% mechanical engineering, 13% computer engineering, 13% electrical engineering, 8% design, 4% polymeric material engineering and 4% textile engineering	25% mechanical engineering, 20.83% industrial engineering, 4% chemical engineering 16.67%, Aerospace engineering 12.5%, electrical engineering 8.33% and computer engineering, statistic, biology and architecture each one 4%
Experiences in R&D units	67% among 7-9 years, 16% among 5-6 years and 17% among 3-4 years	17% among 7-10 years, 25% among 5-6 years and 58% among 3-4 years
Familiar to technology forecasting methodologies	No one has any experiences in real technology forecasting projects while 12% not even familiar with the related theories and methodologies and 88% familiar with the theoretical part of the field	No one has any experiences in real technology forecasting projects while 62.5% not even familiar with the related theories and methodologies and 37% familiar with the theoretical part of the field

Table 49 - The similarities of participants of different parts of Experiment #1

Table 50 shows the participants of Parts 1 and 2 are the same, and are similar in profile to those participants of Part 3. The biggest difference is in the experiences of participants in R&D departments. It seems on average, the experiences of Part 1 and 2 participants in years is less than the participants of Part 3. Therefore, lower performances are expected for participants in Parts 1 and 2 in respects to those in Part 3.

3.1.4. Data collection

Data collection in Parts 1 and 2 of Experiment #1 is performed by the players of the Techno-shift game by filling the idea cards and score card. In other words, all necessary information for the research were considered and mentioned in these cards. On the other hand, as mentioned, due to the limitations of the research especially time and accessibility to the different R&D engineers, Part 3 is not performed again and the information from the previous empirical study is used for Part 3 of this experiment.
There is a difference among these parts of the experiment which must be considered. In Parts 1 and 2, players write the version of the ideas when they discuss them together in the groups, while the ideas in Part 3, were collected by transcribing the speeches of participants in the protocol study, and any version of the idea is computed as one idea. It is therefore expected that there will be less total number of ideas in Parts 1 and 2 of the experiment in respects to the Part 3.

3.1.5. Quality of design sessions

Quality of design sessions in both forms of the Techno-shift game and the normal design session are studied by the quantity of the acceptable ideas as candidates for the next generation of technical systems. In Part 3, the acceptability of ideas was checked through the opinion of three experts on the developed set of criteria for ranking the degrees of novelty, technical plausibility and relevance from 1 to 4 (Chapter 3).
In Parts 1 and 2, the players assess the quality of their ideas according to the same criteria on the idea cards. To improve player self-assessment, all generated ideas were evaluated again by the researcher, and one of the three previous experts performed the final ranking.

3.1.6. Observed results

Experiment #1 studied some issues related to the usability and effectiveness of the Techno-shift game by observing the results of some indexes, and comparing them in three different conditions in Parts 1, 2 and 3. Table 51 shows the observed indexes and their corresponding values.

No.	Indexes for studying usability and effectiveness of Techno-shift game		Parts of the Experiment #1: Part 1 (game/ round 1)		Part 2 (game/ round 2)		Part 3 (normal design session)	
			Average	STD	Average	STD	Average	STD
1	Dedicated time (min)	Take on the board (Table of resources)	9.92	1.44	8.42	2.43		
		Play on the board (Idea generation line)	30.00	0.00	30.00	0.00	42.15	5.24
		Take off the board (Score card)	14.50	9.06	12.08	7.22		
2	# passed think stations		7.75	2.01	7.42	2.47	-	-
3	# generated ideas		14.42	5.20	13.92	4.60	25.58	7.06
4	# candidates		8.25	2.80	10.75	3.49	1.00	0.95
5	% candidates respect to total ideas		57.23		77.25		3.91	
6	% non-related ideas to think stations		22.54		20.96		-	-
7	% non-correct self-assessment of candidate ideas		-21.18	23.37	-41.57	21.79	-	-

Table 50 - Observed indexes for studying the usability and effectiveness of the Techno-shift game

The Techno-shift game is usable and also more effective than the normal design session in designing the next generation of technical systems by R&D engineers. Parts 1 and 2 of the experiment show that the target players could play the game in the suggested time, and on average, go through 7 of 12 think stations. As a result of playing the game, they generated on average around 14 ideas, of which around 60% of them in Part 1 and around 37% of them in Part 2 are distinguished as candidate ideas for the next generation of technical systems. The table also shows that only around 20% of the generated ideas in the game are not related to the reported think stations by players; this means that players could follow the heuristics and examples of the think station. The self-assessment shows around 21% not correct assessment in Part 1 and around 41% in Part 2 which shows this parameter must be considered for improving the game. In other words, to respond to Checks #9 and #10, the Techno-shift game works for both the fridge and any other technical system, as the target players who are similar in profile to the previous research, could follow the game and propose candidate ideas.

A comparison between Parts 1 and 2 is shown in the second round of playing the game. Despite a reduction in the total number of ideas and the self-assessment accuracy, the percentage of candidate ideas increased; this can be interpreted as the players were being more precise in the quality of ideas in the second round. This observation can also be considered as the response for Check #10. Furthermore, to approach Check #8, a comparison between Parts 1 and 3 shows the game is more effective in leading target players to generate candidate ideas with respect to the normal design session. In other words, although the quantity of generated ideas is more in the design session, the quantity of candidate ideas is more in the Techno-shift game. Figure 31 demonstrates the effectiveness of the Techno-shift game in relation to the normal design session.

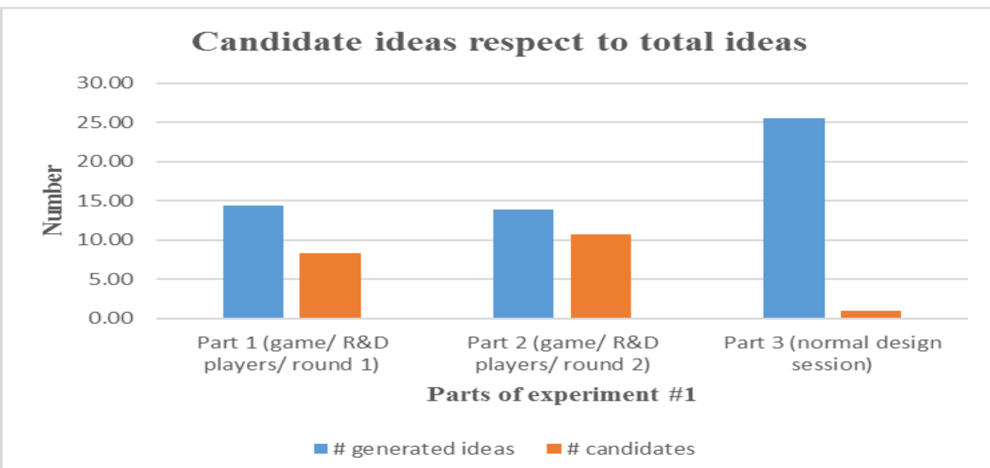


Figure 31 - Effectiveness of the Techno-shift game in respect to the normal design session in terms of the required task

To develop the game, an increase in the number of total ideas such as normal design session (around 25 ideas) is expected, with most of them covering the desire quality as the candidate ideas for the next generation of technical systems.

3.2. Experiment #2: Usability and effectiveness of the Techno-shift game for less professional target players in one other target system

Experiment #2 is an experiment for studying the usability and effectiveness of the Techno-shift game; the profile of the target players is changed in respect to the baseline in Parts 1 and 2 of Experiment #1, and the target system is changed in respect to Part 1 of Experiment #1.

3.2.1. Research question and the specific investigations

Experiment #2 is designed to study Checks #8, #10 and #11 as follows:
Check #8: Is the developed game more effective than design sessions with the same task?
Check #10: Does the developed game work the same for any technical system?
Check #11: Does the developed game work the same for different kind of players?
Usability for Checks #10 and #11 are approached by looking at the time dedicated to the game, the quantity of generated ideas, the relations of generated ideas with think stations, and finally the quantity of generated candidates. Effectiveness for Check #8 is studied through a comparison of the quantity of total generated ideas and the quantity of candidate in the two conditions of normal design sessions and using the Techno-shift game.

3.2.2. Planned structure for the experiment

Experiment #2 checks both usability and effectiveness of the Techno-shift game in respects to Parts 1, 2 and 3 of Experiment #1, with more professional players and a new target system. Table 52 shows the planned structure for this experiment.

Part 1. Techno-shift/ first round playing	**Part 2. Techno-shift/ Second round playing**
Target players: 12 teams of R&D engineers **Time:** 45-60 min **Task:** next generation of **fridge**	**Target players:** 12 teams of R&D engineers **Time:** 45-60 min **Task:** next generation of **any free technical system**
Part 3. Normal design session	**Part 4. Techno-shift/ new teams**
Participants: 12 teams of R&D engineers **Time:** 45-60 min **Task:** next generation of **fridge**	**Participants:** 5 teams of more professional people in problem solving **Time:** 45-60 min **Task:** next generation of cell phone

Table 51 - The planned structure for Experiment #2

As the table shows, this experiment consists of 4 parts, with Part 4 being the main part of this experiment, while for Parts 1, 2 and 3, the observed information in the scope of Experiment #1 are used.

3.2.3. Participants and design teams

12 engineers participated in the experiment as members of 5 teams (3 teams of 2 members and 2 teams of 3 members). The specific characteristics of the participants can be summarized as follows:

- Gender: 66.6% male and 33.3% female (8 Men and 4 women);
- Ages: ranged from 25 to 60 years;
- Level of education: 33.3% PhD, 58.3% master and 8.3% bachelor;
- Engineering field: -;
- Experiences in R&D units: -;
- Familiar to technology forecasting methodologies: 90% familiar with the theoretical part of the field;
- Familiar to problem-solving techniques: the game is played in the professional conference in TRIZ, where the participants are familiar with TRIZ and some of them have experience in TRIZ- problem solving projects.

3.2.4. Data collection

Data collection in Part 4 of Experiment #2 is performed by the players of the Techno-shift game, by filling the idea cards and score card (such as Parts 1 and 2 of Experiment #1). It is worth considering also here the difference among the data collection of Part 3 with other parts such as those mentioned in Experiment #1.

3.2.5. Quality of design sessions

As mentioned in Experiment #1, the quality of design sessions in the Techno-shift game in Part 4, was studied first through player self-assessments and then checking them, undertaken by the researcher and one expert.

3.2.6. Observed results

Experiment #2 studies some issues related to the usability and effectiveness of the Techno-shift game for more professional players than in baseline in Parts 1, 2 and 3 of Experiment #1, by observing the results of some indexes, and comparing them in four different conditions in Parts 1, 2, 3 and 4. Table 53 shows the observed indexes and their corresponding values.

No.	Indexes for studying usability and effectiveness of Techno-shift game		Parts of the Experiment #2							
			Part 1 (game/ R&D engineers/ round 1)		Part 2 (game/ R&D engineers/ round 2)		Part 3 (normal design session/ R&D engineers)		Part 4 (game/ more professional engineers)	
			Average	STD	Average	STD	Average	STD	Average	STD
1	Dedicated time (min)	Take on the board (Table of resources)	9.92	1.44	8.42	2.43			10.00	0.00
		Play on the board (Line of idea generation)	30.00	0.00	30.00	0.00	42.15	5.24	30.00	0.00
		Take off the board (Score card)	14.50	9.06	12.08	7.22			10.00	0.00
2	# passed think stations		7.75	2.01	7.47	2.47	-	-	4.60	2.07
3	# generated ideas		14.42	5.20	13.92	4.60	25.58	7.06	12.40	5.94
4	# candidates		8.25	2.80	10.75	3.49	1.00	0.95	9.00	3.32
5	% candidates respect to total ideas		57.23		77.25		3.91		72.58	
6	% non-related ideas to think stations		22.54		20.96		-	-	43.55	
7	% non-correct self-assessment of candidate ideas		-21.18	23.37	-41.57	21.79	-	-	-11.50	22.30

Table 52 - Observed indexes for studying the usability and effectiveness of the Techno-shift game

In Part 4 of the experiment, the time was fixed for all sections of the game for all the teams. The players generated on average around 12 ideas, which on average, 9 of them were distinguished as acceptable candidates for the next generation of technical systems. It means that around 72% of generated ideas covered the desire quality of the game. To reach this result, the teams on average passed through 5 think stations. The table also shows that around 43% of the generated ideas in the game are not related to the reported think stations by players; this means that players could follow the heuristics and examples of the think station for near 60% of ideas. The self-assessment shows around 11% of misinterpreting criteria. These observations support the idea that the game is usable for more professional players in problem-solving than R&D engineers for new target systems, which are the issues of Checks #10 and #11. Comparison among Part 4 with Parts 1 and 2 shows despite a reduction in the quantity of generated ideas, the percentage of candidate ideas among them is similar to Part 2, and more than Part 1. The self-assessment shows improvements in this type of player, which means they have understood the criteria better. On the other hand, the percentage of non-related ideas increased, which can be interpreted that this type of player uses their own knowledge for idea generation too.

Also, to approach Check #8, comparison among Parts 1, 2 and 4 in respect to Part 3, shows the game is more effective in leading target players in generating candidate ideas in respect to normal design sessions. In other words, although the quantity of generated ideas is more in the design session, the quantity of candidate ideas is more in the Techno-shift game. Effectiveness of Techno-shift game in respect to the normal design session is more obvious in Figure 32.

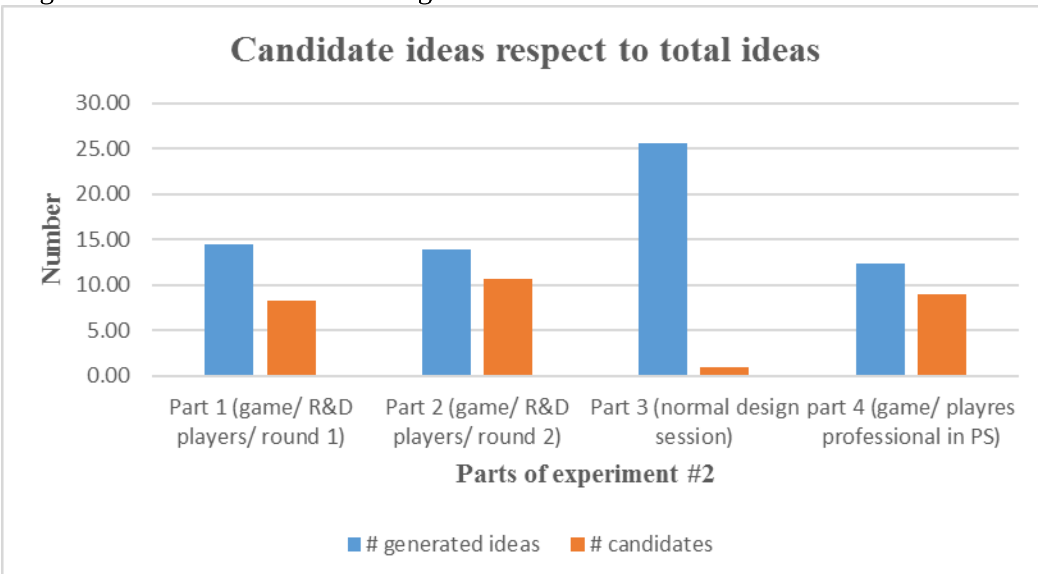


Figure 32 - Effectiveness of the Techno-shift game in respect to the normal design session in terms of the required task

To develop the game, the number of total ideas are expected to be increased such as the normal design session (around 25 ideas), with most of them covering the desire quality as candidate ideas for the next generation of technical systems.

3.3. Experiment #3: Experiment #3: Usability and robustness of the Techno-shift game for less professional target players in one other target system with four different versions of the game

Experiment #3 is another experiment similar to Experiment #2, for studying the usability and robustness of the Techno-shift game; while the profile of the target players is changed in respect to the base line in Parts 1 and 2 of Experiment #1, the target system is changed in respect to Part 1 of Experiment #1.

3.3.1. Research question and the specific investigations

Experiment #3 is designed to study Checks #7, #8, #10 and #11; though the main focus is on Check #7.
Check #7: Does the developed game work with less elements than configured?
Check #8: Is the developed game more effective than design sessions with the same task?
Check #10: Does the developed game work the same for any technical system?
Check #11: Does the developed game work the same for different kind of players?
Usability for checks #10 and #11 are approached by looking at the time dedicated to the game, the quantity of generated ideas, the relations of generated ideas with think stations, and finally the quantity of generated candidates.
Effectiveness for Check #8 is studied through comparing the quantity of total generated ideas and the quantity of candidate ideas in the two conditions of normal design sessions and using the Techno-shift game. Robustness for Check #7 is studied through comparing the quantity of total generated ideas and the

quantity of candidates in four conditions: the full version of the game, a game without the hints on the table of the resources, a game without example cards, and a game without the sentences of heuristics. Errors, mistakes, misunderstandings and forgotten options are part of the nature of human beings, so robustness can be considered as the sensitivity of the results of playing the game, incompletely in respect to the nature of players. From this perspective, playing the game with various incomplete versions can be used to study the robustness of the Techno-shift game. It is worth considering that this study also can be used for checking the effectiveness of different versions of the game.

3.3.2. Planned structure for the experiment

Experiment #3 checks usability, effectiveness and robustness of the Techno-shift game in respects to Parts 1, 2 and 3 of Experiment #1, with less professional players and a new target system. Table 54 shows the planned structure for this experiment.

Part 1. Techno-shift/ first round playing	Part 2. Techno-shift/ Second round playing
Target players: 12 teams of R&D engineers **Time:** 45-60 min **Task:** next generation of **fridge**	**Target players:** 12 teams of R&D engineers **Time:** 45-60 min **Task:** next generation of **any free technical system**
Part 3. Normal design session	**Part 5. Techno-shift/ new teams**
Participants: 12 teams of R&D engineers **Time:** 45-60 min **Task:** next generation of **fridge**	**Participants:** 8 teams of less professional people in R&D experiences; **Time:** 45-60 min **Task:** next generation of two other systems

Table 53 - The planned structure for Experiment #3

As the table shows, this experiment consists of 4 parts. Part 5 is the main part of the experiment, while for the parts 1, 2 and 3, the observed information in the scope of experiment #1 are used.

3.3.3. Participants and design teams

24 mechanical engineering Masters students participated in the experiment (8 teams of 3 members). The specific characteristics of the participants can be summarized as follows:

- Gender: 79.16% male and 20.83% female (19 Men and 5 women);
- Ages: ranged from 21 to 28 years;
- Level of education: 8.33% PhD and 83.33% master;
- Engineering field: 95.84% mechanical engineering and 4.16% management;
- Experiences in R&D units of Iranian companies: -;
- Familiar to technology forecasting methodologies: -;
- Familiar to problem solving techniques: the game is played in the course of systematic innovation and inventive problem solving after about 4 sessions out of 17 sessions of the course.

3.3.4. Data collection

Data collection in Part 5 of Experiment #3 is performed by the players of the Techno-shift game by filling the idea cards and score card such as Parts 1 and 2 of Experiment #1. It is worth considering also here the difference among the data collection of Part 3 with other parts such as mentioned in Experiment #1.

3.3.5. Quality of design sessions

As mentioned in experiment #1, the quality of design sessions in Techno-shift game in part 5, was studied first through self-assessing of the players and then checking by the researcher and one expert.

3.3.6. Observed results

Experiment #3 studied some issues related to the usability, effectiveness and robustness of the Techno-shift game for players less professional than base line in Parts 1, 2 and 3 of Experiment #1. The usability and effectiveness are studied by observing the results of some indexes and comparing them in four different conditions in Parts 1, 2, 3 and 5. Table 55 shows the observed indexes and their corresponding values. In Part 5 of the experiment, the time was fixed for all sections of the game for all the teams. The players generated on average around 8 ideas, which on average 3.5 of them were distinguished as acceptable candidate ideas for the next generation of technical systems. It means that around 42% of the generated ideas covered the desire quality of the game.

To reach this result, the teams on average passed through 4 think stations. The table also shows that around 29% of the generated ideas in the game are not related to the reported think stations by players; this means that players could follow the heuristics and examples of the think station for nearly 71% of the ideas. The self-assessment shows around 19% of errors and misinterpretations of criteria. These observations can support the idea that the game is usable for less professional players than R&D engineers for new target systems, which were the issues of Checks #10 and #11.

No.	Indexes for studying usability and effectiveness of Techno-shift game		Parts of the Experiment #3: Part 1 (game/ R&D engineers/ round 1)		Part 2 (game/ R&D engineers/ round 2)		Part 3 (normal design session/ R&D engineers)		Part 5 (game/ less professional engineers)	
			Average	STD	Average	STD	Average	STD	Average	STD
1	Dedicated time (min)	Take on the board (Table of resources)	9.92	1.44	8.42	2.43			10.00	0.00
		Play on the board (Line of idea generation)	30.00	0.00	30.00	0.00	42.15	5.24	30.00	0.00
		Take off the board (Score card)	14.50	9.06	12.08	7.22			10.00	0.00
2	# passed think stations		7.75	2.01	7.47	2.47	-	-	4.38	1.51
3	# generated ideas		14.42	5.20	13.92	4.60	25.58	7.06	8.50	2.56
4	# candidates		8.25	2.80	10.75	3.49	1.00	0.95	3.63	1.60
5	% candidates respect to total ideas		57.23		77.25		3.91		42.65	
6	% non-related ideas to think stations		22.54		20.96		-	-	29.41	
7	% non-correct self-assessment of candidate ideas		-21.18	23.37	-41.57	21.79	-	-	-19.11	21.82

Table 54 - Observed indexes for studying the usability and effectiveness of the Techno-shift game

Comparison among Part 5 with Parts 1 and 2 shows despite a reduction in the quantity of generated ideas, the percentage of candidate ideas among them is more than Part 1. The self-assessment shows improvements in this type of player which means they have understood better the criteria, or they are very pessimistic about their performance. The percentage of non-related ideas does not show big differences to Parts 1 and 2; this can be interpreted as this type of player follows heuristics.

To approach Check #8, a comparison among Parts 1, 2 and 5 in respects to Part 3 shows the game is more effective in leading target players in generating candidate ideas, in respects to normal design sessions. In other words, although the quantity of generated ideas is more in the design session, the quantity of candidate ideas is more in the Techno-shift game. Effectiveness of the Techno-shift game in respects to the normal design session is more evident in Figure 33.

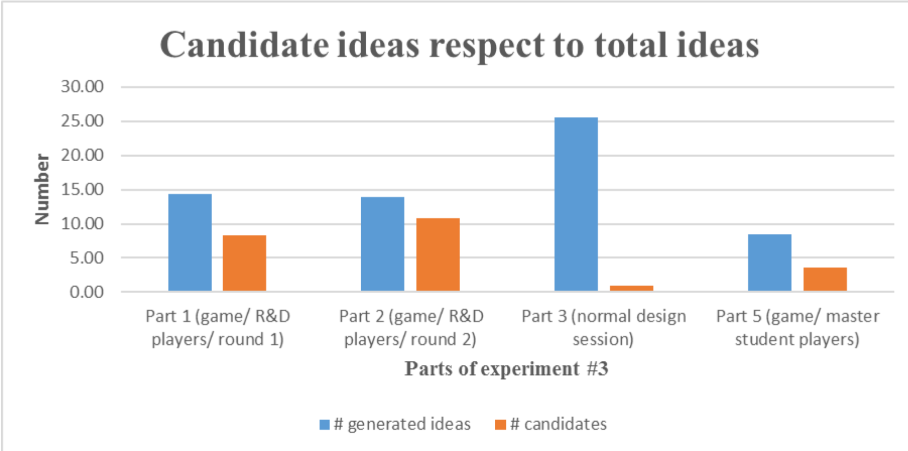


Figure 33 - Effectiveness of the Techno-shift game in respect to the normal design session in terms of the required task

To develop the game, it can be expected to increase the number of total ideas such as normal design session (around 25 ideas) while the most percentage of them are covering the desire quality as the candidate ideas for the next generation of the technical systems.

The robustness which is the issue of check #7, is studied through sub-parts for Part 5 of Experiment #3. Table 56 compares the performance of players in four conditions of full game, game without examples, game without table of resources and game without heuristics.

	Part 5 (game/ Mechanical master student players)										Part 3 (Design normal session/ R&D engineers)	
	Full game		Without examples		Without resources		without heuristics		All			
	Average	STD	Average	STD	Average	STD	Average	STD	Average	STD	Average	STD
# generated ideas	5.50	2.12	8.50	0.71	11.50	2.12	8.50	0.71	8.50	2.56	25.58	7.06
# candidates	2.50	2.83	4.00	0.71	5.00	1.41	3.00	0.71	3.63	1.60	1.00	0.95

Table 55 - Observed indexes for studying the robustness of the Techno-shift game

As the table shows, the performance of players among these four conditions is minimal for full game; while the highest is for the game without the table of resources. This observation can be interpreted as the full game seeming more complicated for players from the beginning, and any trimmings show better performances. Figure 34 shows this comparison graphically.

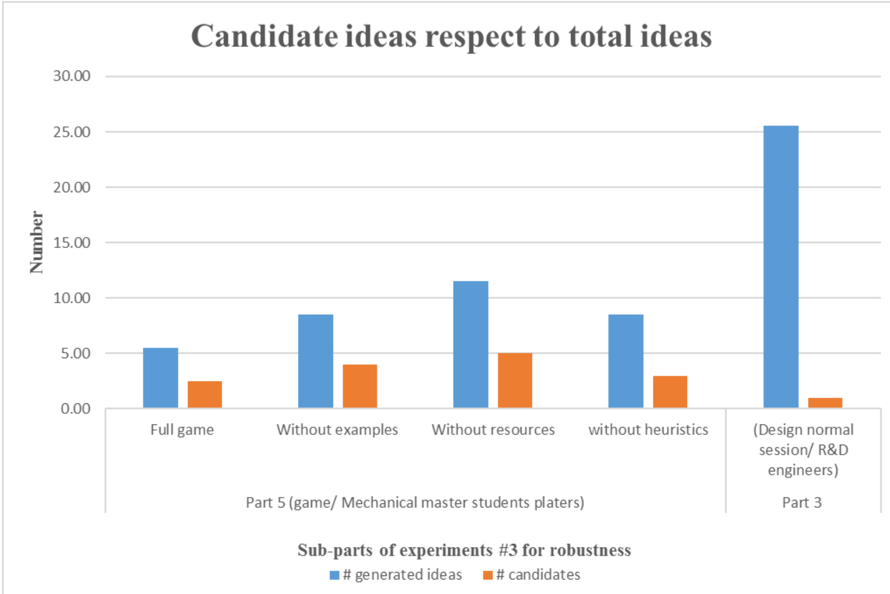


Figure 34 - Robustness and effectiveness of the Techno-shift game in respect to the normal design session in terms of the required task

As Figure 22 shows, the results for all four conditions are not significantly different; the game can be considered as robust in variations of playing incompletely. In addition, all four conditions are more effective in designing the next generation of technical systems than in the normal design session. It is worth considering that the number of teams in each condition is so low, and more studies are needed for a more precise conclusion about the effects of each part of the game on engineers.

3.4. Findings together; discussion and conclusion

Supporting R&D engineers in proposing the next generation of technical systems is the ultimate goal of this research. To approach this goal, a serious game was developed based on the effective heuristics used by R&D engineers in the same task, and effective stimuli on R&D engineers' performances. In the scope of this chapter, the following research question and some corresponding investigations were studied.
Research question # 2: How effective is the developed serious game?
Check #7: Does the developed game work with less elements than configured?
Check #8: Is the developed game more effective than design sessions with the same task?
Check #9: Does the developed game work the same for the same technical system?
Check #10: Does the developed game work the same for any technical system?
Check #11: Does the developed game work the same for different kind of players?
To approach Checks #7 to #11, in total 3 experiments in 5 parts were developed. Parts 1, 2, 4 and 5 are the four parts of the empirical study that the participants play the Techno-shift game; this was developed specifically for promoting players' performance in designing the next generation of technical system. Part 3 is a kind of control group for the whole empirical study; the participants were asked to propose the next generation of target technical systems with their preference methods. Due to the limitations of the research, specifically time and accessibility to the different R&D engineers, Part 3 is not performed again and the information from the previous empirical study for revealing the applied heuristics by R&D engineers (Chapter 3) is used for Part 3 of this experiment. Figure 35 shows players and participants performance of these parts.

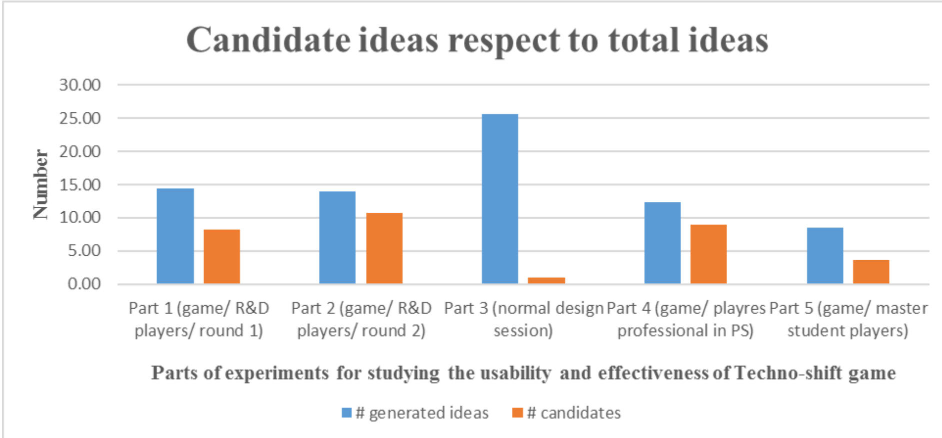


Figure 35 - Effectiveness of the Techno-shift game in respects to the normal design session in terms of the required task

Figure 35 shows that despite the highest observed quantity of generated ideas for Part 3, the quantity of the generated candidate ideas for the next generation of technical systems are more, when the Techno-shift game was played by different kind of players. In other words, in approaching Check #8, in approximately the same duration of time, the effectiveness of the game is higher than the normal design session with used preference methods by R&D engineers. These observations can also support the usability of the developed game as the players were successful on producing ideas according to the requested quality. In comparison among Parts 1, 2, 4 and 5, it can be discussed in approximately the same duration of time; R&D engineers are approximately as productive as problem-solving professional players in generating candidate ideas for the next generation of technical systems, and are more productive than less professional players such as mechanical Masters students. Table 56 shows the percentage of effectiveness of Techno-shift game respect to the normal design session.

Parts of Experiments	# generated ideas	Changes of # ideas respect to Part 3 (%)	# candidates	Changes of # candidates respect to Part 3 (%)
Part 1	14.42	- 43.64	8.25	725.00
Part 2	13.92	- 45.60	10.75	975.00
Part 3 (Control group)	25.58	- 0.00	1.00	0.00
Part 4	12.40	- 51.52	9.00	800.00
Part 5	8.50	- 66.77	3.63	263.00
Ave	12.31	- 51.88	7.91	690.75
STD	2.68	10.48	3.04	303.80

Table 56- The percentage of effectiveness of developed serious game respect to the control group

As the Table 56 shows, the effectiveness of developed serious game in terms percentage of growth in quantity of candidate ideas respect to the control group is almost similar for Parts 1, 2 and 4. For further improvements, it can be considered a possibility of more productivity by the game, as the quantity of Part 3, while around more than 70% of them will be acceptable as candidate ideas like Parts 1, 2 and 4.
Some other information gathered during game play in Parts 1, 2, 4 and 5, or whilst studying the quality of the generated ideas, support studying the usability of the game too; these are the issues of Checks #9, #10 and #11. The number of passed think stations, the percentage of non-related ideas to the game's think stations, and the percentage of non-correct self-assessment of ideas are three indexes for completing the usability study, besides the quantity of generated ideas and quantity of candidate ideas. The number of passed think stations can be interpreted as the possibility to go through the game for idea generation. The think stations which supported players for idea generation are counted as passed think stations. The non-

related ideas to the reported think stations show the misunderstanding and misinterpretation of heuristics and examples of the think stations. The incorrect self-assessment of generated ideas shows there is not enough clarity in the assessment criteria. Figure 36 shows the values of these issues for Parts 1, 2, 4 and 5.

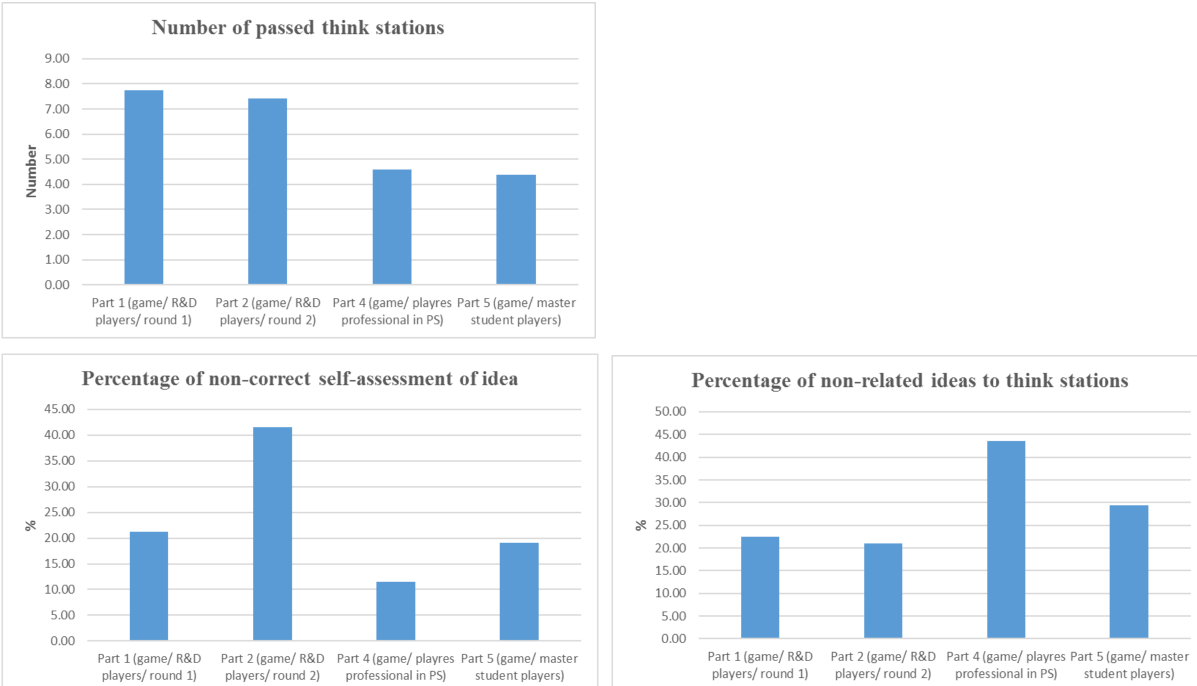


Figure 36 - Studying the usability of the Techno-shift game through some information of playing game

The figure shows that R&D engineers, which were the main target players of the game, passed around 7 think stations in each part, with both more and less professional players passing a less number of think stations. The percentage of non-related ideas to the think stations is less also for Parts 1 and 2; this means in these two parts, not only have the players passed more think stations, they generated more acceptable ideas. It further shows in worst case the non-related ideas to the think stations is around 40%. Both more and less professional players in Parts 4 and 5 showed more non-relation among the think stations and ideas. For the less professional players, the heuristics or examples were not obvious enough, while for the problem-solving professional players, they used their previous knowledge and experiences without considering the think stations precisely. The percentage of incorrect self-assessment also showed less values for more professional players, while in the worst case, the wrong assessment is around 40%. Considering the generated candidate ideas in these four parts (Figure 35) with the values of indexes in Figure 36, Techno-shift is usable; however, some amendments must be pursued.

Additionally, to approach the game's robustness (Check #7), the difference among the results of the game with the same players, while removing some parts of the game, was studied. The full version of the game, the game without examples, the game without the table of resources, and the game without heuristics in the think stations are the four considered versions of the game for this study (Figure 34). The player performance among these four conditions are not significantly different; it is minimal for the full game and it is highest for the game without the table of resources. This observation suggests that the full game seems complicated for players from the beginning, and any trimming shows better performances. It is worth considering that all four conditions are more effective for designing the next generation of technical systems than the normal design session. In total, there is a strong suggestion that further investigation into the usability, effectiveness and robustness of the Techno-shift game, with more player numbers and more studies, is needed.

Chapter 5

Discussion and conclusions

This chapter summarizes briefly the research and proposes some ideas for future studies.

1. Summary of research

This research aims at supporting R&D engineers in designing the next generation of technical systems, as despite the importance of this issue for industries, the models and methods, in addition to supportive strategies and precedents, are not developed enough to be both convenient and improved, as respected for industry usage. In this research, after reviewing the related literature for developing methods and tools, serious game as a completely new tool in this field was selected. The Techno-shift game was developed based on the corresponding literature and some necessary empirical studies in the field. Finally, the effects of the Techno-shift game on the ultimate goal were discussed.

1.1. Scientific and industrial relevance of the topic

In an industry that is changing fast, firms must continually revise their design and range of products. This is necessary due to (i) continuous technological change and development, (ii) their competitors, and (iii) changing customer preference. The next generation of technical systems is a kind of radical innovation with radical technological changes; this substitutes the current version of the system in the market. Interest in radical technological change originated with Schumpeter (1934); one of the first to claim that radical technological change is a powerful mechanism that can challenge the power of monopolists. Schumpeter's main argument was that the nature of radical technological change undermines the very foundation of a large firm's competitive advantage – cost leadership due to large production volumes in an established technology – by rendering the established technology irrelevant. Therefore, distinguishing and developing the next generations of technical systems is important for companies.
Relevant previous research can be searched and studied through research on the next generation of technical systems directly, or through other relevant types of innovations or changes in technical systems, such as breakthrough innovation and radical technological changes, indirectly. Characteristics of the next generation of technical systems can be defined by considering the researches related to innovation, radical innovation, radical technological changes, technology paradigm, technology-push innovation, market-pull innovation, design-driven innovation, breakthrough innovation and radical novelty (Cooper & Schendel, 1976; Dosi, 1982; Coombs et al., 1987; Anderson & Tushman, 1990; Christensen & Rosenbloom, 1995; Tripsas, 1997; Geels, 2004; Verganti, 2008). In total, the next generation of technical systems is a kind of breakthrough innovation (Geels, 2004), which is defined by overlapping characteristics between the outcomes of the technology-push innovation (Dosi, 1982) and design-driven innovation (Verganti, 2008). In other words, the next generation of technical systems is the version of the system consisting of radical technological change and radical meaning change of the system for same or new requirements of existing or new customers. Radical novelty, which is at the core of the next generation of technical systems, is

achieved through re-combining already established elements (Fleming, 2001) or by introducing and bringing in an established element into a new setting (Hargadon & Sutton, 1997; Van de Poel, 2003). It provides a new technological trajectory for solving the system's problems (Dosi, 1982). Radical novelty is a result of resolving a contradiction (Altshuller, 1988).

Literature shows direct researches on the tools and methods for designing the next generation of technical systems. Technology forecasting among future studies, including technology forecasting, technology foresight, technology intelligence, technology road mapping, and technology assessment (Porter & Cunningham, 2004), is mostly used by R&D management to support R&D engineers for predicting the next generation of technical systems. The most general models and methods used to describe and measure the radicalness of innovation are (Dahlin & Behrens, 2005), technology cycles (Anderson & Tushman, 1990), s-curves (Foster, 1985) and technological trajectories (Dosi, 1982; Christensen & Rosenbloom, 1995), hedonic price models (Henderson, 1993), and expert panels (Dewar & Dutton, 1986). For example, technological radical innovation and technological substitution can be described through a technology evolution path by a logistic growth curve (Griliches, 1957). Some of the mentioned methods are more effective in forecasting the time when the current system faces limitations, instead of proposing a new structure concept for the next generation. In other words, most technology forecasting methods show the limitations and problems, and designers must proceed through proposing solutions for them as the next step. TRIZ-based anticipatory methods are the methods of design which are used to propose the structure concept of the next generation of systems. The more developed methods in this field exploit some previous forecasting methods as the base, and then they proceed by guiding designers through templates of an entire class of solutions and use analogy to propose solutions (Cascini, 2012). The mentioned methods use previous precise data of the system to forecast, which is not easy to find in many real projects, especially in a design session for designing the concept of the new technical system. Furthermore, technology forecasting methods are known as time consuming activities. For example, using the FORMAT method takes on average 10-12 sessions, with each session being 2 hours, by different team members; however, the consumed time for methods such as Delfi is far higher than that of the FORMAT method. Finally, it is not convenient for designers and R&D engineers to use the developed methods, as they most are not easy to follow, and they tend to follow the phases in a rather ad-hoc, unsystematic (Cross, 2001) and opportunistic way (Visser, 1990).

Apart from the shortages mentioned in the literature for effectiveness of technology forecasting methods in radical innovation and consequently next generation of technical systems, the nature of technology forecasting methods can be discussed respect to the characteristics of the next generation of technical systems. Considering reviewed literature in technology forecasting methods respect to the reviewed literature in characteristics of next generation of technical system, reveals next generation of technical systems is kind of breakthrough innovation, include new meaning (new message and new requirement) for product, which a radical novelty, by recombining already established elements or bringing in an(/some) established element(s) to the set, can generate it. Therefore, a specific technology forecasting method for anticipating the next generation of technical systems, can start by design issues instead of technology and market issues.

While technology forecasting methods are developed to directly support R&D engineers for designing the next generation of technical systems, this task is still mostly followed in typical design sessions by focusing on improving the characteristics of design proposals, primarily through using effective design heuristics, models and methods. Design heuristics are the sentences (hints and tricks) which serve as a starting point for transforming an existing concept, altering it to introduce variation, or defining variations among individual design elements (Yilmaz & Seifert, 2011). In general, each discovered strategy or usage of precedents, as the result of previous researches in design cognition field, can be considered as a potential concept for a strategy-based or precedent-based heuristic to be suggested and prescribed to the designers. Design strategies are the most appropriate suggestions for sequences and patterns of sequences, the time dedicated to problem formulation and solution generation, and the rate of transitions among them in respect to the requested task (Lawson, 1979; Visser, 1990; Akin & Lin, 1995; Ball & Ormerod, 1995; McNeill et al., 1998; Atman et al., 1999; Cross, 2001). Knowledge of the different time scopes of the target system, or the hierarchy of related system to the target system (Pasman, 2003; Lawson, 2004; Eilouti, 2009), is a part of precedents; while the knowledge of any other system (Marslen-Wilson & Tyler, 1980; Jansson & Smith, 1991; Purcell & Gero, 1992; Smith et al., 1993; Dunbar, 1997; Benami & Jin, 2002; Nijstad et al., 2002, Tseng et al., 2008; Mak & Shu, 2008; Helms et al., 2009; Weisberg, 2009, Linsey et al., 2010; Chan et al. 2011; Fu et al., 2013; Gonçalves et al., 2013; Moreno et al., 2014) and also knowledge of design methods and tools (Archer, 1968; Booz et al., 1968; Radcliffe & Lee, 1989; Fricke, 1993; Fricke, 1996; Basadur et al., 2000; Shneiderman, 2000; Kryssanov et al., 2001; Howard et al., 2008) are the other parts of precedents. Literature is not so rich in studying the effects of heuristics on design proposals in general. Despite the derived design heuristics for technical novelty, there is no specified research in design heuristics for the next generation of technical systems.

As discussed above, despite the importance of the next generation of technical systems for industries, the current tools and methods developed for forecasting and designing the next generation of technical systems, are not mature enough for supporting R&D engineers.

1.2. Innovative feature of research

Developing a serious game to approach the ultimate goal of the research (i.e. improving R&D engineer performance in designing the next generation of technical systems) is the main innovative feature of the research, though other novelties are pursued in this research.

The idea of playing a game dates back to the ancient past and is considered an integral part of all societies. Today serious games are used for professional learning and social networking, where knowledge sharing is performed easily. There are researches referring to the effectiveness of serious games in learning (Rieber, 1996; Bellotti et al., 2003; Hong & Liu, 2003; Squire & Jenkins, 2003; Kirriemuir & McFarlane, 2004; Mitchell & Savill-Smith, 2004; Connolly et al., 2007; Angehrn et al., 2009; Connolly et al., 2012; Islas Sedano et al., 2013; Wendel et al., 2013; Wouters et al., 2013; Mayer et al., 2014). Many reasons are discussed for using serious games for learning and self-learning, among which, three are more popular. Firstly, the thinking patterns of learners today have changed, and today's students are native speakers in the language of digital media. This new form of digital entertainment has shaped their preferences and abilities and offers an enormous potential for their learning, both as children and as adults (Prensky, 2001). Secondly, using the latest simulation and visualization technologies, serious games allow learners to experience situations that are impossible to be experienced in the real world for reasons of safety, cost, time, etc. (Squire & Jenkins, 2003; Corti, 2006; Jarvis & de Freitas, 2009; Kincaid et al., 2009). Thirdly, exploiting the latest simulation and visualization technologies, serious games are able to contextualize the player's experience in challenging, realistic environments, supporting situated cognition (Watkins et al., 1998); this means the players exercise freedom that can complement formal learning by encouraging learners to explore various situations (Klopfer et al., 2009), with limited barriers of monitoring, space and time. Although studies discuss the advantages of exploiting serious games in fields such as management, defense and healthcare, marketing, education (Zyda, 2005), no serious game has been developed in the field of engineering design. In architecture and design, some existing computer games such as Tetris are used as a means of developing student confidence and abilities in spatial modelling, design composition, form creation, enhancing town planning and capacity for mental rotation (Radford, 2000; De Lisi & Wolford, 2002; Coyne, 2003).

Research shows the companies follow focusing on future key technologies by keeping recent developments of technologies under surveillance, often via organizing taskforce teams. This approach is expert-centric, time-consuming and labor-intensive as markets shift rapidly, technologies proliferate unceasingly, and thus innovation cycles become shorter (Lee & Sukoco, 2013). Considering the effect of intensive work in taskforce teams, the success of a radical innovation requires multiple facilitators within and across organizational boundaries. Knowledge sharing and unlearning are two important subjects discussed in research for increasing organizational capabilities, and those of work groups and taskforce teams, in proposing innovation. Knowledge is widely considered as a valuable organizational resource that is central to sustaining and improving an organization's product or service offerings, customer base, market share, innovation and competitive position in the industry. Unlike other organizational resources, knowledge typically resides in the minds of workgroup members and is only invoked during use. Such knowledge, when sharing processing, and utilizing such as ideas, models, and decisions, can create organizational value by reducing the needs of information search and processing among collaborating workers; this makes them more efficient and effective in achieving their job goals (Konstantinou et al., 2009; Geiger et al., 2011). As knowledge sharing enables the sharing of relevant experiences and information between workgroup members (Lin & Joe, 2012), it is therefore important for workgroups to improve knowledge sharing so as to ultimately achieve their goals. The competitive position and effectiveness of workgroups are likely undermined in the case of a lack of knowledge sharing (Lin, 2007). A key driver of knowledge sharing in workgroups is social capital, referring to the features of social organizations that facilitate coordination and cooperation among workgroup members (Putnam, 1995). Over the last decade or so, the concept of social capital has captured the attention of sociologists (Coleman, 1988; Putnam, 1995) and organizational theorists (Nahapiet & Ghoshal, 1988) as a way of understanding why people in social communities, workgroups, and organizations share knowledge, ideas, and support with each other, even when there is no legal obligation or expectations of personal gains from doing so. The social network perspective provides an interesting explanation about how inter-organizational relationships affect innovation (Subramaniam Venkatraman, 2001). Social relations positively affect radical innovation, whereas the forgetting dimension has a negative effect (Yang et al., 2014). Unlearning is considered as organizational unlearning, which refers to the discarding of old routines and past knowledge or skills to make way for new ones, if any (Tsang et al., 2008). Scholars have proposed that unlearning, a process of ridding an organization of certain things, can facilitate the ability to adapt to a new environment and produce innovations (Akgün et al., 2006; Tsang & Zahra, 2008).

In addition, design heuristics can be studied as cognitive heuristics (Nisbett & Ross, 1980) that are captured in the designer’s memory, or heuristics are applied in design proposals (Yilmaz & Seifert, 2011). Cognitive research shows that experts utilize heuristics effectively, and this skill distinguishes them from novices (Klein, 1998). Expert designers apply cognitive heuristics in order to improve the variety, quality, and creativity of potential designs, though they mostly use them unconsciously. Experienced designers use strategic knowledge while do not identify their strategic knowledge (Kavakli & Gero, 2002). This pattern fits with findings on the application of procedural skills (Anderson, 1982) and supports the opinion that the heuristics must be so well learned to be used as procedural skills, because conscious access to their content is limited. A Research also shows that novices are provided heuristics for creating new concepts, they are able to apply heuristics easily to a simple product design task, and that the usage of heuristics increases the creativity of concepts (Yilmaz & Seifert, 2011).

Considering the effects of social networking and other organizational factors on the capabilities of R&D teams in knowledge sharing and un-learning (which are crucial for focusing on future key technologies), the effects of serious game on social networking, and the simplicity of usage and learning heuristics by professionals and novices, it seems logical to develop a serious game for improving R&D engineers’ performance in designing the next generation of technical systems, through using effective heuristics of strategies and precedents.

To develop the mechanics of the Techno-shift game, an empirical study was done through protocol analysis mostly to highlight the skills of R&D engineers to exploit their knowledge and experiences through design heuristics. A set of criteria for assessing candidate ideas, a coding scheme to highlight the used heuristics by R&D engineers, and a set of stimuli for improving the R&D engineers’ performance in designing the next generation of technical systems, became the three main other innovative features of the research. The next generation of technical systems is a kind of breakthrough innovation (Geels, 2004), which is defined by overlapping characteristics between the outcomes of the technology-push innovation (Dosi, 1982) and design-driven innovation (Verganti, 2008). In other words, the next generation of technical systems is the version of the system consisting of radical technological change and radical meaning change of the system for existing or new customers. Radical novelty, which is at the core of the next generation of technical systems, is achieved through re-combining already established elements (Fleming, 2001) or by introducing and bringing in an established element into a new setting (Hargadon & Sutton, 1997; Van de Poel, 2003). It provides a new technological trajectory for solving the system's problems (Dosi, 1982). Radical novelty is a result of resolving a contradiction (Altshuller, 1988).

The set of criteria for assessing the candidate ideas are developed by considering the general criteria of assessing design proposals as the main criteria and the target characteristics as the sub-criteria. Quantity (Nijstad et al. 2002; Shah et al., 2003; Perttula & Sipilä, 2007) and quality (Wierenga & Van Bruggen, 1998; Shah et al., 2003) are the two main criteria; though quality is divided into novelty, technical plausibility and relevance. Novelty is the main characteristic of the next generation of technical systems. Potential feasibility even beyond current technical knowledge, without violating established physical laws, is considered as being technically plausible. The usability of the idea for a group of people within society as customers, and the degree of sensibility of them to the proposed idea is considered as relevance. Each criterion is divided into 4 levels; only levels 3 and 4 are considered as acceptable quality for the next generation of technical systems.

Correspondingly, it is expected that R&D engineers could search and add these traits to the target system. To study the corresponding skills in R&D engineers, a content-oriented coding scheme developed. Most content-oriented coding schemes separate the sentences related to an idea from the discussions that support that idea (Schön, 1983; Oxman, 1990; McGinnis & Ullman, 1992; Visser, 1995; Dorst & Dijkhuis, 1995; Chi, 1997; Sowa, 2006). An idea is classified and studied through the corresponding problem, suggested concept and suggested form. The supportive discussion is also classified as the parts related to the requested requirements by the design task, the potential appropriate knowledge and previous experiences for formulating and solving the problems (episodic knowledge), and the analysis of the appropriateness of the suggested knowledge (semantic knowledge). On the other hand, the most promising spaces for design as creative problem-solving (Akin, 1978; Thomas & Carroll, 1979) is described by a multi-screen model, also called the system operator model and powerful thinking schema (Altshuller, 1988). This model is established based on the three dimensions of system hierarchy, time, and interfaces of anti-systems for describing promising spaces (Khomenko & Ashtiani, 2007). Therefore, an appropriate coding scheme was developed by considering multi-screen thinking and the general characteristics of content-oriented coding schemes. Nature of speech with five-sub classes, time horizon with three sub-classes and system hierarchy with six sub-classes, are the dimensions of the developed coding scheme for clarifying the precedent-based heuristics applied by R&D engineers, in designing the next generation of technical systems. According to the sub-classes of these dimensions of the developed coding scheme, 90 combinations can be developed as heuristics.

In addition, there is no related information in the literature about R&D engineers' performance in designing the next generation of technical systems, though the effects of different kinds and forms of stimuli on the quantity and novelty of design proposals are studied. Among the different forms of stimuli, examples are more used as stimuli as it can be applied for increasing the number of ideas for the next generation of technical systems. The studies show that despite some doubts about the positive effects of examples on the quantity and novelty of design proposals (Jansson & Smith, 1991; Purcell & Gero, 1992; Smith et al., 1993; Mak & Shu, 2008; Helms et al., 2009), they are positively effective (Dunbar, 1997; McKoy, 2001; Nijstad et al., 2002; Ishibashi & Okada, 2006; Tseng et al., 2008; Weisberg, 2009; Linsey et al., 2010; Chan et al., 2011; Fu et al., 2013; Gonçalves et al., 2013; Moreno et al., 2014). On the other hand, examples are a kind of singular representation of precedents and it can be suggested and studied that using examples as some structural representation forms of precedents can be more effective as structural representations seem more effective in increasing both quantity and quality (Luchins, 1942; Marslen-Wilson & Tyler, 1980; Oxman 1990; Lane & Jensen, 1993; Liikkanen & Perttula, 2006; Zahner et al., 2010; Goldschmidt, 2011; Howard et al., 2013; Doboli & Umbarkar, 2014). Additionally, a pictorial representation of the precedents is positively effective in increasing novelty (McKoy, 2001); it can therefore be recommended that one form of stimuli for increasing candidates for the next generation of technical systems is by composing three previous findings in the form of pictorial representation of examples, for one form of structural representation of precedents. Previous solutions are another form of precedents; studies show this form of precedents is also effective in increasing novelty and diversity if they are presented with more diversity and ambiguity (Benami & Jin, 2002; Nijstad et al., 2002; Simonton, 2010); however, there is some doubt about their influence on novelty or if it can even reduce novelty (Jansson & Smith, 1991; Smith et al., 1993; Doboli & Umbarkar, 2014). It is also discussed that novel artworks are positive in increasing novelty. Therefore, one other appropriate form of stimuli can be considered - a combination of novel artwork, previous solution and examples with more diversity and ambiguity. Examples of a simple and summarized evolution tree of 5 technical systems are called trends (Mann, 1999; Domb, 1999; Sawaguchi, 2001; Zlotin & Zusman, 2001; Domb, 2003). An abstract of the 5 patents related to cooling or any part of fridge are called patents; they are considered as the final form of proposed stimuli for the experiment. As mentioned, the effects of these stimuli were studied in comparison to a control group and a group which received an engineering procedure as another form of stimuli. It is believed that mature engineering procedure can lead users straight to the target.

1.3. Methodological approach

This research proposes developing a special serious game for supporting R&D engineers in designing the next generation of technical systems. Based on the discussed characteristics for the next generation of technical systems in the literature and also capability of professional designers to exploit their available knowledge and resources in the form of precedent-based heuristics while designing, the idea is that the game supports R&D engineers to exploit their available knowledge and experiences which are useful and effective in designing the concept of next generation of the technical systems. Therefore, it is expected the game focuses on increasing the R&D capabilities in proposing design-driven innovations which are technically new, preferably their technical plausibility is checking after generating the concepts. Two main research questions and some investigations were defined for the whole research in order to reach this goal.
Research question # 1: How should the serious game for promoting R&D engineer's performance in designing the next generation of technical systems be structured?

Check #1: What are the average R&D engineers' performance in terms of the quantity of total generated ideas, the quantity of candidate ideas, the quantity of ideas with acceptable degree of novelty, the quantity of ideas with acceptable degree of technical plausibility, and the quantity of ideas with acceptable degree of relevance for the next generation of the technical systems?

Check #2: What are the effects of suggestive stimuli on the R&D engineers' performance in terms of the same indexes mentioned in Check #1, while the suggestive stimuli are proposed according to the most effective stimuli of the quantity and quality of design sessions mentioned in literature?

Check #3: How many different heuristics are used by designers to propose the next generation of technical systems (skills)?

Check #4: Which heuristics are used more by designers to propose the next generation of technical systems (active skills)?

Check #5: Which heuristics used by designers are more effective than the others (effective skills)?

Check #6: What are the effects of suggestive stimuli on the heuristics used by R&D in proposing the next generation of technical systems?

Research question # 2: How effective is the developed serious game?

Check #7: Does the developed game work with less elements than configured?

Check #8: Is the developed game more effective than design sessions with same task?

Check #9: Does the developed game work the same for the same technical system?

Check #10: Does the developed game work the same for any technical system?

Check #11: Does the developed game work the same for different kind of players?

With these research questions in mind, this research proceeded in the following way. The first step was to review the literature highlighting the characteristics of the next generation of technical systems, the shortcomings of technology forecasting methods and design heuristics in supporting R&D engineers for designing the next generation of technical systems. A review then took place of the approaches of developing serious games, in order to identify the main mechanics and descriptors to be considered. To acquire the necessary information for the main mechanics and descriptors of target serious games, design cognition approaches in deriving design heuristics were studied. The study then designed and performed a set of empirical studies to look at the effects of some mentioned design heuristics in the literature and some new design heuristics, in respects to the desired target task. To perform the empirical studies through protocol analysis, a coding scheme and a set of criteria to evaluate the acceptable ideas as candidates for next generation of technical systems were constructed. In next step, according to the results of the empirical studies, the serious game for supporting R&D engineers in designing the next generation of technical systems was developed.

The game mimics the production line of industries and starts with the 'Table of resources' and then follows through the 'Idea generation line', where the player can propose new ideas by means of the 'Think stations and design heuristics', the 'Tips and tricks', the 'Examples for creativity stimulation' and the 'Idea cards'. Eventually, the game finishes by summarizing and assessing the results through completing the 'Score card'. Finally, the effectiveness, usability and robustness of the proposed serious game were studied in a set of empirical studies.

2. Achievements of objectives

As mentioned in previous section, the ultimate aim of current research was pursued through two main research questions and eleven checks and investigations. In other words, the responds for each main research question is followed through some other checks based on some assumptions. On the other hand, there are some expectations beyond research questions, which let reflections on existing theories after studying the research questions and corresponding checks.

In total, two expectations can be highlighted beyond the research questions whereas each one can be followed in different levels. Possibility to design systematically a serious game specifically for a design task for target players from the domain of design proficiency, and level of success of the developed serious game respect to the other most applied tools in the field, are the two expectations beyond the research questions of the current research.

Reflecting and discussing on the possibility of following a systematic approach in designing a specific serious game for a target design task for target players in the field of design, is the first expectation of the current research. This expectation can be stated as two following levels which the level 2 is wider and more comprehensive that the level 1:

> Level 1: Possibility to design a serious game systematically specialized for proposing the concept of the next generation of technical systems by R&D engineers as one example of various design task expected from special kind of engineering design proficiency;
>
> Level 2: Possibility to design serious games systematically for any target design task for any target players from the domain of design proficiency;

Reflecting on the level of success of the developed serious game, is the second expectation beyond current research. This expectation can be followed in three following levels:

> Level 1: Success ability of a developed serious game respect to target players' performance;
>
> Level 2: Success ability of a developed serious game respect to target players learning;
>
> Level 3: Success ability of a developed serious game respect to the expectation of the society of target players;

The current research is going to reflect in just some of the above mentioned levels based on the type and domain of empirical studies to respond the corresponding checks to these expectations. Table 57, highlights the level of each expectation, relation of them with the eleven checks of the research, the possible approaches to study and reflect on them, and the scope of current research for each level.

<table>
<tr><th>Expectation</th><th colspan="2">Expectations beyond the research question</th><th>Overall possible approaches to respond the expectations</th></tr>
<tr><td rowspan="2">#1</td><td>Level 1</td><td>A systematic approach for designing:
- a serious game for proposing the concept of the next generation of technical systems as one example of various design task
- for R&D engineers as special kind of engineering design proficiency
- to be played for learning and fun between the serious tasks or voluntary as part of serious tasks</td><td>-Applying LM-GM for designing the serious game;
- Capturing and applying the following information for learning mechanics:
• Common characteristics of R&D engineers and their workspaces;
• General required skills of designers for designing;
• Specific required skills of R&D engineers for designing the next generation of technical systems (Checks #3 to #5);
• Specific performance of R&D engineers in designing the next generation of technical systems (Checks #1);
• The most effective stimuli on the skills & performance of R&D engineers in the same task (Checks #2 & #6).
- Studying the usability and robustness of the developed serious game (Checks #7 to #11)</td></tr>
<tr><td>Level 2</td><td>A systematic approach for designing:
- serious games for any target design task
- for any target players from the domain of design proficiency
- to be played as part of serious tasks accompany with learning and fun</td><td>- Applying LM-GM for designing the serious game;
- Capturing and applying the following information for learning mechanics:
• Common characteristics of target players in the field of design proficiency and their workspaces;
• General required skills of designers for designing;
• Specific required skills of target players for target design tasks;
• Specific performance of target players in performing target design tasks;
• The most effective stimuli on the skills & performance of target players in target design tasks.
- Studying the usability and robustness of the developed serious game</td></tr>
<tr><td rowspan="3">#2</td><td>Level 1</td><td>Success ability of a developed serious game respect to the target players' performance</td><td>- Applying the developed serious game for target design task whereas comparing the results with other most applied tools for the same task in the field (Checks #8 to #11)</td></tr>
<tr><td>Level 2</td><td>Success ability of a developed serious game respect to the target players learning</td><td>- Applying the developed serious game for target design task whereas comparing the results of doing the same task without game or any other tools for the same target players after various round of playing the game</td></tr>
<tr><td>Level 3</td><td>Success ability of a developed serious game respect to the expectation of the society of target players</td><td>- Applying the developed serious game for target design task in the serious tasks whereas comparing the results with the routine situation in the workspace</td></tr>
</table>

Table 57- The expectations beyond research questions to reflect on the existing theories

The current research is going to the study the first level of each expectation and reflect on the existing theories in these two levels. In addition, based on the results of studies on level 1 of Expectation 1, the reflection of corresponding theories will be discussed. Therefore, in this section, after reviewing the results of empirical studies on each check, the reflection on the theories of defined levels in Table 57 will be discussed.

2.1. Possibility of designing a serious game for a specific design task through a systematic approach

As mentioned in Table 57, possibility of designing a serious game for a specific design task through a systematic approach, is the first expectation beyond the research questions of the current study. This expectation consists of two concepts, possibility of designing the game systematically and workability of the game. This expectation can be followed in two levels. The level 1 was studied in the scope of current research, whereas, based on the results of the level 1, some reflections can be done for the level 2. LM-GM model was applied for designing a serious game and it was decided to capture and apply R&D engineers' skills and performance to pursue the LM-GM model systematically. The R&D engineers' performance and the effects of some promising stimuli on them were studied through Check #1 and #2. The R&D engineers' skills and effects of the same stimuli on them were studied through Checks #3, #4, #5 and #6 of the research. Workability of the developed game, was studied through Checks #7 to #11. To approach the checks #1 to #6, a two part-design session was performed. The normal R&D engineers' performance and skills were studied in the first session, and the effects of the suggested stimuli on their performance and skills, were studied in the second session. To approach Checks #7 to #11, three experiments in five parts, were done to study the usability and robustness of the developed game. Table 58, summarizes the results of empirical studies corresponding to the first expectation and some general reflections on existing theories. The complete versions of observations were discussed in the Chapters 3 and 4.

<table>
<tr><th>Levels of expectation #1</th><th>Followed systematic approach for the study</th><th colspan="2">Observed results & reflections on the theories</th></tr>
<tr><td rowspan="2">Level 1:
A systematic approach for designing:
- a serious game for proposing the concept of the next generation of technical systems as one example of various design task
- for R&D engineers as special kind of engineering design proficiency
- to be played for learning and fun between the serious tasks or voluntary as part of serious tasks</td><td rowspan="2">-Applying LM-GM for designing the serious game
- Capturing and applying the following information for learning mechanics</td><td>Common characteristics of R&D engineers and their workspaces</td><td>Results:
- R&D engineers; engineering or design field
- who are responsible for improving and controlling product of production line in the workshops
Reflections:
-</td></tr>
<tr><td>General required skills of designers for designing</td><td>Theories:
- Designers apply design strategies and design precedents in designing
- Protocol analysis is used for studying design strategies and design precedents
Results:
Design strategies:
Start designing:
- co-evolving problem & solution
- using previous solutions
-reframing the problem by resetting the boundaries
Pursue designing:
- scrapping initial solutions
-reframing five times periodically
-rapid alternation in design moves
Design precedents:
Episodic/ Searching knowledge of:
- different time scope of target system
- any other system
Semantic/ Analyzing, generalizing & performing analogy for searched episodic knowledge:
- based on characteristics of problems
- based on characteristics of solutions
- based on domain distance of analogy
Reflections:</td></tr>
</table>

		It was possible to highlight the general required skills of designers in abstract level in two classes of applied strategies and applied precedents by reviewing literature
	Specific required skills of R&D engineers for designing the next generation of technical systems;	**Theories:** - Experts apply heuristics in designing - Heuristics are studied through analyzing the design proposals by experts **Results:** **Design heuristics:** - 12 combinations of 30 combinations of codes on dimensions of nature of speech and system hierarchy that can be reported in the abstract level as: - analyzing the requirements of users & objects - searching co-systems & similar systems for novel traits - Pattern searching and generalizing the novel traits of other systems for customizing in the target system (the equality between dedicated time to the present and future in the scope of time horizon, let to decrease the 90 combination of codes to 30) - engineering procedure and then trend are effective in increasing the usage of heuristics by R&D engineers **Reflections:** - It was possible to capture the heuristics applied by R&D engineers by coding scheme of nature of speech, time horizon, system hierarchy through a protocol analysis instead of analyzing the design proposals - Engineering procedure guides R&D engineers to the promising spaces, but it is not successful in supporting them for the requested final results
	Specific performance of R&D engineers in designing the next generation of technical systems;	**Theories:** - Rate of idea generation is relatively constant throughout the first 30 min and around 0.7 on average - 75% of the appropriate ideas in the first 30 min occurred before 15 min which is the half of the session **Results:** **Managing time:** - Overall tolerable time: 42.15 min (5.24 STD) - Searching time (episodic): 8.28 min (2.09 STD)/ 20% - Analyzing time (semantic): 20.67 min (4.67 STD)/ 50% - Idea description time: 8.74 min (2.60 STD)/ 10% - Interpreting design task: 2.90 min (2.01 STD)/ 10% **Performance:** - # generated ideas: 25.58 (7.06 STD) - # candidate ideas: 1.00 (0.95 STD)

			- Team productivity: 0.62 (0.2 STD), 89% were generated before 22.5 min which is the half the considered time for a design session - Team effectiveness: 3.9% (12 candidates out of 307 ideas in first session) - % of acceptable ideas in terms of novelty: 23% - % of acceptable ideas in terms of technical plausibility: 75% - % of acceptable ideas in terms of relevance: 75% **Reflections:** - Rate of ideas generation and percentage of acceptable ideas are similar to the literature - It was possible to highlight the characteristics of the next generation of technical systems by reviewing the literature - It was possible to develop set of criteria for assessing the candidate ideas for the next generation of technical systems by covering the characteristics of the next generation of technical systems in the three main applied criteria for assessing design proposals - It is needed to improve the explanations of sub-criteria as the agreement among experts were low
		The most effective stimuli on the skills & performance of R&D engineers in the same task.	**Theories:** - Structural presentation of precedents are more effective in increasing the novelty of ideas than singular presentation - Examples are effective on increasing quantity and novelty of ideas while there are some doubts about it - pictorial representation of examples increase the novelty of ideas **Results:** - Examples of trends of evolution of some technical systems as a stimulus is more effective in influencing the R&D engineers' performance in terms of total quantity of generated ideas, quantity of ideas with acceptable degree of technical plausibility and relevance, and also compensating more than the other stimuli in terms of quantity of ideas with acceptable degree of novelty. **Reflections:** - Another proof for some effective precedents in improving the novelty of design proposals as the trend as a stimulus is composed of following concepts which each one were discussed in the literature as an effective precedent on improving the novelty of design proposals: - structural representation of precedents (templates describing entire class of solutions) - pictorial representation of examples - Some tricks for resolving contradictions
	- Studying the workability of	The usability of the game by checking the results on:	**Theories:**

	the developed game	- Three type of players in 4 parts; R&D engineers, engineering master students, problem-solving professionals - Various target systems; same as the system was applied in the protocol analysis for extracting heuristics, free target systems	- Suggestive time for completing the table of resources based on the time of searching precedents in protocol analysis: 10 min - Suggestive time for idea generation through line of generation of ideas and think stations based on the time of semantic precedent and idea description: 30-45 min - Suggestive quantity of candidates based on the best performance of the teams participated in protocol analysis: at least 3 **Results:** For 37 teams all together with the same and different target system: - Time of table of resources: 9.46 min (1.73 STD) - Time of line of idea generation: 30.00 (0 STD) - Time of score card: 12.14 (6.67 STD) - # generated ideas: 12.70 (5.03 STD) - # candidate ideas (expert opinion): 6.22 (3.15 STD) - # passed think stations: 6.49 (2.51 STD) - % non-related ideas to the think station: 25.46 (15.81 STD) - % incorrect self-assessment: 25.77 (23.31 STD) Whereas considering the result was the best for R&D engineers which are the main target players. **Reflections:** The developed serious game is usable as: - Different players with various experiences in design could follow the game in the suggestive time; - They generate candidate ideas 600% on average more than normal design session in same amount of time; - They had misinterpretation about think stations just around 25% on average; They had incorrect self-assessment only around 25% on average;
		The robustness of the game by checking the results on: - Three different version of the game which in each one, a component of game is missing respect to the full version of the game	**Results:** - The performance among the four versions was not significantly different - The performance is minimal for the full game and highest for the game without the table of resources **Reflections:** It can be interpreted that the full game is complicated for players from the beginning, and that any trimming shows better performances.
Level 2: A systematic approach for designing:	-	-	**Reflections:** It seems that it is possible to:

- serious games for any target design task - for any target players from the domain of design proficiency - to be played as part of serious tasks accompany with learning and fun		- capture the target players' skills and performance (both general and specific respect to the various design tasks) through literature review and protocol analysis & - Apply highlighted players' skills and performance for designing systematically a specific serious game for a specific design task

Table 58- Reflections on the existing theories corresponding to the first expectation

The observations and findings of all relevant checks to the first expectation are summarized in the last column of Table 58. Beyond all findings, it seems promising to apply target players' performance and skills to design a serious game systematically for a design task according to the LM-GM model.

2.2. Possibility of applying a serious game for a specific design task

As mentioned in Table 57, possibility of applying a serious game for a specific design task, is the second expectation beyond the research questions of the current study. This expectation can be followed in three levels. The level 1 was studied partially in the scope of current research, whereas, the scope of the research didn't let to go further in the second and third levels. Effectiveness of the developed serious game was studied to check the possibility of applying the serious game instead of the other tools for the same design task. Effectiveness of the developed game, was studied through Checks #8 to #11. To approach these checks, three experiments in five parts were performed. Table 59, summarizes the results of corresponding empirical studies and some general reflections on existing theories. The complete version of observations was presented in the Chapter 4.

Levels of expectation #2	**Followed systematic approach for the study**	**Observed results & reflections on the theories**
Level 1: Success ability of a developed serious game respect to the performance of target players	- Studying the effectiveness of the game by checking the results on: - Three type of players in 4 parts respect to a control group; R&D engineers, engineering master students, problem-solving professionals - Various target systems; same as the system was applied in the control group, and free target systems	**Results:** - # generated ideas for the 12 teams of the control group: 25.58 (7.06 STD) - # generated ideas for the 37 teams played the game: 12.70 (5.03 STD) # candidate ideas for the 12 teams of the control group: 1.00 (0.95 STD) - # candidate ideas for the 37 teams played the game (expert opinion): 6.22 (3.15 STD) - Despite the highest observed quantity of generated ideas for the control group, the quantity of candidate ideas is more for the Techno-shift game which was played by a different kind of players - Effectiveness for the teams **Reflections:** - It seems promising to design and use serious games for design tasks
Level 2: Success ability of a developed serious game respect to the learning of target players	-	-
Level 3: Success ability of a developed serious game respect to the expectation of the society of target players	-	-

Table 59- Reflections beyond second research question on the existing theories

The observations and findings of all relevant checks to the second expectation are summarized in the last column of Table 59. Beyond all findings, it seems promising to design and apply a serious game for some of specific design task. The game must be designed based on the required skills of target players' performance and skills for the target design task which are observed systematically as the performance and skills of professional designers in the same task.

3. Limitations of research and complementary studies

The empirical studies in the scope of this research were undertaken in two groups, each having their limitations. The first studied R&D engineers' performance and skills in designing the next generation of technical systems and the second studied the Techno-shift game's usability, effectiveness and robustness. The limitations are mostly related to the available resources, though some of them can be discussed in relation to approaches and tools used for observing the desired events. Therefore, some limitations can be removed by undertaking more expanded studies and for others, some new approaches for observing and some new tools can be proposed. Furthermore, this research's limitations can be discussed from a wider perspective while studying the reasons for developing a serious game for increasing R&D engineers' performance in designing the next generation of technical systems. In the following sections, limitations and some complementary and new approaches are discussed for each one of three mentioned groups.

3.1. Limitations in developing a serious game for improving R&D engineers' performance in designing the next generation of technical systems

Promoting R&D engineers' performance in designing the next generation of technical systems is the ultimate objective of the current research. Developing and applying a specific serious game was pursued to approach this objective. Although the results are positive, there are other possible approaches to the desired objective. In the scope of this research, improving R&D engineers' performance is followed by improving the necessary skills through a serious game. This approach is a kind of indirect training. Direct training of required skills for designing the next generation of technical systems, specific engineering method development, the improvement of normal design sessions by different kinds of creativity stimulation, or the provision of necessary and complementary resources, are some of the other possible approaches to the target objective. The Techno-shift game approaches the objective through improving the required skills, while some of the other approaches address the objective directly. Usually direct approaches are more tangible and convenient. Indirect approaches to the target objective, such as training directly and indirectly required skills, are more time consuming but they are more stable in long-term periods. In other words, for long-term expertise on the subject, improving required skills is considered more trustworthy. Despite the positive results of the Techno-shift game on R&D engineers' performance in designing the next generation of technical systems, it is worth considering this approach as a kind of indirect approach, and like any indirect approach, it suffers some limitations. Behind any indirect approach, there is an opinion about the relationship between two variables, which should be studied too. In the scope of this research, the positive relationship between R&D engineers' performance and their skills were not studied; it is worth considering this for future research.

3.2. Limitations in observing R&D engineers' performance and skills and some suggestions

Content-based protocol analysis as a whole approach, a set of criteria for assessing candidate ideas for the next generation of technical systems, a coding scheme for revealing the used heuristics by R&D engineers in designing the next generation of technical systems, approximate characteristics of R&D engineers and number of teams of R&D engineers, groups of experts and the target system as the initial task were developed and selected approaches and tools for studying the R&D engineers' performances and skills. The limitation of this part of the research can be discussed in relation to each of these developed approaches and tools. Table 54 shows the conditions of developed and selected tools, with some suggestion for further studies.

No.	Issue to be observed in designing the next generation of technical systems	Performed in the scope of the research		Suggestive modifications or complementary observations for future studies	
		What was observed	Tools & resources	What to be observed	Tools & resources
1	R&D engineers' performances	Time	- Time of shot lists	-	-
		# Ideas	- Selecting description of ideas from the speeches in the protocols - The written texts and pictures on the papers by R&D engineers	-	- Involving more R&D engineers in the study for more strong observations - Asking R&D engineers to write and draw their ideas
		# candidate ideas	- Developing and applying set of criteria (novelty, technical plausibility, relevance) - Assessing description of ideas (transcribed protocols) by 3 European experts	-	- Assessing claimed texts and pictures of ideas by 3 experts - Assessing the ideas by Iranian experts to consider also culture for the criterion of relevance - Comparing results with known methods of assessing novelty and variety
2	Effects of some stimuli on R&D engineers' performances	Time	As corresponding item in 1 (rows above)		
		# Ideas			
		# candidate ideas			
3	R&D engineers' skills	Time dedicated to different heuristics	- Developing and applying a coding scheme for revealing heuristics (nature of speech, system hierarchy, time) - Decoding speeches of protocols by one researcher in two different time	-	- Changing the scope of time from past to future version of target system, to, systems before and after target system - Decoding by two researchers
		Time dedicated to different heuristics effective in candidates	- Selecting some keywords related to candidate ideas and searching previous speeches for relative speeches and heuristics	-	- Asking R&D engineers to select the relative speeches or at least prove the selections by researcher
		-	-	Heuristics used in generated ideas	- Developing set of heuristics in novel designs based on literature - Assessing the used heuristics in the claimed text and picture of ideas - Assessing by both groups of experts and own R&D engineers

		-	-	Heuristics used in candidate ideas	- Assessing the used heuristics in the claimed text and picture of candidate ideas - Assessing by both groups of experts and own R&D engineers
4	Effects of some stimuli on R&D engineers' skills	Time dedicated to different heuristics effective in candidates	As corresponding item in 3 (2 rows above)		
		-	-	Heuristics used in candidate ideas	As corresponding item in 3 (2 rows above)

Table 60 - Suggestion for observing R&D engineers' performance and skills in the scope of current research

The table discusses the current conditions and suggestions in four parts of observing R&D engineers' performance, the effects of some stimuli on their performance, R&D engineers' skills, and the effects of some stimuli on R&D engineers' skills.
Time, quantity of ideas, and quantity of candidate ideas are the selected and observed indexes for the studies. The limitation for studying these indexes was mostly related to assessing the ideas by a set of criteria and the groups of experts. As mentioned in these parts in the table, the study can be expanded and become stronger by involving more R&D engineers in the study. For complementary data, R&D engineers could be asked to draw and write their ideas, so they can be used as data for both counting and assessing in parallel to selected ideas from their speeches. It is also suggested to involve Iranian experts to assess the ideas for more appropriateness on the relevance criterion. Asking R&D engineers to assess their ideas based on the set of criteria, can be considered as another complementary data in this part. In addition, comparing the candidate ideas as the results of these set of criteria with results of exploiting some other known criteria for finding novel ideas in the same set of ideas can show new direction in improving the proposed set of criteria.
Time dedicated to different heuristics and the time dedicated to different heuristics effective in candidate ideas, are the two indexes selected and observed to study the heuristics used by R&D engineers. Studying the applied heuristics in the pictures of ideas is a completely different approach for this part of the research. This study can be done by the R&D engineers or by the experts. This approach needs a set of heuristics from the beginning which must be extracted from the literature. This study also can be considered as the next step of related researches in this field as there is a current set of heuristics now.

3.3. Limitations in checking the usability, effectiveness and robustness of the Techno-shift game and some suggestions

The usability, effectiveness and robustness of the Techno-shift game were studied considering different players in different conditions. The results are compared with the results of the normal design sessions. Table 55 shows some suggestions for more precise studies.

No.	Issue to be observed in designing the next generation of technical systems	Performed in the scope of the research		Suggestive modifications or complementary observations for future studies	
		What was observed	Tools & resources	What to be observed	Tools & resources
1	Techno-shift usability	# Ideas	- Comparing the results with a normal design session with same duration of time and same	-	- Completing the assessment by exchanging ideas among teams and

		# candidate ideas	participants in profile for different technical systems - At least the same amount of candidate ideas while the percentages of non-related ideas to think stations and non-correct self-assessment of ideas are less of 40% - Performing the main study for 12 teams (24 R&D) engineers - Expanding the study to teams of more and less professionals - Play inside each team collaboratively and with other teams competitively for increasing market share - Self-assessing candidate ideas followed by assessment of an expert	-	asking for second round assessment instead of an expert, while considering new scores for final score formula
		# passed think stations		-	
		% non-related ideas to think stations		-	
		% non-correct self-assessment of candidate ideas		-	
		-	-	# rounds for learning the game	- Computing the rounds which the results become sustainable or the players prefer not to spend time for examples of think stations
				- Usability of the game in real projects - Usability of the game in real tasks of R&D units	-
2	Techno-shift effectiveness	# Ideas	- Comparing the results with a normal design session with same duration of time in following conditions: • Same participants in profile and less and more professional players • Same and new technical systems	-	- Involving more R&D engineers in the study for more strong observations
		# candidate ideas		-	
		-	-	# New ideas in real projects	- Considering the game as part of process of real projects
3	Techno-shift robustness	# Ideas	- Comparing the results of playing by different version of the game: • Full version • without table of resources • without examples		- Involving more R&D engineers in the study for more strong observations - Considering randomly forgetting each part of the game
		# candidate ideas			

	• without heuristics	or removing each part of the game from the procedure

Table 61- Suggestion for checking the usability, effectiveness and robustness of the Techno-shift game

The table discusses the limitations in studying usability, effectiveness and robustness through observing the quantity of ideas and the quantity of candidate ideas generated by players. The scope of these studies can be expanded by simply involving more participants in the study, and also more precisely by studying the potential position and role of the game in the real process of idea generation for the next generation of technical systems. For more robustness, it is also worth studying the random usage of the different components while playing by using second die.

4. Potential applications

The Techno-shift game as any tool can be used for the specific aims and goals which it is developed for, but also for some secondary usages. The Techno-shift game was developed to improve R&D engineers' performance in designing the next generation of technical systems. Therefore, the main applications of the game can be clarified as follows:

- Applying Techno-shift game:
  - in parts for idea generation and concept design of real projects when designing the next generation of technical systems;
  - as part of the tasks of companies' R&D units corresponding to new product development;
  - for professional training of R&D units' engineers;
  - for professional training of engineering students in courses related to technology forecasting.

Furthermore, the Techno-shift game can be applied for the following company objectives:

- To promote:
  - R&D engineers' abilities in idea generation;
  - R&D engineers' vision in cycles of evolutions of technical systems;
  - Team working among engineers of companies;
  - Social networking in the companies.
- To select more creative and more collaborative people among potential employee recruits for R&D units and companies;

In addition, it can be used for tutorial plans:

- To train engineering students in courses of engineering design for more creativity;

The list of main and secondary applications can be added according to the requirements of a company's R&D unit.

5. Future (further) developments and studies

Some suggestions were proposed in Parts 2 and 3 of this chapter as complementary studies for this research. Despite these suggestions, further developments and studies can be followed for the Techno-shift game. Further improvement in the Techno-shift game can be pursued through:

- Studying the effects of using more strategy-based heuristics in the game rather than content-based heuristics;
- Studying the effects of more randomness, simpler and less procedural structure for the game respect to the current version;

Some suggestions can be followed to check the effectiveness of the Techno-shift game:

- Studying the effectiveness of the Techno-shift game compared to some of the well-known engineering design models and methods with the same task but with different type of players;

- Study the effectiveness of the Techno-shift game compared to some of the well-known technology forecasting methods with the same task but with different type of players;
- Studying the effectiveness and attractiveness of the Techno-shift game compared to other attractive games for professionals;
- To check whether the proposed approach/game applies to a broad range of technical systems, or if it is more convenient to focus on a narrower domain, such consuming products;
- Studying the effectiveness of the Techno-shift game compared to very simple games such as card games including heuristics.

Some suggestions also can be discussed beyond developing the game, being more related to its customization in real tasks and processes of company R&D units:

- Studying the behaviors of companies in accepting and applying the Techno-shift game;
- Studying the ultimate effects of different applications of the Techno-shift game and the ultimate effects in R&D units and companies.

Some other studies can be followed to expand the application of the game beyond R&D engineers:

- Studying the simplified version of the game on creativity and design abilities of high-school students;
- Developing a digital version of the game and studying the difference among attractiveness, usability and effectiveness of the two versions of paper and digital for different types of players.

In addition, some other complementary research is needed as follows:

- Special model for developing serious games for open-ended tasks such as design.

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Appendix

Appendix 1: Speeches of R&D engineers while designing the next generation of fridge

1. Team 1/ Session 1: without stimulus, Session 2: without stimulus

Part	**Time (end)**			**Sentences**	**Concept**	**Idea**	**Precedent**	**Interpreter**	**Time**	**Space**	**Sys**	**Sup**	**Si**
	Min	Sec	interval		(idea, precedent, interpreter)	(initial, developed)	(episodic, semantic, stimuli)	(given, find)	(past, present, future)	(system, super system, sub system)	(subsystem, object)	(co-systems, user)	(alternative, analogy)
1	1	0	60	transparent door	id	in			fu	sys	sub		
		40	40	it is repetitive, I've seen it in ads	p		ep		pr	sys	sub		
	2	0	20	waste of energy after opening door	p		se		pr	sys	sub		
		10	10	it is not good when you have guest	p		se		pr	sys	sub		
		20	10	help to decide before opening	p		se		pr	sys	sub		
		30	10	like fridge of the shops	p		ep		pr	si			an
		45	15	transparent not whole door but just some parts of the door	id	dev			fu	sys	sub		
		55	10	multi doors	id	dev			fu	sys	sub		
	3	5	10	with various temperature for each door	id	dev			fu	sys	sub		
		20	15	you jump to another idea	p		se		fu	sys	sub		
		30	10	the effect of multi-door on saving energy	p		se		fu	sys	sub		
		40	10	there is a chiller in some fridge which has its own door	p		ep		pr	sys	sub		
	6	5	145	draw the ideas	p		se		fu	sys	sub		
		20	15	the amount of each kind of food for each home is constant usually	p		se		pr	sup		user	
	7	0	40	different boxes for the various kind of food	id	dev			fu	sys	obj		
		5	5	sometime low temperature damages the food	p		se		pr	sys	obj		
		15	10	sometimes we need humidity	p		se		pr	sys	obj		
		30	15	adjustability of various boxes for different temperature and humidity	id	in			fu	sys	sub		
	8	20	50	explain the benefit of solution for some kind of food (nuts, sweet, …)	p		se		fu	sys	obj		
		30	10	special place for drinking for rapid cooling	id	dev			fu	sys	obj		
	9	15	45	using co2 for rapid cooling in a box which collects the co2 after finishing its performance	id	dev			fu	si			alt
		45	30	investigating the effect of slow freezing on the vegetables	p		se		pr	sys	obj		
	10	50	65	investigating effect of rapid freezing on the vegetables	p		se		pr	sys	obj		
	11	15	25	dedicate some part of fridge to Coleman	id	in			fu	sup		co	
		25	10	with the ammonia in the wall that can preserve the temperature	id	dev			fu	sys	sub		
		35	10	possibility to convey for various usage	p		se		pr	sys	sub		
	12	25	50	structure of current Coleman	p		ep		pr	sup		co	
		45	20	the advantages of proposed Coleman respect to previous one (10 hours keeping the temperature)	p		se		fu	sys	sub		
	13	5	20	10 hours is not enough for long period trip	p		se		pr	sys	sub		
		50	45	it is useful for one-day picnic	p		se		pr	sys	sub		
	14	5	15	mechanism of hosting Coleman inside fridge and connecting	p		se		fu	sys	sub		
		20	15	small portable fridge	id	dev			fu	sys	sub		
		45	25	the small fridge is very useful for labors without definite space of work	p		se		pr	sup		user	
	15	5	20	chargeable small fridge	id	dev			fu	sys	sub		
		20	15	current condenser and the mechanism of decreasing the temperature of fridge	p		ep		pr	sys	sub		
	16	10	50	fridge in 1 foot	id	dev			fu	sys	sub		
		45	35	discuss about the importance of portable 1-foot fridge	p		se		fu	sys	sub		
	17	0	15	let's look at the back of fridge	p		ep		pr	sys	sub		

	18	40	100	draw the back of fridge	p		ep		pr	sys	sub		
		50	10	the necessity of distance among fridge and wall for air circulation	int			f	pr	sys	sub		
	19	20	30	small fans on the back of fridge for air circulation	id	in			fu	sys	sub		
		40	20	less need to energy because of decreasing the temperature of gas and less space for fridge	p		se		fu	sys	sub		
	20	30	50	mechanism of air circulation and the direction of it	id	dev			fu	sys	sub		
	21	25	55	it also does not let dust be absorbed by tubes of back of fridge	p		se		fu	sys	sub		
		45	20	the size of the fans is the same as fans of computer	id	dev			fu	sys	sub		
	22	0	15	according to the temperature of back of the fridge, different quantity of fans can be run automatically	id	dev			fu	sys	sub		
		10	10	the fans can work when the load of engine is low	id	dev			fu	sys	sub		
		30	20	asking of relation of this idea with portable fridge	p		se		fu	sys	sub		
		45	15	the engine is the heaviest part of fridge	p		ep		pr	sys	sub		
		55	10	to separate engine from the fridge to make it portable	id	dev			fu	sys	sub		
	23	5	10	like split air conditioners	p		ep		pr	si			an
		15	10	container separated from engine and condenser	p		se		pr	si			an
		30	15	it needs less energy because the condenser is in the open environment	p		se		fu	sys	sub		
	24	10	40	draw the ideas	p		se		fu	sys	sub		
		30	20	less space inside home	p		se		fu	sup		co	
		40	10	less noise in the home	p		se		fu	sup		co	
		50	10	any new idea?	p		se		fu	sys	sub		
	25	15	25	review ideas	p		se		fu	sys	sub		
		30	15	adding something additional like cold water device	id	in			fu	sup		co	
	26	20	50	rejected idea because it is not technical and we need technical radical changes	p		se		fu	sys	sub		
	27	10	50	the idea of separated engine is practical	p		se		fu	sys	sub		
		35	25	merging the engine and condenser of fridge and air conditioner	id	dev			fu	si			an
	28	45	70	draw the ideas	p		se		fu	sys	sub		
	29	5	20	fridge becomes lighter and needs less space	p		se		fu	sup		co	
		10	5	the less energy resources because the condenser is in open space	p		se		fu	sup		co	
		20	10	but the life cycle is decreasing	p		se		fu	sys	sub		
		35	15	the engine and condenser must be in a shelter	p		se		fu	sys	sub		
		50	15	an special place for cooling system of all apartments of buildings	id	dev			fu	sys	sub		
	30	5	15	like the heating systems of buildings	p		ep		pr	si			an
		30	25	life cycle of cooling system will increase by this way	p		se		fu	sys	sub		
	31	0	30	idea of using clay in the air conditioner	id	in			fu	sys	sub		
		30	30	it can absorb water and the system does not need water pomp	p		se		fu	sys	sub		
	32	0	30	draw idea	p		se		fu	sys	sub		
		35	35	the permeable effect which we can see in the clay like the Iranian vase	p		ep		fu	si			an
	33	35	60	an air conditioner with fan, clay, water and metal	p		se		fu	sys	sub		
		45	10	use fan, clay, water and metal instead of gas and condenser	id	dev			fu	sys	sub		
	34	20	35	mechanism of chillers on the roof of tall buildings	p		ep		fu	si			an
		45	25	play the game	*								
	38	45	240	ending announcement	*								
2	0	40	40	we started from needs of user	p		se		pr	sup		user	
		55	15	we proposed new ideas for needs of user (find problems and propose solution)	p		se		pr	sup		user	
	1	35	40	instead of user needs, what other things we can think about?	p		se		pr	sup		user	
		55	20	some of them were not about the needs but they were related to better performance	p		se		pr	sys	sub		
	2	20	25	we tried to change the current situation to desire situation	p		se		pr	sys	sub		
		55	35	remind the idea of fan for the back of fridge and effect of that on the less distance to the wall	p		se		pr	sys	sub		
	3	5	10	the modern kitchen has special wooden box for fridge	p		ep		pr	sup		co	
		20	15	so we need smaller space for the wooden box	p		se		pr	sys	sub		
		45	25	it is better to change the direction of thinking	p		se		pr	sys	sub		
	4	30	45	review some of ideas	p		se		pr	sys	sub		
		35	5	which direction we can go?	p		se		pr	sys	sub		
		40	5	think about future and changes in needs of users	p		se		fu	sup		user	
	5	20	40	houses is going to become smaller because the cost of land is increasing	p		se		fu	sup		user	
		25	5	so we need smaller devices inside home	int			f	fu	sys	sub		
		50	25	also in future we have restrict rules for using energy and it is expensive	int			f	fu	sys	sub		
	6	10	20	so we need smaller devices with less energy consumption	p		se		fu	sys	sub		
		30	20	fridge without need to energy	id	dev			fu	sys	sub		
	7	10	40	or using other sources of energy	id	dev			fu	sys	sub		

		30	20	also smaller foods and other things inside the fridge	p		se		fu	sys	obj		
	8	0	30	remind of last generations of fridge working with a candle	p		se		pa	sys	sub		
		45	45	invent another material instead of gas for cooling	id	dev			fu	sys	sub		
		55	10	using solar cell for energy	id	dev			fu	sys	sub		
	9	5	10	using the energy of wind by a turbine	id	dev			fu	sys	sub		
	10	20	75	cost of energy is so high and so the previous ideas are so useful	p		se		pr	sup		user	
	11	0	40	one energy source for whole building and one cooling system also for whole building and just a container in each house	id	dev			fu	sup		co	
		20	20	like the radiators of apartments	p		ep		pr	si			an
	12	0	40	using more effective insulators in the body of fridge	id	dev			fu	sys	sub		
		40	40	to find a new direction of thinking	p		se		fu	sys	sub		
	13	10	30	new fridge instead of improving the existing ones	p		se		fu	sys	sub		
		40	30	houses need high temperature for desire temperature of environment and also warm water	p		se		pr	sup		co	
	14	10	30	we need a system to get temperature of some parts of house to give it to water for make some other parts warmer	id	dev			fu	sup		co	
		40	30	fridge is getting the temperature from the food and give it to the kitchen	id	dev			fu	sys	sub		
	15	50	70	merging the system of cooling and warming of houses to each other	id	dev			fu	sup		co	
	16	25	35	we need a special space for controlling the temperature around 2 to 5 Celsius degree	p		se		fu	sys	sub		
	17	0	35	it means to get the temperature and control the temperature in every place at home	p		se		fu	sys	sub		
		20	20	we need a material to get the temperature like silicate that absorbs humidity	p		ep		pr	si			an
		35	15	this new material must not need energy for its working	id	dev			fu	sys	sub		
	18	30	55	so we can use everywhere as fridge like each cabinet by adjusting and controlling the temperature degree	id	dev			fu	sup		co	
	19	0	30	it must be rechargeable material or reusable material	id	dev			fu	sys	sub		
		25	25	we are wishing something so far just using imagination	p		se		fu	sys	sub		
	20	0	35	we want something like a tube to suck the hot and warm air which is in the upper part of room	p		se		fu	sys	sub		
		15	15	some new materials are invented that can absorb pollution and various particles in the air	p		ep		pr	si			an
		55	40	something on the roof of the house that absorb the heat and convey it to water	id	dev			fu	sup		co	
	21	30	35	something like a capacitor or paint	id	dev			fu	sys	sub		
		40	10	with some water container on the ceiling	id	dev			fu	sys		co	
		45	5	it is heavy	p		se		fu	sys	sub		
	22	15	30	the container can be wide but with less depth in all over the ceiling	id	dev			fu	sys	sub		
	23	30	75	to use all the ceiling as a condenser to absorb the heat and transfer it to the heating system and water	p		se		fu	sup		co	
	25	0	90	we thought differently in both parts	*								

2. Team 2/ Session 1: without stimulus, Session 2: patent as a stimulus

Part	Time (end)			Sentences	Concept	Idea	Precedent	Interpreter	Time	Space	Sys	Sup	Si
	Min	Sec	interval		(idea, precedent, interpreter)	(initial, developed)	(episodic, semantic, stimuli)	(given, find)	(past, present, future)	(system, super system, sub system)	(subsystem, object)	(co-systems, user)	(alternative, analogy)
1	0	50	50	we have paper to write and draw if we like	*								
	1	10	20	I write messy on the paper	*								
		20	10	I write according a previous plan	*								
		30	10	what is the function of fridge?	p		se		pr	sys	sub		
	2	10	40	we need to put ourselves in the situation of user and then think to the task	p		se		pr	sup		user	
		20	10	what is our feeling and behavior when we are in front of the fridge to take a food	p		se		pr	sup		user	
		40	20	interesting point: we open the fridge door so much even we don't want to take out any thing	p		ep		pr	sup		user	
		55	15	we talk to our fridge (a poem which says I confabulate with my fridge 70 times a day)	p		ep		pr	sup		user	
	3	10	15	what is our feeling and expectation in front of fridge? And how fridge can satisfy my feelings	p		ep		pr	sup		user	
		40	30	instead of engineering analysis of system, we can look at it from the side of user	p		se		pr	sup		user	

		55	15	engineering analysis starts by function of fridge which is not cooling, and is keeping quality of food so we can think about the methods for long period keeping	p		se		pr	sys	obj		
	4	5	10	which is a systematic approach	p		se		pr	sys	sub		
		25	20	instead we can start from user feelings and expectations	p		se		pr	sup		user	
		45	20	also we can think about the initial image and differences from that, can be acceptable and not acceptable by user (like spout out ink from the pen which is not acceptable)	p		se		pr	sup		user	
	5	10	25	I Just know to first think about function and then think for better way for delivering same function	p		se		pr	sys	sub		
	6	0	50	first we can start according to engineering procedures and then think about feelings of user	p		se		pr	sys	sub		
		10	10	function is keeping quality of food	p		ep		pr	sys	obj		
		20	10	as long as possible	p		ep		pr	sys	obj		
		30	10	I am thinking about cooling food	p		se		pr	sys	obj		
		45	15	cooling is important but do we use to cool food or do we need it	p		se		pr	sup		user	
	7	10	25	we need cooling even for enjoying some food	p		ep		pr	sup		user	
		20	10	but at first human search for cooler spaces like inside the ground for preserving food not for enjoying cold food	p		se		pr	sup		user	
		35	15	but we don't eat some fruit unless it is cold	p		se		pr	sup		user	
	8	10	35	we can ask this question to psychologists	p		se		pr	sup		user	
		20	10	write the sentence	p		se		pr	sup		user	
	9	20	60	we need a research to answer the question on different kind of people/ different age and different culture	p		se		pr	sup		user	
		30	10	so now we focus on keeping the quality of food	id	in			fu	sys	obj		
	10	20	50	if we say food save the quality of food is out of scope of fridge	id	dev			fu	sys	obj		
	11	0	40	so we focus on the role of fridge in keeping quality of current type of food for longer periods	id	dev			fu	sys	obj		
		30	30	the current situation is that for keeping the quality of food, we cool them	p		se		pr	sys	obj		
		40	10	we can say get the temperature instead of cooling	p		se		pr	sys	sub		
	12	30	50	or even decreasing the ability of bacteria	id	dev			fu	sys	obj		
		40	10	we are investing on decreasing temperature	p		se		pr	sys	sub		
		50	10	we can focus on decreasing cost for decreasing temperature	p		se		fu	sys	sub		
	13	5	15	or we can focus on decreasing the growth of bacteria	p		se		fu	sys	obj		
		10	5	we have other mental inertia too	p		se		pr	sys	sub		
		25	15	we have also the effect of air on food, there are some kind of packaging can keep quality of food longer	p		ep		pr	sup	si		an
		40	15	the conservation is supported by this fact	p		se		pr	sys	obj		
		50	10	it is mostly about cooked food	p		se		pr	sys	obj		
	14	15	25	but also they do vacuum the air	p		se		pr	sys	sub		
		40	25	but we need original quality and in the previous methods the quality is changing like cooking	int			f	pr	sys	obj		
	15	10	30	so we can write the known methods	p		se		pr	si			alt
	16	0	50	vacuum, conservation,	p		se		pr	si			alt
		25	25	if we could vacuum fresh tomato and keep its quality for long period, we reach the aim	id	dev			fu	sys	sub		
		50	25	some food can keep themselves like watermelon if we don't cut it	p		ep		pr	si			an
	17	0	10	in this situation we have to store them in some places at home	p		se		fu	sys	obj		
		35	35	the role of fridge inside the home is like a cabinet to store food	p		ep		fu	sup		co	
		40	5	the other role is to cool the food	p		ep		pr	sup		user	
		50	10	and also to listen to our talks and complains like a live friend	id	in			fu	sup		user	
	18	10	20	like the person leaves its working or dressing stuff in the fridge	p		ep		pr	sup		user	
		20	10	let think about the other methods to decrease the growth of bacteria like laser	p		se		pr	sys	sub		
		45	25	we want special cover for food to keep bacteria growing	id	dev			fu	sys	sub		
	19	10	25	let ask the chemist of R&D department that the bacteria which are affective in spoiling food can be removed from the food	p		se		pr	sys	obj		
		25	15	or manipulating them do effect the vitamin of food	p		se		pr	sys	obj		
	20	0	35	or changing the appearance quality	p		se		pr	sys	obj		
		5	5	I am thinking why do we have special place and volume for fridge in the kitchens?	p		se		pr	sup		co	
		10	5	we can add the function we need to the cabinets	id	in			fu	sup		co	
		25	15	if we use the concept of JIT for the food, what will happen?	id	dev			fu	sup		co	
		30	5	let's think about growing every food at home and have all resources at home	id	dev			fu	sup		co	
		50	20	it is not possible in our life style and apartments	p		se		pr	sup		co	
	21	0	10	a shop that give us food just in time	p		se		fu	sup		co	
		10	10	this is in the business side not technical	p		se		pr	sup		co	
		20	10	how can technology help us to cover this idea?	p		se		fu	sys	sub		

		50	30	if we give the order to the fridge one day before and it give us the fruit or vegetables in the right time according to the seeds it have	id	dev			fu	sys	sub		
	22	10	20	it reminds me of 3D printing	p		ep		pr	si			an
		40	30	so we don't need to preserve food and we don't need fridge	p		se		fu	sys	sub		
	23	5	25	but this idea is not useful for excessive food after meals	p		se		fu	sys	obj		
	24	15	70	so we can divide the concept of keeping food before meals and after meals and we have waste also	id	dev			fu	sys	sub		
		25	10	so we can have a device to keep food for few hours to eat excessive food	id	dev			fu	sys	sub		
		50	25	we keep food by methods that we can add to them like vacuum, laser	id	dev			fu	sys	sub		
	25	30	40	do users accept to use laser and waves for food so even for micro wave there is not good image	p		se		pr	sup		user	
	26	30	60	we are thinking of user. what are the need of users? What user expect of fridge?	p		se		fu	sup		user	
		50	20	I am thinking of cooling again	p		se		fu	sys	sub		
	27	0	10	do we need new technology for fridge?	p		se		fu	sys	sub		
		10	10	we want to compete	p		se		fu	sys	sub		
		30	20	if our fridge can call our name and talk to us about the food inside and propose plan for eating them, is it a new technology?	id	dev			fu	sys	sub		
		45	15	it is a characteristic that is incremental	p		se		pr	sys	sub		
	28	15	30	so do we want new technology in this industry?	p		se		pr	sys	sub		
		40	25	R&D must think about new technology but the time to market is something different	p		se		pr	sys	sub		
		50	10	instead using gas for cooling what we can use?	p		se		fu	sys	sub		
	29	10	20	we can think about something in our mouth that can prevent the side effect of spoiling food for body	id	in			fu	sys	sub		
		30	20	it is not acceptable by user because user wants nice and fresh appearance of food	p		se		pr	sup		user	
		40	10	we can focus on appearance of food and not let it damage even if it is spoiling	id	dev			fu	sys	obj		
	30	0	20	let focus on user expectation instead of thinking about function	p		se		fu	sup		user	
	31	0	60	user wants to enjoy using food and he is not so interested in time of keeping food for long time like cool water melon or excessive food of last night to eat today	p		ep		pr	sup		user	
		30	30	the user wants to keep food for one week, he is not expecting keeping food for whole season these days	p		ep		pr	sup		user	
		40	10	so we have to think about keeping food for one week	p		se		pr	sys	obj		
		50	10	so thinking about other methods like vacuum or waves are not meaningful from the side of user expectation	p		se		pr	sys	sub		
	32	40	50	so we can think about the resources of user, like space, energy, initial cost for current technology,	p		se		pr	sup		user	
	33	0	20	for example, more isolated fridge to save the energy	id	in			fu	sys	sub		
		30	30	it means that we have to decrease the space or energy or cost if we want to improve current structure	int			f	fu	sys	sub		
		40	10	if we go this way, our suggestion will be incremental	p		se		pr	sys	sub		
	34	10	30	home laundry which is evolving to have washing and ironing together	p		ep		pr	si			an
		40	30	it makes the sequences of activities simultaneously	p		se		pr	si			an
	35	10	30	technology is not changed in this example	p		se		pr	si			an
		20	10	we have to realize changes in technology	int			f	pr	si			an
	37	15	115	the hot vapor and detergent clean the cloth but it drying it and ironing it. It is new combination	p		se		pr	si			an
		25	10	we want to have food inside cabinet for one or two weeks. Why they are spoiling?	p		se		pr	sys	obj		
		55	30	because the bacteria are growing in the normal temperature of room	p		se		pr	sys	obj		
	38	10	15	cooling is one way to decrease the growing of bacteria	p		se		pr	si			alt
		50	40	we want fridge with less space (in cabinets) to decrease growing of bacteria	p		se		fu	sup		co	
	39	20	30	even already the most part of fridge is using as cabinet	p		se		pr	sys	sub		
		30	10	but the cost of fridge is more than cabinet	p		se		pr	sys	sub		
		40	10	and also using cabinet instead of fridge is less usage of energy	p		se		fu	sup		co	
	40	0	20	we need a new technology to decrease the growing of bacteria	p		se		fu	sys	sub		
		45	45	we are in lack of time and we need a game and we were not systematic	*								
	41	10	25	we can think about a new field for decreasing the growth of bacteria	id	dev			fu	sys	sub		
		25	15	if we remove the gas	id	dev			fu	sys	sub		
		40	15	it is good to remove the whole process of cooling	id	dev			fu	sys	sub		
	42	40	60	we need a new field, new substance or both	p		se		fu	sys	sub		

		50	10	substance like deodorant to attach it to food that attract the bacteria	id	dev			fu	sys	sub		
	43	10	20	like the device of killing insects by waves	p		ep		pr	si			an
	44	0	50	like ultrasonic which does not add the cost of technology for user	id	dev			fu	sys	sub		
		50	50	electromagnetic waves, acoustic waves, …	id	dev			fu	sys	sub		
			2690	review the idea	p		se		pr	sys	sub		
	0		0	read the patents	p		st		fu	si			an
	3	45	225	this one is about ice cream maker	p		st		fu	si			an
		55	10	this one is about the door of fridge	p		st		fu	sys	sub		
	4	40	45	this one is like the idea of JIT to order according to inventory	p		st		fu	sys	sub		
	6	30	110	they are not radical improvements	p		se		fu	sys	sub		
	7	55	85	read the new one this one is about customizable assembles of boxes	p		st		fu	sys	sub		
	8	40	45	imagine we can take a box and put it in bedroom according to demand	id	in			fu	sys	sub		
		55	15	assemble according to the need like the project of google for phone	p		ep		fu	si			an
	9	10	15	we can move different parts to every part of house	id	dev			fu	sys	sub		
	11	10	120	read the other one, it is related to furnace	p		st		fu	si			an
	13	45	155	what we have totally	p		se		fu	sys	sub		
	14	10	25	the technology is toward complexity and then simplicity	p		se		fu	sys	sub		
		20	10	the patent related to boxes is mono-bi-poly	p		se		fu	sys	sub		
		40	20	is principle of division	p		se		fu	sys	sub		
	15	0	20	these patents say we are not facing radical changes in technology	p		se		fu	sys	sub		
		10	10	the functions are increasing	p		se		fu	sys	sub		
		35	25	ice cream maker to realize the expected performance is focusing on the quality expected by user	p		st		fu	si			an
	16	0	25	automatic door useful for saving energy	p		st		fu	sys	sub		
	18	50	170	check the inventory and compute time for buying is helping user for managing food	p		st		fu	sys	sub		
	19	20	30	it is like our idea about JIT	p		se		fu	sys	sub		
		40	20	the fridge can show the pattern of consumption of a week	p		se		fu	sys	sub		
	20	25	45	inventory systems is working based on the point of ordering which is before finishing all inventory	p		se		fu	sys	sub		
		55	30	modular fridge which is useful for using every part for different food at different parts of home	p		st		fu	sys	sub		
	21	35	40	one of them is more radical for next generation which is adding managing software	p		se		fu	sys	sub		
	22	5	30	new LG fridge has two layer doors to save energy	p		ep		pr	sys	sub		
		35	30	they show direction of less energy in less space	p		se		fu	sys	sub		
		50	15	they are not about gas and condenser	p		se		fu	sys	sub		
	23	10	20	when they make fridge modular it means even they changed condenser	p		se		fu	sys	sub		
		25	15	they are about happier and satisfied user	p		se		fu	sup		user	
		40	15	so we can focus on customer needs more	p		se		fu	sup		user	
	24	5	25	user has difficulty in managing inventory, sometimes he wants something but it has finished before	p		se		fu	sys	obj		
		20	15	a fridge that we can have access to list of its content by message from out of home	id	in			fu	sys	sub		
		45	25	as we usually live with family in our home, it seems it is not so necessary for us	p		se		pr	sup		user	
	25	15	30	also it can be completed by the pattern of consumption of family	id	dev			fu	sys	sub		
		20	5	people buy usually every week	p		ep		fu	sup		user	
		30	10	but some people prefer to buy the time that they finish previous food	p		ep		fu	sup		user	
	26	0	30	we have considered the people life style	p		se		fu	sup		user	
		55	55	fridge which can propose the food for cooking according to its content and cooking recipes	id	dev			fu	sys	sub		
	27	5	10	is it technological improvement	p		se		fu	sys	sub		
		15	10	we add technological options	p		se		fu	sys	sub		
		35	20	in splitting fridge may be we have another technology	p		se		fu	sys	sub		
		45	10	how we can transfer cold air to separated boxes all around the home?	p		se		fu	sys	sub		
	28	15	30	which problem the splinted fridge is solved?	p		se		fu	sys	sub		
		40	25	because we need different food in different places at home	p		se		fu	sup		user	
	29	0	20	even each kind of food in different places need different temperature	p		se		fu	sys	obj		

		10	10	the boxes that are conveying in home can work like a Coleman	id	dev			fu	sys	sub		
		35	25	can the fridge also warm the food for us	id	in			fu	sys	sub		
		50	15	to use the heat of back of fridge	id	dev			fu	sys	sub		
	30	30	40	like the merge of fridge and oven which oven automatically receive the ingredients according to initial plan of user	id	dev			fu	sup		co	
		45	15	this idea needs also a programmable oven	id	dev			fu	sys	sub		
		55	10	we can concentrate more on the fridge can receive raw material and prepare them for the programed food and deliver it	id	dev			fu	sys	sub		
	31	55	60	fridge like a slow cooker which can be cook food, the user set it before living home in the morning and have cooked food in the evening by the heat of back of fridge	id	dev			fu	sys	sub		
	32	30	35	also possible to realize the condition of cooking food and manage it from distance	id	dev			fu	sys	sub		
		40	10	by video or photo with a camera in the fridge	id	dev			fu	sys	sub		
	33	5	25	using RFID technology is easier	id	dev			fu	sys	sub		
		20	15	we want to decide to stop cooking or adding something	p		se		fu	sys	sub		
	34	5	45	camera let us to enjoy	p		se		fu	sys	sub		
		40	35	also camera let me to check the color of cooking food because fresh ingredients are not like each other and we need a chef	p		se		fu	sys	sub		
		50	10	we need a technology to work instead of our taste	id	dev			fu	sys	sub		
	35	10	20	by transferring taste to codes	id	dev			fu	sys	sub		
		15	5	what is the aim	p		se		fu	sys	sub		
	36	0	45	in our culture we believe that food must be prepared by love	p		ep		pr	sup		user	
		30	30	the taste is related to love	p		ep		pr	sup		user	
	37	30	60	review the idea of fridge related to oven and is programmable	p		se		fu	sys	sub		
		55	25	we can see trend of division and merging every where	p		se		fu	sys	sub		
	39	15	80	fridge with TV	id	dev			fu	sys	sub		
		45	30	adding various function in one device can be followed	p		se		fu	sys	sub		
	40	10	25	it is easier than other kind of innovation because we merge existing systems	p		se		fu	sys	sub		
		35	25	the technological improvement is adding ability of taste to fridge and understand the health by that	p		se		fu	sys	sub		
		45	10	but the fridge must not let spoiling at all	int			f	fu	sys	obj		
		55	10	the technology of tasting is useful only we merge fridge with cooking device	p		se		fu	sys	obj		
	41	50	55	the food is not binary 0 and 1, the tastes and quality are phazy	p		se		fu	sys	obj		
	42	25	35	we want to know healthy one and spoiled ones, we don't need tasting	p		se		fu	sys	obj		
	43	0	35	fridge which show the quality of food, even when we buy fresh tomato we are facing different type and quality	id	dev			fu	sys	obj		
		30	30	to alarm which one of tomatoes is spoiling and you don't remove it. It damages the others too	id	dev			fu	sys	sub		
	44	0	30	what do we propose after distinguishing the food that is spoiling?	p		se		fu	sys	sub		
		30	30	propose the food eating according the ones they are spoiling sooner	id	dev			fu	sys	sub		

3. Team 3/ Session 1: without stimulus, Session 2: engineering procedure as a stimulus

Part	**Time (end)**			**Sentences**	**Concept**	**Idea**	**Precedent**	**Interpreter**	**Time**	**Space**	**Sys**	**Sup**	**Si**
	Min	Sec	interval		(idea, precedent, interpreter)	(initial, developed)	(episodic, semantic, stimuli)	(given, find)	(past, present, future)	(system, super system, sub system)	(subsystem, object)	(co-systems, user)	(alternative, analogy)
1	0	30	30	if we are thinking about radical shift, it means that we have to think about a system completely instead of current fridge	int			g	fu	sys	sub		
		40	10	the food must keep its quality by itself	id	in			fu	sys	obj		
		50	10	or something with food that can protect it	id	dev			fu	sys	sub		
	1	0	10	you are thinking about the function and you want to remove the system	p		se		fu	sys	sub		
		10	10	we can think about the system of fridge if it needs such this radical changes or not? We can focus on sub-systems of fridge and propose radical changes for them	p		se		fu	sys	sub		
		20	10	fridge doesn't need energy	id	dev			fu	sys	sub		
		30	10	fridge doesn't need engine	id	dev			fu	sys	sub		
		40	10	fridge doesn't need compressor	id	dev			fu	sys	sub		

	2	5	25	which ones can be considered as technology shifts and changes in paradigms of sub-systems	p		se		fu	sys	sub		
		45	40	so we want radical changes in technology of fridge	int			g	fu	sys	sub		
	3	0	15	we can focus on fridge as a whole or in each sub-system	p		se		fu	sys	sub		
		40	40	does radical changes in sub-systems can show radical changes in whole system?	p		se		fu	sys	sub		
	4	0	20	washing Machin is still washing machine but we have radical change by direct drive	p		ep		pr	si			an
	5	0	60	we can select to have radical changes in system level or sub-system level	p		se		fu	sys	sub		
		20	20	when fridge with oil changed to electrical fridge we faced a radical change	p		ep		pa	sys	sub		
	6	15	55	the first fridge was working with ammonia, device warm ammonia by oil and then send it to the wall of fridge, when ammonia wants to back to its normal mood, it absorbs heat	p		ep		pa	sys	sub		
		40	25	the cooling device of fridge had radical changes to use gas instead of ammonia	p		ep		pa	sys	sub		
		10	30	we can go through 2 directions, think about future device instead of fridge, or think about radical improvements in sub-systems	p		se		fu	sys	sub		
	7	25	15	as we are thinking from the side of company of producing fridge, so we think of radical changes in sub-systems	p		se		fu	sys	sub		
		35	10	but from the side of user, may be we can focus on whole system	p		se		fu	sys	sub		
	8	0	25	usually all other competitors are also interested on exploiting current product instead radically change every thing	p		se		fu	sys	sub		
		10	10	first we can proceed by function for whole system	p		se		fu	sys	sub		
		20	10	what is the function of the system	p		ep		pr	sys	sub		
		35	15	keep the quality of food for x time as it was in initial situation for a desire period of time	id	in			fu	sys	obj		
		55	20	also we like to eat some food cold	id	dev			fu	sys	obj		
	9	5	10	the main need of user was keeping food longer and then eating cool food is added to people interest	p		ep		pr	sys	obj		
		20	15	but I think cooling is important as well because we see device for cool water in current version of fridge	p		ep		pr	sup		user	
		30	10	we can see this options as multi functionality	p		se		pr	sys	sub		
	10	5	35	we prefer not to have fridge but we have food healthy for longer period and the food are able to keep themselves fresh	p		ep		pr	sup		user	
		10	5	why we cannot achieve that?	p		se		pr	sys	obj		
	11	10	60	bacteria in the air or speed of chemical reaction of food and air in the normal temperature	p		se		pr	sys	obj		
	12	10	60	high temperature speeds up the reaction	p		se		pr	sys	obj		
		25	15	how to remove this barrier?	p		se		fu	sys	sub		
		50	25	not let food and air have chemical reaction by controlling the interaction of food and bacteria	id	in			fu	sys	sub		
	13	5	15	it is two parts, one the bacteria inside food and the other bacteria in the air	p		se		pr	sys	obj		
		25	10	I think oxygen is more effective than bacteria and we have remove the presence of oxygen	id	dev			fu	sys	sub		
	14	25	60	so we have to consider both temperature and chemical reaction of food and air	p		se		fu	sys	obj		
		35	10	also the bacteria inside food	p		se		fu	sys	obj		
		50	25	but if we can control the air, we can increase enough and it is not necessary to think about bacteria inside food	p		se		fu	sys	sub		
	15	10	20	you mean we accept spoiling food but in longer period	int			f	fu	sys	sub		
		20	10	otherwise we are not thinking in home appliances factory, we are in agriculture industry	p		se		pr	sup		co	
		25	5	why an apple on the tree can keep its quality?	p		se		pr	sys	obj		
		40	15	because it is alive. The chemical reaction with air is present but the apple is not spoiling	p		se		pr	sys	obj		
	16	0	20	if we provide another kind of reaction with fridge that doesn't let it to have reaction with bacteria	id	dev			fu	sys	sub		
		45	45	like the shell of turtle shell that is damaging easily after killing the turtle	p		ep		pr	si			an
	17	20	35	but the shell of oyster is so strong	p		ep		pr	si			an
		40	20	like nail and hair which are not alive and they decay late	p		ep		pr	si			an
		50	10	so we don't want to look at inside food and we want to focus on connections outside	p		se		pr	sys	obj		
	18	5	15	we want to increase the time of freshness	int			f	fu	sys	sub		
		10	5	what are the resources around?	p		se		pr	sup		co	
		50	40	cold air, space of inside fridge, …	p		ep		pr	sup		co	
	19	10	20	which resources do we look for? They are available now or we can have them if we want?	p		se		pr	sup		co	
		45	35	we are looking to some resources to help us to get more benefits for our problem	p		se		pr	sup		co	
	20	35	50	electrical energy, food, darkness inside fridge, light of bulb,	p		ep		pr	sup		co	

	21	0	25	what are the stages from farm to final customer	p		se		pr	sup		co	
		20	20	the ideal solution is that to have type of wax to cover food in whole stages	id	dev			fu	sys	sub		
	22	0	40	we are not mentioning the bio solutions here which genetically modified food for example does not let insects to become close to raw food	p		ep		pr	si			alt
		20	20	also conservation is keeping food from air outside which proposed by sailors	p		ep		pa	si			alt
	23	30	70	we have also conservation for can in industry which means try to remove the connections that decay it and instead fill it or make shell somewhere to separate from the surrounding	id	dev			fu	sys	sub		
	24	30	60	so from the user side we substitute some waxes on the food instead of fridge and we run a project to find the wax	p		se		fu	sys	sub		
		55	25	this idea is not the desire of customers like they prefer fridge instead of conservation, they prefer normal food instead of GM	p		ep		pr	sup		user	
	25	30	35	also the home appliances industry prefer to follow its current production lines	p		se		pr	sup		co	
		40	10	so we are focusing on some new solutions in industry	p		se		fu	sys	sub		
	26	50	70	like a capsule inside food that we can bring them out when we want using food. It is better not to inject something inside but have something inside to preserve it from there. Like small chips for cooling inside	id	dev			fu	sys	sub		
	27	30	40	bio technology wants to go inside food and change it from inside but I am proposing some technical system inside food	p		se		pr	si			an
	28	15	45	like using dry ice for cooling drinking instead using fridge	p		se		pr	si			an
		45	30	this idea again is out of scope of fridge industry	p		se		pr	sys	sub		
	29	20	35	we can focus on more realistic targets in fridge industry; reserving food for longer period	p		se		pr	sys	sub		
	30	35	75	fridge with less energy usage	id	in			fu	sys	sub		
		50	15	fridge with less components	id	dev			fu	sys	sub		
	31	25	35	I think the technology is in somewhere in his life that the technology is enough extended and we can now merge the parts and components together	p		se		fu	sys	sub		
		45	20	or we can add more functions to fridge	p		se		fu	sys	sub		
		55	10	also we can compete on some features of existing fridge	p		se		fu	sys	sub		
	32	5	10	working on existing feature cannot be radical shift	p		se		fu	sys	sub		
		15	10	unless we change source of energy	p		se		fu	sys	sub		
		45	30	without using non-renewal energy	id	dev			fu	sys	sub		
	33	30	45	reminding initial way of preserving food	p		se		pa	si			alt
		55	25	for example, we are using energy of reaction of food together as a source of energy	id	dev			fu	sys	sub		
	34	55	60	it means we want to use the temperature of surrounding as a resource for preserving	id	dev			fu	sys	sub		
	35	0	5	what are the barriers?	p		se		fu	sup		co	
		55	55	maybe it is better to focus on the available energies around or in the system	p		se		fu	sup		co	
	36	5	10	system only uses electrical energy	p		ep		pr	sys	sub		
	37	5	60	the gas must circulate in condenser and compressor must be condensed so the fridge needs electrical energy	p		ep		pr	sys	sub		
		10	5	how to remove this barrier?	int			f	fu	sys	sub		
		25	15	we can look for something instead condensing gas and it means changing cooling technology	id	in			fu	sys	sub		
	38	40	75	and also we can use other energies in surrounding for condensing gas	id	dev			fu	sup		co	
		55	15	now we can look to our resources again to use them differently	p		se		pr	sup		co	
	39	0	5	do we remember any solution of new energies?	p		ep		pr	si			an
		10	10	the question is: which methods do we know for cooling without condensing gas?	p		ep		pr	si			an
		20	10	we need to search	p		se		pr	si			an
		45	25	maybe in space satellite	p		ep		pr	si			an
	40	25	40	but we are thinking about gas and we have to change thinking to energy	p		se		pr	sys	sub		
		55	30	but even we can think about Neutral environment instead of cooling for preserving food	p		se		pr	sys	sub		
	41	20	25	using vacuum for food	id	dev			fu	sys	sub		
		30	10	that is enough	*								
2	1	30	90	step 1: what is the function of fridge? Read the question	p		st		pr	sys	sub		
	2	0	30	keeping the quality of food for longer period	p		ep		pr	sys	obj		
		30	30	also we can say increasing the food for longer period	p		ep		pr	sys	obj		
		50	20	also we can say: increasing the time of spoiling or making delay in spoiling	p		ep		pr	sys	obj		
	4	45	11 5	step 2: what problems the system solved? Read the question	p		st		pr	sys	sub		
		55	10	system is fridge	p		ep		pr	sys	sub		

	5	45	50	sub systems are condenser, body, compressor, engine, gas, …, temperature	p		ep		pr	sys	sub		
	6	45	60	we can see energy source and food, air, oxygen, bacteria, ... in super system	p		ep		pr	sys	sub		
	7	0	15	also we can see fields and functions as part of sub-system like	p		ep		pr	sys	sub		
		45	45	in past we had oil-based fridge	p		ep		pa	sys	sub		
	8	30	45	in the sub-system we had Freon gas, ammonia, …	p		ep		pa	sys	sub		
		55	25	in super system we had oil and air, …	p		ep		pa	sup		co	
	9	45	50	also we had ice inside Yonolit container as previous generation of system	p		ep		pa	sys	sub		
	10	10	25	ice and container, door were the sub-systems	p		ep		pa	sys	sub		
		35	25	we also can mention water cooling device as sub-system of present system	p		ep		pr	sys	sub		
		45	10	it is better not to mention because it is not about main function	p		se		pr	sys	sub		
	11	5	20	we have to be conscious that we want technical shift	int			g	fu	sys	sub		
		10	5	the first version of fridge were cool dark rooms under ground	p		ep		pa	sys	sub		
	12	25	75	darkness and colder atmosphere and soil were their sub-systems	p		ep		pa	sys	sub		
		45	20	in the super system we have air, …	p		ep		pa	sup		co	
	13	15	30	the technological evolution happened by invention of fridge	p		ep		pa	sys	sub		
		50	35	now we have to find the problems solved before in technological evolution	p		st		pa	sys	sub		
	14	30	40	it became possible to keep food longer	int			f	pa	sys	obj		
	15	10	40	the delay for spoiling increased	p		se		pa	sys	obj		
	17	30	140	ok. Also we had to change the ice every few hours	p		se		pa	sys	sub		
	18	30	60	they want to increase the time of keeping and then they tried to cool the food and	p		se		pa	sys	sub		
		50	20	freezer can increase the time but it changes the quality and freshness of food	p		se		pr	sys	sub		
	19	20	30	but there are new methods for freezing very fast that they can keep the initial quality	p		se		pr	sys	sub		
	20	50	90	the problem between the 2 generations were same but something else has change, comfort and usability	p		se		pa	sys	sub		
	21	20	30	we had to change the ice or go to the under ground	p		se		pa	sys	sub		
	22	20	60	also we have better accessibility to food and cooling system	int			f	pa	sys	sub		
		30	10	why oil version changed to electrical version?	p		se		pa	sys	sub		
		45	15	because of smell in the home	p		se		pa	sup		co	
		55	10	and it means comfort and accessibility again	p		se		pa	sup		user	
	24	30	95	it seems the line of progress is on comfort	int			f	pa	sup		user	
	26	45	135	so we can say it was responding to user request of accessibility and comfort	p		se		pa	sup		user	
	27	0	15	the fridge is considered as an aesthetic device in kitchen	p		ep		pa	sup		user	
		55	55	this is also can be considered as comfort and also adding options like TV and water cooling device	p		se		pa	sup		user	
	28	0	5	step 3: what were technical improvements	p		st		pa	sys	sub		
		20	20	we wanted fresh food for longer period with less time consuming process for user	p		se		pr	sup		user	
		45	25	let's think	p		se		pr	sup		user	
	30	55	130	before, we wanted fresh food for longer period but we wanted less effort of user	p		se		pr	sup		user	
	33	50	175	think again	p		se		pr	sup		user	
	34	10	20	speed of chemical reactions was high	p		se		pr	sys	obj		
		15	5	I found a contradiction	p		se		pr	sys	sub		
	35	30	75	high temperature speeds up the reaction but we want to control it by cooling, so if the temperature is high, the time of keeping is low and consumption of energy is low, the less temperature, the time of keeping is increasing but the consumption of energy is increasing too	p		se		pr	sys	sub		
	36	30	60	we had this contradiction before in all previous versions and generations	p		se		pa	sys	sub		
		40	10	is this contradiction solved completely?	p		se		pa	sys	sub		
	37	30	50	no. still this contradiction is alive despite there were lots of improvements	p		se		pa	sys	sub		
		50	20	but the contradiction between underground and first Yonolit box is related to accessibility and less effort has resolved	p		se		pa	sys	sub		
	39	30	100	we can think about rapid cooling as some available solutions that they are about changing the temperature in less time but still fresh food	id	dev			fu	sys	sub		
	40	30	60	now we have to think what solution solved the contradiction partially	p		st		pa	sys	sub		
	43	5	155	the fridge was a solution for above mentioned contradiction	p		se		pa	sys	sub		

		45	40	the final solution is cooling without energy consumption	p		st		fu	sys	sub		
	44	30	45	for solution we have to change substances, physical law, …	p		st		fu	sys	sub		
	45	0	30	new physical law for preventing chemical reactions and so spoiling	p		st		fu	sys	sub		
	46	0	60	what others?	p		se		fu	sys	sub		
	48	0	120	using magnetic field in new type of container	id	dev			fu	sys	sub		
		35	35	we can call it mag-box	p		se		fu	sys	sub		
	49	0	25	we can use permanent magnet without using energy	p		se		fu	sys	sub		
	50	0	60	the other is related to substances	p		se		fu	sys	sub		
		20	20	genetically modification of food	id	dev			fu	sys	obj		

4. Team 4/ Session 1: without stimulus, Session 2: without stimulus

Part	**Time (end)**			**Sentences**	**Concept**	**Idea**	**Precedent**	**Interpreter**	**Time**	**Space**	**Sys**	**Sup**	**Si**
	Min	Sec	interval		(idea, precedent, interpreter)	(initial, developed)	(episodic, semantic, stimuli)	(given, find)	(past, present, future)	(system, super system, sub system)	(subsystem, object)	(co-systems, user)	(alternative, analogy)
1	0	15	15	what does fridge do for us? What requirements does it satisfy?	p		ep		pr	sys	sub		
		20	5	this direction is wrong	p		se		pr	sup		user	
		40	20	we have to see what does owner of the company expect from us	p		se		pr	sup		user	
		50	10	we want to change the level of technology	int			g	fu	sys	sub		
	1	10	20	the fridge works based on thermodynamics law; it gets the heat of somewhere and release it somewhere else	p		ep		pr	sys	sub		
		20	10	we have gas, compressor, condenser	p		ep		pr	sys	sub		
	2	0	40	in compressor the pressure of gas is increasing and when the gas release in condenser, it gives the heat of container of fridge	p		ep		pr	sys	sub		
		15	15	we want to change this technology and just to propose some technology for cooling without any part that warm somewhere else	int			f	fu	sys	sub		
		35	20	so one solution is working for technology which can cool the system without heat	id	in			fu	sys	sub		
		45	10	another thing can be changing the energy of compressor to another source of energy	id	in			fu	sys	sub		
	3	0	15	also we can substitute gas with new technology that is not harmful for environment	id	dev			fu	sys	sub		
		10	10	if we find a cool gas	id	dev			fu	sys	sub		
		35	25	the characteristics of new gas: not harmful for environment, it must need heat to be cold,	int			f	fu	sys	sub		
	4	15	40	to find a material that absorbs heat for its metabolism	id	dev			fu	sys	sub		
		35	20	we can use energy of wind, sun, magnetic, mechanical that can automatically work, chemical,	id	dev			fu	sys	sub		
		55	20	to have chemical action that we need it for another purpose and use it to reduce the heat of food inside the fridge	id	dev			fu	sys	sub		
	5	0	5	we can change the technology by looking in its technology	p		se		fu	sys	sub		
		15	15	we want fridge to cool the food and we look at its technology	p		se		pr	sys	sub		
		30	15	we can also look at the other applications of fridge to change the technology	p		se		fu	sup		user	
	6	0	30	cooling food, freezing food, to provide ice, to provide cool drinking water,	p		ep		pr	sys	sub		
		30	30	preventing spoiling,	id	in			fu	sys	sub		
		45	15	the fridge can provide tasty water with essence of various fruit	id	dev			fu	sys	sub		
	8	10	85	let's list all kind of food: drinking, semi-cooked meat, fruit, vegetables, beans, cheese, butter and milk, jam and …, excessive of cooked food, bread, medicine,	p		ep		pr	sys	obj		
		20	10	let's list what we put inside freezer	p		se		pr	sys	obj		
	10	0	100	meat, vegetables, bread, or semi-cooked food	p		ep		pr	sys	obj		
	11	15	75	what we have in the part of treating water: to provide drinking water with adjustable temperature, to make ice	p		ep		pr	sys	sub		
		30	15	we can think also about the air and similarity of air conditioner and fridge	p		ep		pr	si			an
		45	15	we can merge fridge and air conditioner together	id	dev			fu	sup		co	
		50	5	is the technology really the same?	p		se		pr	si			an
	12	15	25	they both have same technology and even one kind of gas	p		se		pr	si			an

		30	15	so we can merge this two, together	p		se		fu	sup		co	
		45	15	in this solution we didn't change the technology but we merge it with something similar	p		se		fu	sys	sub		
	13	20	35	as we were talking about the part related to treating on water, I was thinking why not add it for cooling air?	p		se		fu	sys	obj		
		45	25	even in the car, the fridge and cooling system are merged together like this	p		ep		pr	si			an
		55	10	it is enough because we propose a good solution	p		se		pr	sys	sub		
	14	0	5	let's proceed	p		se		pr	sys	sub		
		15	15	come back to the previous idea, we were thinking about drinking with various tastes	p		se		pr	sys	sub		
		45	30	add the juice maker to the fridge	id	dev			fu	sup		co	
	15	0	15	it means that we add something else to the fridge	p		se		fu	sys	sub		
		10	10	what else can we propose? We can make fridge smart	id	in			fu	sys	sub		
		30	20	smart fridge that declare the ordering time of food on a list on the door of fridge or in an application	id	dev			fu	sys	sub		
		35	5	it means that we don't want to see the finishing of each food, we want to order before finishing point	p		se		fu	sup		user	
		45	10	it is like a store that the contents must not finish	p		ep		pr	si			an
	16	0	15	digital LCD on the door of fridge to show the information	id	dev			fu	sys	sub		
	17	5	65	the ordering list can be connected to a super market for real purchase	id	dev			fu	sup		co	
	19	30	145	review ideas (showing the lists of the contents, the ordering point of them, print the list, connected to the market)	p		se		fu	sys	sub		
		40	10	what we can add more? What are the features important for users?	p		se		pr	sup		user	
	20	15	35	propose the ordering for using food based on FIFO	id	dev			fu	sys	obj		
		50	35	what we can add more? What are the features important for users?	p		se		pr	sup		user	
	21	10	20	the fridge alarms the spoiling time of food inside	id	dev			fu	sys	obj		
		50	40	if we have smart surfaces that can distinguish the healthiness of food and fruit	id	dev			fu	sys	sub		
	22	5	15	the fridge that can clean itself	id	in			fu	sys	sub		
		35	30	How?	p		se		fu	sys	sub		
		45	10	let's think another way, if we think that we use food in a way that we don't need fridge any more	id	in			fu	sup		user	
	23	0	15	we don't want to remove fridge; we just want to change the technology	int			g	fu	sys	sub		
		5	5	fridge that clean itself by using Nano material	id	dev			fu	sys	sub		
		15	10	fridge that doesn't get bad smell	id	dev			fu	sys	sub		
		35	20	fridge that can remove spoiled food	id	dev			fu	sys	sub		
		55	20	the fridge that is loaded more than its capacity, it doesn't work well	p		se		pr	sys	sub		
	24	20	25	alarm for the maximum capacity for cooling when we fill it	id	dev			fu	sys	sub		
	26	10	110	also alarm for the bad positioning of food in front of the windows for cooling	id	dev			fu	sys	sub		
		25	15	let's come back to the level of technology	p		se		fu	sys	sub		
	27	25	60	first let's review ideas about smart fridge. Our ideas are related to smartness. Shall we add something new as smartness to the fridge?	p		se		fu	sys	sub		
		45	20	we thought first about changing the technology of cooling	p		se		fu	sys	sub		
		50	5	the other thing was adding new functions to the fridge	p		se		fu	sys	sub		
		55	5	why not thinking about fridge that can add boiler to the fridge?	id	dev			fu	sup		co	
	28	30	35	using the heat of back of fridge for boiling water. If we cannot change the cooling technology, why not using the heat for something useful?	id	dev			fu	sys	sub		
		45	15	this idea is similar to devices that provide both cold and hot water	p		ep		pr	si			an
	29	0	15	merging to water heater of home	id	dev			fu	sup		co	
		30	30	using the heat for warming the food	id	dev			fu	sys	sub		
	30	10	40	what else?	p		se		fu	sys	sub		
	31	15	65	also we thought before about removing heat or new source of energy	p		se		fu	sys	sub		
		35	20	shall we propose a new automatic mechanical energy?	p		se		fu	sys	sub		
	32	0	25	I cannot propose something new and let's finish	p		se		fu	sys	sub		
2	0	30	30	let's start with reviewing our ideas in previous session	p		se		fu	sys	sub		
	1	20	50	we can classify our thinking in different directions	p		se		fu	sys	sub		
		50	30	first we look at the technology of cooling and try to propose new way of cooling that doesn't produce heat	p		se		fu	sys	sub		
	2	10	20	like cool gas	p		se		fu	sys	sub		
		25	15	also we thought for new source of energy	p		se		fu	sys	sub		
		45	20	using energy of wind, chemical reaction for compressor	p		se		fu	sys	sub		
	3	10	25	also we thought for using heat for useful applications	p		se		fu	sys	sub		
		50	40	like using heat for boiling water or warming the food	p		se		fu	sys	sub		

	4	20	30	we learned that we can also merge some other appliances to the fridge	p		se		fu	sys	sub		
		55	35	like merging fridge with air conditioner and juice maker	p		se		fu	sys	sub		
	5	25	30	also we thought about smart fridge	p		se		fu	sys	sub		
	6	0	35	like the fridge that can manage the food and purchasing and cleaning	p		se		fu	sys	sub		
	7	35	95	now we have to think in a new way	p		se		fu	sys	sub		
		55	20	which new way we can think	p		se		fu	sys	sub		
	9	0	65	we have to find something for big change in technology	int			g	fu	sys	sub		
		15	15	let's start again about cooling system	p		se		fu	sys	sub		
		25	10	we want to cool down food	p		ep		pr	sys	obj		
		35	10	but we don't want the cooling system warm somewhere else	int			f	fu	sys	sub		
	10	0	25	we proposed cool gas that need heat to become cool	p		se		fu	sys	sub		
		25	25	what else we can propose?	p		se		fu	sys	sub		
		55	30	imagine kind of material that can absorb heat and release it somewhere else	id	dev			fu	sys	sub		
	11	45	50	using some Nano materials for the body of fridge	id	dev			fu	sys	sub		
	13	0	75	this material is full of tiny hollows that let warm air go outside and just cool air come inside	id	dev			fu	sys	sub		
		30	30	this Nano material also can be the material for self-cleaning as we proposed before	p		se		fu	sys	sub		
	14	45	75	in this way we remove all parts of cooling system. No need to condenser, gas, compressor and engine	p		se		fu	sys	sub		
	15	0	15	it means no need for energy	p		se		fu	sys	sub		
		30	30	is it possible to have such this Nano material?	p		se		fu	si			an
		45	15	otherwise we have to think again about new sources of energy	p		se		fu	sys	sub		
	16	0	15	energy is very important issue for future	p		se		fu	sup		uer	
		20	20	we proposed using heat also for warming or boiling water	p		se		fu	sys	sub		
		35	15	it means that we are not thinking only about cooling food	p		se		fu	sup		user	
	17	30	55	fridge can use for both cooling and warming and it means that fridge is a device for changing and controlling temperature inside kitchen	p		se		fu	sup		user	
		45	15	we can merge it with oven too	id	dev			fu	sup		co	
	18	10	25	I think we have to focus of function of fridge, it is for cooling food	p		se		fu	sys	sub		
	19	0	50	actually it is for preventing spoiling of food	p		ep		pr	sys	obj		
		40	40	it means that we can think about new way of prevention of spoiling even without cooling	id	dev			fu	sys	obj		
	20	10	30	the quality of food must be considered as same. It means that we want to keep fresh food healthy	int			f	pr	sys	obj		
		35	25	what are the causes for spoiling of food?	p		se		pr	sys	obj		
		55	20	bacteria can be considered as cause for spoiling	p		se		pr	sys	obj		
	21	15	20	how we can decrease the growth of bacteria?	p		se		pr	sys	obj		
		50	35	if we can propose a way to decrease the growth of bacteria	id	dev			fu	sys	sub		
	22	35	45	vacuuming can decrease the oxygen around food so the growth of bacteria decreases	p		ep		pr	si			an
		50	15	can vacuuming consider instead of fridge?	p		se		pr	si			alt
	23	15	25	we need new mechanism of vacuuming in special glasses that can decrease the growth of bacteria	id	dev			fu	sys	sub		
		35	20	vacuuming boxes are manageable in every cabinet	id	dev			fu	sup		co	
	24	10	35	vacuum boxes can be put even outside of kitchen	p		se		fu	sup		co	
		55	45	so we are facing some changes in apartments because fridge is one of important devices of fridge	p		se		fu	sup		co	
	25	25	30	no. still kitchen is needed for washing, packaging and vacuuming food and also cooking food	p		se		fu	sup		co	
		45	20	so let's think about the growth of bacteria	p		se		pr	sys	obj		
	26	10	25	bacteria are inside food and also inside the air around the food	p		se		pr	sys	obj		
		45	35	what are the other ways of decreasing the growth of bacteria?	p		se		pr	si			alt
	27	0	15	at least we proposed vacuuming for preventing spoiling	p		se		fu	sys	sub		

5. Team 5/ Session 1: without stimulus, Session 2: patent as a stimulus

Part	**Time (end)**			**Sentences**	**Concept** (idea, precedent, interpreter)	**Idea** (initial, developed)	**Precedent** (episodic, semantic, stimuli)	**Interpreter** (given, find)	**Time** (past, present, future)	**Space** (system, super system, sub system)	**Sys** (subsystem, object)	**Sup** (co-systems, user)	**Si** (alternative, analogy)
	Min	Sec	interval										
1	0	15	15	what we have to do?	*								
		30	15	we want to propose a new fridge	int			g	fu	sys	sub		

		40	10	do we work together or fist think individually	*								
		50	10	it is better to work together	*								
	1	0	10	what is the function of fridge?	p		se		pr	sys	sub		
		5	5	it cools down food	p		ep		pr	sys	sub		
		10	5	and also it is a container that occupy some places at home	p		ep		pr	sup		co	
		15	5	inside is cold	p		ep		pr	sys	sub		
		20	5	it has 2 parts one for fridge and one for freezer	p		ep		pr	sys	sub		
		30	10	why do we need fridge?	p		se		pr	sys	obj		
		40	10	it keeps food fresh	p		se		pr	sys	obj		
	2	0	20	shall we change the task subject? Something instead of fridge? No, we have to propose new fridge.	*								
		10	10	the fridge keeps food fresh	p		se		pr	sys	obj		
		20	10	do we want to improve the function of fridge?	p		se		fu	sys	sub		
		30	10	we want to satisfy the function with a radical change in technology	int			g	fu	sys	sub		
		40	10	by using less resources, receive same performance or even more	int			f	fu	sys	sub		
		45	5	do we want to reduce the cost?	int			f	fu	sys	sub		
		50	5	cost is one of factors	int			f	fu	sys	sub		
	3	0	10	let see what do we pay?	p		ep		pr	sys	sub		
	4	0	60	the cost we pay for purchasing the fridge, the cost of usage like the place, the energy, maintenance	p		ep		pr	sup		co	
		30	30	also the guarantee pays back some of maintenance	p		ep		pr	sup		user	
		45	15	they are some of characteristics of fridge	p		ep		pr	sys	sub		
	5	0	15	we can list the components of fridge	p		ep		pr	sys	sub		
		10	10	also we can mention the pollution of its gas	p		se		pr	sys	sub		
	6	40	90	cabinet, engine, compressor, condenser, door, the tubes for water providing, device for ice making, shelves, freezer, light, water filter, air filter, plastic drain around door, handle, wheels in bottom, anti-shock for electricity, electrical board, thermostat	p		ep		pr	sys	sub		
		55	15	the body is consisting of form, color, size,	p		ep		pr	sys	sub		
	7	0	5	we have now some characteristics and some elements	p		ep		pr	sys	sub		
		5	5	what are the differences among them?	p		se		pr	sys	sub		
		30	25	some of them are related to physical characteristics and some others are related to requirements of user that can be classified as market need	p		se		pr	sup		user	
		45	15	can we add some other requirements?	p		se		pr	sup		user	
	8	10	25	the cost of purchasing is based on the production costs, material and process	p		se		pr	sys	sub		
		20	10	we have to think about the need of market	p		se		pr	sup		user	
		45	25	let see again the cost; we had conceptual design, then design and engineering, then production, then marking, distribution and sale	p		se		pr	sup		co	
	9	20	35	again for market, we consider cost, pollution and environmental issues, ergonomic, aesthetic,	p		ep		pr	sup		co	
		30	10	if we want to improve the cost, we have to come back to company	p		se		pr	sup		co	
		50	20	we don't want to improve the cost. We want to propose new fridge that it for sure improve some things	int			g	fu	sys	sub		
	10	0	10	we also have to consider a significant change, not incremental improvements	int			g	fu	sys	sub		
		10	10	you mean we have not to consider the production line?	p		se		fu	sup		co	
		45	35	I think that we have to focus more on the product. You are more considering cost than any other issues	p		se		fu	sys	sub		
		55	10	what else can we consider?	p		se		fu	sys	sub		
	11	5	10	longer life-cycle	int			f	fu	sys	sub		
		15	10	it is an independent characteristic, because the fridge can be the same but works in a longer period	p		se		fu	sys	sub		
		25	10	for longer life-cycle, what technical aspects do we have to consider?	p		se		fu	sys	sub		
		45	20	for example, if we change something in the mechanism of the door, may be the door works for a longer period	p		se		fu	sys	sub		
	12	0	15	or when we have a transparent door after the outer door, it increases the life-cycle of the compressor	id	in			fu	sys	sub		
		10	10	because you decide without wasting the energy	p		se		fu	sys	sub		
		20	10	but I mean if we want to analyze the life-cycle, it refers to design	p		se		pr	sys	sub		
		35	15	every changes come back to design and then changes in production line	p		se		pr	sys	sub		
		45	10	let's think to the problems of the existing generation of fridge	p		se		pr	sys	sub		
	13	10	25	for example, we are working for LG, and we want to list the problems of our fridge to remove them	p		se		pr	sys	sub		
		20	10	the weight is so important especially for side-by side	p		se		pr	sys	sub		
		30	10	the fridge can be smaller but more real capacity	id	in			fu	sys	sub		

	14	0	30	also I think after some while the thermostat doesn't work well because in a same degree, nowadays my fridge doesn't work like before	int			f	pr	sys	sub		
		15	15	it means that we want to increase the life-cycle of elements	p		se		fu	sys	sub		
		25	10	also we want to increase the accuracy	p		se		fu	sys	sub		
		45	20	on the other hand, we have to consider that cost does not increase meanwhile	p		se		fu	sys	sub		
	15	10	25	to be flexible in size according to different houses, because we change our houses a lot and we move the fridge with ourselves	id	dev			fu	sys	sub		
		20	10	also we have to consider how to move and transfer	p		se		pr	sys	sub		
		40	20	also we like different color, flexibility in color	id	dev			fu	sys	sub		
		50	10	so we can think about different kind of flexibility	p		se		fu	sys	sub		
	16	0	10	change the color of fridge in different season	p		se		fu	sys	sub		
		10	10	also easier way of cleaning	id	in			fu	sys	sub		
		30	20	because we have to bring out all the layers and then clean the fridge and again bring back the layers	p		se		pr	sys	sub		
		50	20	also we can think about the less energy consumption	id	in			fu	sup		co	
	17	5	15	the condenser makes the wall of kitchen in back of fridge dirty and we need self-cleaning condenser	id	dev			pr	sup		co	
		20	15	the air between back of fridge and wall become hot and stick to the wall	int			f	pr	sup		co	
		30	10	the ice cubes stick together and comes out of its device difficulty	int			f	pr	sys	sub		
		40	10	because it is making ice continuously and when we consume less, the cubes stick together	p		se		pr	sys	sub		
	18	0	20	it stops when it is full but it seems that sometimes the ice melt and stick together	p		se		pr	sys	sub		
		30	30	but I think it is matter of time not temperature and it happens during winter when we consume less than usual	p		se		pr	sys	sub		
		50	20	so the ice making must be flexible to the consumption	id	in			fu	sys	obj		
	19	0	10	even we can order for more according to our need for parties	id	dev			fu	sys	sub		
		15	15	now we can change the position of layers, they are strong for any expected weight, …	p		se		pr	sys	sub		
		40	25	so what are the problems of layers?	p		se		pr	sys	sub		
	20	0	20	material of layers must be stronger to not broken by any kind of strike and self-cleaning	id	dev			fu	sys	sub		
		10	10	do you see any problem related to light?	p		se		pr	sys	sub		
		15	5	no	p		se		pr	sys	sub		
		20	5	what about water filter	p		se		pr	sys	sub		
		30	10	the cost is so high and we have to change it time to time very soon	int			f	pr	sys	sub		
		40	10	when you call for service, they say to push on some keys on the board to make its alarm off, if you don't want to change the filter	p		ep		pr	sys	sub		
		50	10	it is not good, because it worsens something else in the fridge	p		se		pr	sys	sub		
	21	0	10	so we want cheap filter with easy and fast changing procedure	int			f	fu	sys	sub		
		10	10	we can think about the filter	p		se		fu	sys	sub		
		15	5	a self-cleaning filter after some usage period	id	dev			fu	sys	sub		
		25	10	or even it doesn't become dirty	id	dev			fu	sys	sub		
		35	10	or very cheap filter that users change by themselves	id	dev			fu	sys	sub		
		45	10	also one of the problems is that the air of inside fridge gets bad smell after some while	int			f	pr	sys	sub		
		55	10	we have to think about ventilation inside fridge	id	in			fu	sys	sub		
	22	5	10	using materials for body of fridge that don't get smell	id	dev			fu	sys	sub		
		10	5	also the door drain is so important because it keeps the cold air and saves the energy	p		se		pr	sys	sub		
		15	5	but I don't see any problem	p		se		pr	sys	sub		
		25	10	I mean I think it is not a big issue for next generation of fridge	p		se		pr	sys	sub		
		35	10	also I don't see any benefit to consider handle and wheels for changes	p		se		pr	sys	sub		
		45	10	but we have the problem related to anti-shock device	int			f	pr	sys	sub		
	23	0	15	the engine of fridge is sensitive to the stokes in electricity especially for Iran and it needs anti-shock	id	dev			fu	sys	sub		
		15	15	it needs ups like we use in big organizations	id	dev			fu	sys	sub		
		25	10	also we don't have problem with the board	p		se		pr	sys	sub		
		45	20	but we have problem with the thermostat as I mentioned before	int			f	pr	sys	sub		
		55	10	we also mentioned the weight	int			f	pr	sys	sub		
	24	5	10	is the price high compare to its function?	p		se		pr	sup		user	
		15	10	we have to consider the affordability of people for buying home appliances	p		se		pr	sup		user	
		35	20	if we think to the average income of an engineer, the price of fridge is so high	p		se		pr	sup		user	

		45	10	also always the customer wants less price	p		se		pr	sup		user	
		55	10	also we mentioned the cost of energy	p		se		pr	sup		user	
	25	5	10	also the cost for maintenance must be considered	p		se		pr	sys	sub		
		15	10	some of the elements even cannot be repaired and we have to change that element completely	p		se		pr	sys	sub		
		40	25	for example, if the door damages in movement, shall we ask for replacement?	p		se		pr	sys	sub		
		55	15	we don't know and we didn't try	p		se		pr	sys	sub		
	26	5	10	now a day the gas is more friendly to nature	p		ep		pr	sys	sub		
	27	0	55	12 years ago, it was a new standard for that but I think it was for purchasing new technology, they also supported for some changes in technology	p		se		pa	sys	sub		
		10	10	for the ergonomic issues we can consider the up-down side fridge and freezer as the children cannot use fridge very well	id	dev			fu	sys	sub		
		20	10	sometimes the door of fridge remains open for this reason	int			f	pr	sys	sub		
		25	5	it is not compatible for all members of family	p		se		pr	sup		user	
		30	5	also sometimes we want that children don't access to somethings	p		se		pr	sup		user	
		35	5	are we talking about the size?	p		se		pr	sys	sub		
		45	10	we are working on the ergonomic issues	p		se		pr	sup		user	
	28	0	15	for example, the fridge is taller than women and they cannot access the food on the upper layer; they cannot see or even if they see, they have to bring out everything in front to access them	p		se		pr	sup		user	
		10	10	also it is better that depth of fridge be not so much to access that forest food easily	id	dev			fu	sys	sub		
		20	10	or inside the fridge can be like a rotator to reach every part easily	id	dev			fu	sys	sub		
		40	20	also the problem is that the place for fruit is in the lowest part while we want to encourage people to eat more fruit than anything else	int			f	fu	sup		user	
		50	10	it is better to change the place of fruits	id	dev			fu	sys	sub		
	29	0	10	this issue is so related to culture	p		se		pr	sup		user	
		15	15	so from the ergonomic point of view, we want easier access to every part	p		se		fu	sys	sub		
		30	15	or even change the priority for accessing food according to culture and needs	p		se		fu	sys	sub		
		40	10	or even we can think about alarms for using the food before the expire time	id	in			fu	sys	obj		
		45	5	these ideas increase the price	p		se		fu	sys	sub		
		55	10	we can make it by barcodes. We get a barcode to each food before put it in the fridge that can control the inventory instead of user	id	dev			fu	sys	sub		
	30	20	25	even it can be some small devices on each food that can analyze the food	id	dev			fu	sys	sub		
		30	10	this idea is a little complicated	p		se		pr	sys	sub		
		40	10	it is better not to think about the details. First think about all potentials for improvement and then select one of them to go to the details	p		se		pr	sys	sub		
		50	10	so we want to show the life period of the food and give alarms respect to that	p		se		pr	sys	obj		
	31	0	10	also if fridge can accept some of our duties	p		se		pr	sup		user	
		15	15	if the fridge can control the amount of food like a store	id	dev			fu	sys	obj		
		20	5	this idea needs orders in putting the food inside the fridge and it is difficult for user	p		se		fu	sys	sub		
		25	5	this is the problem of design	p		se		fu	sys	sub		
		30	5	we can interface with a smart board	p		se		fu	sys	sub		
		35	5	it makes it so digital	p		se		fu	sys	sub		
		45	10	now we just mention that smart storage is important for us	p		se		fu	sys	sub		
		55	10	we are just writing general ideas and then select among them to go deeper	p		se		fu	sys	sub		
	32	0	5	did we talk about the aesthetic issues?	p		se		fu	sys	sub		
		15	15	we talked about flexibility in color and form	p		se		fu	sys	sub		
		30	15	the fridges are similar with only some changes in size	p		se		pa	sys	sub		
		45	15	we need that the size changes according to new place when we move our house	id	dev			fu	sys	sub		
	33	0	15	the size of fridge is measured by foot	p		ep		pr	sys	sub		
		10	10	I think it is better to select one of the issues to work on that in detail	p		se		pr	sys	sub		
	34	10	60	let’s look at the list	p		se		pr	sys	sub		
		20	10	we have to decide which one is more important	p		se		pr	sys	sub		
		25	5	how about weight?	int			f	fu	sys	sub		
		35	10	because the weight is also related to size, material, the sub set devices,	p		se		pr	sys	sub		
		45	10	so it becomes difficult to have good conclusion	p		se		fu	sys	sub		
	35	0	15	I think we can think about the water filter because it is so expensive	int			f	pr	sys	sub		

		15	15	do you know the price of the filter? It costs approximately 45 euro and you have to change it twice in a year	p		ep		pr	sys	sub		
		25	10	it means after 6 years you payed equal to price of fridge	p		ep		pr	sys	sub		
		30	5	yes. We can continue for water filter	int			f	pr	sys	sub		
		40	10	what is the mechanism of water filter?	p		ep		pr	sys	sub		
		50	10	I am a software engineer and I don't know it	*								
	36	15	25	the water comes from tap to the fridge and the filter is inside the device for cooling the water	p		ep		pr	sys	sub		
		35	20	in oil industry we have some different kind of filters; chemical or mechanical	p		ep		pr	si			an
		45	10	mechanical uses mesh	p		ep		pr	si			an
	37	0	15	in oil industry even we use layers of sand and it means that in the mesh they can use different particles to clean the water	p		ep		pr	si			an
		15	15	also we can think about ultrasonic	p		ep		pr	si			an
		20	5	what about the chemical ones?	p		ep		pr	si			an
		25	5	I think for the fridge we have chemical ones	p		ep		pr	si			an
		30	5	no I think it is mechanical	p		ep		pr	si			an
		45	15	in chemical there are some catalyst that make some particles to be acted and merged to become bigger and removable	p		ep		pr	si			an
	38	0	15	I think for mechanical we can add some different layers with different degree	p		ep		pr	si			an
		5	5	let's think about the function of filter	p		se		pr	sys	sub		
		30	25	the filter receives the tap water and transfer it to drinking water	p		ep		pr	sys	sub		
		45	15	the tap water in Tehran is drinkable so do we need this filter?	p		ep		pr	sup		co	
	39	25	40	chemical filter, realize the material of particles and add something to act on them to become collectable	p		ep		pr	si			an
		40	15	also they add some materials to kill bacteria	p		ep		pr	si			an
		50	10	and also make some particles to be settled	p		ep		pr	si			an
	40	10	20	so we have different stages to reach acceptable micron of particles	p		ep		pr	si			an
		15	5	why we were reviewing the mechanism?	p		se		pr	sys	sub		
		25	10	we want a filter with same quality but less price	int			f	fu	sys	sub		
		45	20	we want to change it not less than 2 years because even we have to pay for both filter and service	int			f	fu	sys	sub		
	41	5	20	shall we use internet to check the filter's mechanism?	*								
		45	40	maybe we can propose a new filter even without considering the mechanism of existing filters	p		se		fu	sys	sub		
	42	0	15	we can think about a filter that can satisfy our desires	p		se		fu	sys	sub		
		15	15	we want to increase the life expand of filter	int			f	fu	sys	sub		
		35	20	we have to consider using ultrasound	id	dev			fu	sys	sub		
	43	0	25	when water comes to the fridge in different part, we use different ultrasound waves to separate different particles	id	dev			fu	sys	sub		
		45	45	in oil industry we use metal meshes that they work for 10 years	p		ep		pr	si			an
	44	0	15	these metal meshes separate gases and vapor	p		ep		pr	si			an
		10	10	they are mechanical	p		ep		pr	si			an
		20	10	when we make ice, the particles are separating	p		ep		pr	si			an
		30	10	so we can first let the water to freeze and then melt it again to have drinking water	id	dev			fu	sys	sub		
		45	15	we can use the heat of condenser for melting	id	dev			fu	sys	sub		
	45	0	15	it is better to be as simple as possible	p		se		fu	sys	sub		
2	0		0	read the first patent	p		st		fu	si			an
	2	25	14 5	reading	p		st		fu	si			an
		45	20	it is about a tower that uses different layers to cool down very hot metal	p		st		fu	si			an
		55	10	let's look at the second one	p		st		fu	si			an
	3	45	50	reading	p		st		fu	si			an
	4	35	50	it is about ice cream maker and its sensor to detect the hardness of ice cream	p		st		fu	si			an
	6	15	10 0	read the third one	p		st		fu	sys	sub		
		55	40	it is about the door with actuator that close the open door automatically or even the door is damaged the casing substitute that	p		st		fu	sys	sub		
	7	5	10	it reminds me a cell phone that can be used when the door is open	p		ep		fu	si			an
		10	5	we have actuator in the valves of oil	p		ep		fu	si			an
		50	40	read the fourth patent	p		st		fu	sys	sub		
	8	5	15	it is about the system for automatic storing	p		st		fu	sys	sub		
		10	5	I think the one related to the tower is more related to us	p		se		pr	sys	sub		
	9	50	10 0	read the fifth patent	p		st		fu	sys	sub		
	10	20	30	it seems it is a modular fridge that can be assembled at home	p		st		fu	sys	sub		

		30	10	it means a separated fridge that can be put together easily by user	p		st		fu	sys	sub		
		45	15	it is easier in this way for any movement	p		se		fu	sys	sub		
	11	5	20	and also can be good if we can shape them according to our place	p		se		fu	sys	sub		
		10	5	we don't to follow this direction because we are focused on the filter	p		se		fu	sys	sub		
		45	35	we don't care about closing door, ice cream making	p		se		fu	sys	sub		
	14	0	135	read again the ice cream making	p		st		fu	si			an
	15	0	60	it has a pot that is rotating to mix the ingredients while cooling, and it has a sensor to control the process	p		st		fu	si			an
		25	25	using ultra with different wavelength to separate particles from water	id	dev			fu	sys	sub		
		30	5	you explain static meshes for collecting particles of water	p		se		pr	sys	sub		
		35	5	I am thinking about a dynamic process	p		se		fu	sys	sub		
	16	30	55	tower is like our mechanical idea that we have different layers of meshes	p		se		pr	sys	sub		
	17	30	60	let's read the related patent again	p		st		fu	si			an
		50	20	meshes and the wholes are designed based on particles	p		se		fu	si			an
	18	40	50	read again the patent	p		st		fu	si			an
	19	0	20	the layers are to separate different things	p		se		fu	si			an
	20	0	60	read again the patent	p		st		fu	si			an
	21	5	65	it was first, mesh the layer of graphite and then 3 layers of carbon and finally one ceramic layer	p		st		fu	si			an
		25	20	it changes the temperature	p		st		fu	si			an
	22	0	35	so we can also use condenser temperature to remove some different particles	id	dev			fu	sys	sub		
		45	45	it means that we use the structure of layers and try to remove particles in different layers by different temperature	id	dev			fu	sys	sub		
		55	10	it becomes mechanical- thermal	p		se		fu	sys	sub		
	23	15	20	we have to kill bacteria and remove the particles by using different layers, temperature and also ultrasound	int			f	fu	sys	obj		
		25	10	also we can use Gama waves	id	dev			fu	sys	sub		
		45	20	so we used the one of the patents to propose idea	p		se		pr	sys	sub		
	25	45	120	draw a picture for the idea first layer: mesh for absorbing bigger particles second layer: smaller mesh third layer: smaller mesh using Gamma or ultrasonic for make the water healthy	p		se		fu	sys	sub		
	26	30	45	we can even separate the particles without using temperature	p		se		fu	sys	sub		
		45	15	Gama is for killing bacteria	p		se		fu	sys	sub		
	27	30	45	the fridge can have also a tube for removing not drinking water	id	dev			fu	sys	sub		
		45	15	it can be like washing machine	p		ep		pr	si			an
	28	0	15	we try to remove the particles and the part which is with more hardness, remove out	p		se		fu	sys	sub		
		45	45	we can also add process of enriching water or vitaminize it	id	dev			fu	sys	obj		
	29	0	15	add pills or vitamin	id	dev			fu	sys	obj		
		10	10	some of brands of water claim for this	p		ep		pr	si			an
		30	20	the devices for watering have some parts for adding fertilizer or plant poison	p		ep		pr	si			an
	30	0	30	also we can think that the meshes are like a plate that can be brought out by user to wash it	id	dev			fu	sys	sub		
	31	0	60	it is enough and we have our suggestion	*								

6. Team 6/ Session 1: without stimulus, Session 2: engineering procedure as a stimulus

Part	Time (end)			Sentences	Concept	Idea	Precedent	Interpreter	Time	Space	Sys	Sup	Si
	Min	Sec	interval		(idea, precedent, interpreter)	(initial, developed)	(episodic, semantic, stimuli)	(given, find)	(past, present, future)	(system, super system, sub system)	(subsystem, object)	(co-systems, user)	(alternative, analogy)
1	0	45	45	we want a new fridge	int			g	fu	sys	sub		
	1	0	15	shall we list first the limitations?	p		se		fu	sys	sub		
		10	10	we want a fridge in a new s-curve	p		se		fu	sys	sub		
		20	10	we want a new technology	p		se		fu	sys	sub		
		35	15	it must be aligning with future technologies	p		se		fu	sys	sub		

		45	10	let's start with fridge	p		se		fu	sys	sub		
	2	5	20	our task is a domestic fridge	p		se		fu	sys	sub		
	3	0	55	I think it is better to start with limitations of existing version of fridge then work on some of them to propose a new technology for that	p		se		pr	sys	sub		
		15	15	for example, why do we have to store the food in a box and it limits us.	int			f	pr	sys	sub		
		25	10	it occupies some part of home	int			f	pr	sup		co	
		35	10	We want only that the food to be healthy every where	id	in			fu	sys	sub		
	4	10	35	it means that when we want our food, we have to go to the kitchen to pick up the food	p		se		pr	sup		user	
		35	25	we have different food, with different request, some must be frozen, some must be cool down, and even some food must remain fresh and healthy not cold	p		ep		pr	sys	obj		
		55	20	it means that we use energy as the same for all kind of food and all various requests	p		se		pr	sys	sub		
	5	20	25	we need to adjust temperature for each kind of food	id	in			fu	sys	obj		
		35	15	also the energy usage is one important issue by itself	p		se		pr	sys	sub		
		50	15	you are talking about our expectation from fridge	p		ep		pr	sup		user	
	6	0	10	let's list all and then think about the technologies we can use to remove the limitations	p		se		pr	sys	sub		
		45	45	I think beside the limitation in a box and energy, we have also limitation in space	p		ep		pr	sys	sub		
	7	15	30	I mean that we have to dedicate a space to the fridge in a kitchen	int			f	pr	sup		co	
		30	15	also we have the problem of capacity	int			f	pr	sys	sub		
		40	10	if we had a flexible size, we could use it with different amount of need	id	dev			fu	sys	sub		
	8	0	20	we buy a big fridge because we consider the pick for most amount of usage but a long period of time, we don't need to work with full load	p		se		pr	sup		user	
		30	30	also flexible size can save energy	p		se		pr	sys	sub		
		50	20	so we considered some of limitations up to here	p		se		pr	sys	sub		
	9	0	10	now we can consider about different kind of usage	p		ep		pr	sup		user	
		10	10	we want it for keep food fresh	id	in			pr	sys	obj		
		25	15	we also want it to make the drinking cool down rapidly	id	in			fu	sys	obj		
		40	15	I mean we consider both cooling and keeping food fresh	p		ep		pr	sys	sub		
	10	0	20	usually cooling is short term need	p		se		pr	sup		user	
		10	10	while in freezing we consider even some month, from summer to winter	p		se		pr	sup		user	
		25	15	now we can consider some of the other problems in the home	p		se		pr	sup		co	
		40	15	I mean as we want to propose a new fridge, we can consider home and propose something related to that	p		se		pr	sup		co	
	11	5	25	it means we can consider the limitation of existing fridge and also some of our needs in home	p		se		pr	sup		co	
		10	5	that is a good approach	p		se		pr	sup		co	
		30	20	we have lots of home appliances that we need them and they occupy the space	p		se		pr	sup		co	
		45	15	we have cabinets in the kitchen	p		se		pr	sup		co	
	12	0	15	we always think that fridge must be in the kitchen	p		se		pr	sup		user	
		10	10	if it becomes nicer we can put it in the living room	p		se		pr	sup		user	
		20	10	but we need some part of fridge inside kitchen	p		se		pr	sup		co	
		35	15	we can think to spread the function of fridge in all over the house	p		se		pr	sup		co	
	13	0	25	some part that we need for cooking, inside kitchen and some part for drinking and fruits inside living room	id	dev			fu	sys	sub		
		15	15	also we can think about moveable fridge to move it by yourself when you are in the living room, when you are in the study room, …	id	dev			fu	sys	sub		
		30	15	I had a friend living alone and he said that his fridge is inside his bedroom	p		ep		pr	sup		user	
	14	0	30	we are thinking about possibility of separating the parts like air conditioner	p		ep		pr	si			an
		20	20	separating seems removing some of limitations, like different applications	p		se		pr	si			an
		30	10	but what about energy usage?	p		se		pr	sys	sub		
		40	10	as fridge and freezer are together we save energy	p		se		pr	sys	sub		
		55	15	if we merge fridge with air conditioner, we save energy again	id	dev			fu	sup		co	
	15	5	10	I think splitting in space. I mean one compressor outside and then some air cooling device in some different places	p		se		fu	sys	sub		
		15	10	so the energy usage is not increasing by separating, we just need system of connection of tubes	p		se		fu	sys	sub		
		25	10	for sure we have waste of energy in tubes but maybe at the end it is better	p		se		fu	sys	sub		
		35	10	what other limitations do we have at home?	p		se		pr	sys	sub		
		45	10	as we are proposing fridge for future, also we can consider the time of users	p		se		fu	sup		user	

	16	10	25	we will be less at home	int			f	fu	sup		user	
		25	15	unless we will work from distance at home	p		se		fu	sup		user	
		35	10	I think that we will be less at home	p		se		fu	sup		user	
		55	20	so will cook less	p		se		fu	sup		user	
	17	55	60	so we need to prepare food in a shorter time	p		se		fu	sup		co	
	18	45	50	let's think about price too	int			f	fu	sys	sub		
	19	5	20	yes, cost is an important issue	p		se		fu	sys	sub		
		20	15	the price is increasing because the technology is constant but we add more options on the fridge	p		se		pr	sys	sub		
		45	25	2 layer doors, device for ice making, small door, some systems for less noise	p		ep		pr	sys	sub		
		50	5	the technology is the same	p		se		pr	sys	sub		
	20	10	20	we can add with anti-bacterial device too	id	dev			fu	sup		co	
		30	20	it is like a car, now we are changing the options for safety, …	p		ep		pr	si			an
		45	15	if we want to consider the direction of changes?	p		se		fu	sys	sub		
		55	10	the car can be considered as part of transportation system and we don't have changes in inter connection of car and road	p		se		pr	si			an
	21	15	20	the changes are related to driver. We supprt its information and decisions	p		se		pr	si			an
		20	5	we can think about this direction of changes in fridge	p		se		fu	sys	sub		
		35	15	one direction is related to user and the other direction is related to food	p		se		fu	sup		user	
		40	5	so we can propose our ideas based on these 2 directions	p		se		fu	sup		user	
		50	10	what changes do we have in food in future	p		se		fu	sys	obj		
	22	0	10	or what changes we face in users	p		se		fu	sup		user	
		15	15	we wrote about the user	p		se		fu	sup		user	
		25	10	we didn't talk about the food very precisely	p		se		fu	sys	obj		
		35	10	the final object is food	p		se		fu	sys	obj		
	23	0	25	the final aim is that we want not spoiled food at the end	int			f	fu	sys	obj		
		30	30	we have to also consider always the safety issues because the fridge is electrical and we have fire and water inside kitchen	id	dev			fu	sys	sub		
		45	15	it is one of the limitations	int			f	fu	sys	sub		
	24	0	15	we wash the kitchen floor very often	p		ep		pr	sup		co	
		35	35	so for future fridge, up to now we didn't add a new expectation?	p		se		pr	sup		co	
		50	15	we just consider cooling food respect to future characteristics and limitations	p		se		pr	sys	sub		
	25	20	30	what is the difference for us among cooling and keeping cool?	p		se		pr	sys	sub		
		40	20	we have limited in time now	*								
		55	15	we have 20 min to propose idea	*								
	26	5	10	what are the technologies we can use?	p		se		fu	sys	sub		
		15	10	we didn't change the function and just we studied the condition of future	p		se		fu	sup		user	
		25	10	we are saying that we don't have big difference in future life style	p		se		fu	sup		user	
		35	10	and so the problem is the same	p		se		fu	sup		user	
	27	0	25	we just mentioned that the cooking must be faster	p		se		fu	sup		user	
		10	10	we can consider some changes in the culture too	p		se		fu	sup		user	
		20	10	some factors, pushes us to use fast food	p		se		fu	sys	obj		
		35	15	I mean that according to our culture we don't accept fast food and frozen ingredients from the market	p		ep		fu	sup		user	
		50	15	but it happened and we buy frozen ingredients and fast food	p		se		fu	sys	obj		
	28	10	20	in cooking, we have less time and we have to buy frozen ingredients	p		se		fu	sys	obj		
		20	10	so do we have to be supportive for this changes?	int			f	fu	sys	sub		
		30	10	we want to propose new fridge and we have to consider these changes	p		se		fu	sys	sub		
	29	30	60	so the food in future, are frozen or semi-cooked food	p		se		fu	sys	obj		
		45	15	semi-cooked food means more risk for spoiling and we have to control it	p		se		fu	sys	obj		
		55	10	what are the ways we know?	p		se		fu	sys	obj		
	30	30	35	I mean in past we were keeping the fresh food	p		se		pa	sys	obj		
		40	10	and in future we are preserving frozen and semi-cooked food	p		se		fu	sys	obj		
	31	10	30	it means that in past we got the food from natural farms	p		se		pa	sup		co	
		20	10	but now we receive from factories	p		se		pr	sup		co	
		45	25	may be the differences can help us. We have new kind of packing now and in future compare to the past	p		se		pr	sup		co	
	32	0	15	do we have any changes?	p		se		pr	sup		co	
		30	30	I cannot mention something more	p		se		pr	sup		co	
		55	25	let's think for a while	p		se		pr	sup		co	
	33	0	5	now the question is what is the next technology?	p		se		fu	sys	sub		
		10	10	what is the technology of cooling?	p		se		pr	sys	sub		
		20	10	split works like fridge	p		ep		pr	si			an
		30	10	split is also using thermal and solar energy for more efficiency	p		ep		pr	si			an

		40	10	we have less humidity in split compare to previous generations of air conditioner	p		ep		pr	si			an
	34	0	20	the air conditioner is like fridge so we can consider the changes of its technology for the fridge too	p		ep		pr	si			an
		30	30	we can use solar energy for energy of fridge too	id	dev			fu	sys	sub		
		50	20	you mean that we divide the frige in different parts and put every part in different place?	p		se		fu	sys	sub		
	35	0	10	no. I just want to add a panel to the fridge outside of home to use solar energy and less electrical energy	p		se		fu	sys	sub		
		10	10	it is not a significant change in technology	p		se		fu	sys	sub		
		50	40	if we want to change the technology, we can consider changing in devices or even methods and knowledge	p		se		fu	sys	sub		
	36	5	15	it means we have two directions	p		se		fu	sys	sub		
		20	15	to propose a new device for cooling	p		se		fu	sys	sub		
		35	15	or devices for keeping food healthy	p		se		fu	sys	sub		
		45	10	think about cooling or keeping healthy	p		se		fu	sys	sub		
	37	10	25	I don't know how to proceed	p		se		fu	sys	sub		
		30	20	I mean propose a solution for keeping food healthy instead of cooling	p		se		fu	sys	sub		
		50	20	it reminds me of pills of essence of meat that it does not to be kepth in the fridge	p		ep		pr	si			an
	38	25	35	for selecting the direction, I think we select cooling, we propose a system that can be substitute the current fridge	p		se		fu	sys	sub		
		30	5	it doesn't change any thing in the house	p		se		fu	sup		co	
		35	5	there is a market for that	p		se		pr	sup		user	
		45	10	but if we propose an idea for keeping food healthy, we make some changes in around	p		se		fu	sup		co	
		55	10	and it is new market that we don't know about that	p		se		pr	sup		user	
	39	10	15	it is better to work on cooling	int			f	fu	sys	sub		
		30	20	also may be it takes less time to propose idea	p		se		fu	sys	sub		
	40	0	30	because in the other scenarios we have to analyze many things and consider new elements	p		se		fu	sys	sub		
		20	20	we can think about all the other situations that we do cooling	p		ep		pr	si			alt
		35	15	we can do brain storming for writing technonolgies for cooling	*								
		50	15	we have to list cooling technologies for food that most of them have water inside	p		ep		pr	si			alt
	41	0	10	It reminds me of warming in the microwave	p		ep		pr	si			an
		10	10	and this water was the important factor for possibility of using microwave	p		ep		pr	si			an
		25	15	using the movement of water particles	p		ep		pr	si			an
		35	10	when this movement fixes, we have frozen food?	p		se		pr	sys	obj		
		45	10	yes. It makes them solid	p		se		pr	sys	obj		
	42	0	15	do we have any technology to fix the movement of water molecules?	p		se		pr	sys	sub		
		15	15	cooling, gets the energy of food and release outside to decrease the movement	p		ep		pr	sys	sub		
		35	20	it means we can change the problem: transfer the heat outside the fridge	p		ep		pr	sys	sub		
		45	10	now there is a mediator, gas, that transfer the heat outside	p		ep		pr	sys	sub		
		55	10	because of that we have heat in back of the fridge around condenser	p		se		pr	sys	sub		
	43	5	10	shall we use this heat for a useful function	id	dev			fu	sup		co	
		45	40	the technology for thermal transfer are convection, radiation, …	p		se		pr	si			an
	44	30	45	we use a box to control the amount of air for transferring heat	p		ep		pr	sys	sub		
	45	40	70	which technology can we use to transfer heat?	p		se		pr	sys	sub		
	46	10	30	also in current technology they use changes in pressure and speed	p		ep		pr	sys	sub		
		20	10	using very thin tubes to make more pressure and the gas release its heat	p		ep		pr	sys	sub		
		30	10	so here they use of some characteristics of gas, relation of its pressure and temperature	p		ep		pr	sys	sub		
	47	0	30	we are thinking that we don't want the mediator	id	in			fu	sys	sub		
		35	35	so our new technology could remove mediator by being in touch with a cold material	id	dev			fu	sys	sub		
		45	10	a metal that become cold by waves	id	dev			fu	sys	sub		
	48	5	20	the air of inside fridge is in touch with this metal or cold plate	p		se		fu	sys	sub		
		30	25	we have to consider the efficiency of this method too	p		se		fu	sys	sub		
	49	45	75	you mean the temperature is relation in volume and pressure?	p		se		pr	sys	sub		
		55	10	yes, we use this relation in current version of fridge	p		se		pr	sys	sub		
	50	5	10	in this mechanism gas transfer to liquid to release the heat and then transfer to gas to absorb heat	p		ep		pr	sys	sub		
		10	5	we are thinking to remove the gas	p		se		fu	sys	sub		
2	0	30	30	first stage: duty of system	p		st		pr	sys	sub		

	1	0	30	the function of system is obvious	p		ep		pr	sys	sub		
		30	30	cooling the food	p		ep		pr	sys	sub		
	2	30	60	or storing food inside fridge to keep it healthy	id	dev			fu	sys	sub		
	3	15	45	also I was thinking about ready to use food not just cooling	id	dev			fu	sys	obj		
		30	15	why do we need coldness?	p		se		pr	sys	sub		
		40	10	we use cooling just for increasing the time span	p		se		pr	sys	sub		
	4	15	35	second stage: we want to analyze the system	p		st		pr	sys	sub		
		45	30	we want to propose next generation of system and it is future	int			g	fu	sys	sub		
	5	0	15	while we are analyzing current version of fridge	p		st		pr	sys	sub		
		15	15	the current generation is no-frost technology	p		ep		pr	sys	sub		
		25	10	what were the previous generation?	p		st		pa	sys	sub		
	6	0	35	if we don't want to focus only on cooling, in past we had some special places in basement of our home for keeping food healthy	p		ep		pa	si			alt
		10	10	that room usually were colder than every other part of home and also dark	p		ep		pa	si			alt
		25	15	also we had some Coleman with changeable ice that the people used to buy ice every day	p		ep		pa	sys	sub		
		35	10	do we have a generation between?	p		ep		pa	sys	sub		
		55	20	we had a fridge with another kind of energy sources	p		ep		pa	sys	sub		
	7	5	10	the mechanism was similar to current generation but the used oil	p		se		pa	sys	sub		
		25	20	I didn't know that we had fridge working with oil	p		ep		pa	sys	sub		
		35	10	it wasn't so long period because electricity came soon to the life	p		ep		pa	sys	sub		
		55	20	so we can consider the oil-fridge as previous generation	p		ep		pa	sys	sub		
	8	25	30	so we face transition among to generation when the electricity came to the houses and buildings	p		se		pa	sys	sub		
		40	15	also we have version between with the name of no-frost	p		se		pa	sys	sub		
	9	25	45	what do we have to do?	p		st		pr	sys	sub		
		45	20	what are the changes among past to present?	p		st		pr	sys	sub		
	10	15	30	we can consider the first version of fridge from the version that we consumed energy to cool down food	p		se		pa	sys	sub		
		30	15	the generation that do cooling completely at home and we didn’t need to buy ice	p		se		pa	sys	sub		
	11	30	60	what were the differences among normal fridge and no-frost?	p		st		pa	sys	sub		
	12	30	60	what were changes in the super-system?	p		st		pa	sup		co	
		45	15	we have smaller houses and kitchens	p		ep		fu	sup		co	
	13	10	25	we are living more alone than before	p		ep		fu	sup		user	
		25	15	but the fridges are bigger than before	p		ep		pr	sys	sub		
		40	15	first they became taller but now even bigger	p		ep		pr	sys	sub		
	14	0	20	shall we analyze fridge alone and freezer alone?	p		se		pr	sys	sub		
		35	35	yes, it becomes bigger because these two devices merged together	p		se		pr	sup		co	
	15	25	50	also in the super-system level we have changes in the life-style of users that they want rapid cooking	p		se		pa	sup		user	
		45	20	we have also increases in the price of energy	p		se		pa	sup		co	
		55	10	what else?	p		ep		pa	sup		co	
	16	50	55	also everything is affected by digital and IT	p		ep		pa	sup		co	
	17	15	25	also we are all connected	p		ep		pa	sup		co	
		30	15	let's look at the elements	p		st		pr	sys	sub		
	20	30	18 0	in the current version, more efficient compressor, board for adjusting and controlling temperature, fluidity of air in the container, device for cooling water, ice maker, multi-door and small door,	p		ep		pr	sys	sub		
	21	10	40	we don't see any significant changes in layers and shelves	p		ep		pr	sys	sub		
		25	15	what were the elements of previous generation?	p		ep		pa	sys	sub		
	25	0	21 5	we didn't have no-frost, we had condenser, mechanical internal device for temperature control, just some small part for freezer,	p		ep		pa	sys	sub		
		10	10	what about super-system of past?	p		st		pa	sup		co	
		35	25	ingredients were fresh, more time for cooking,	p		ep		pa	sys	obj		
		45	10	do you think that now we put the food inside fridge longer or in the past?	p		se		pa	sup		user	
	26	5	20	in past the family numbers were higher and they bought more	p		se		pa	sup		user	
		15	10	I think we put for longer now, because we are less in numbers	p		se		pr	sup		user	
		25	10	shall we say that the time span of keeping food in fridge has changed?	p		se		pr	sys	obj		
		35	10	we have to be faster, we don't have time	p		se		pr	sup		user	
		45	10	what do we have to do next?	p		st		pa	sys	sub		
	27	10	25	we have to find the problems were solved from past to present	p		st		pa	sys	sub		
		45	35	the most important is removing the frost	int			f	pa	sys	sub		
		50	5	what else?	p		st		pa	sys	sub		
	28	30	40	easier access to water and ice and also separate freezer	int			f	pa	sup		co	

	29	10	40	control and change the temperature from outside	int			f	pr	sys	sub		
		50	40	less usage of energy	int			f	pr	sys	sub		
		55	5	what in the super-system?	p		st		pr	sup		co	
	30	30	35	less usage of energy is also related to super-system	int			f	pr	sup		co	
	31	0	30	the price of energy has increased	p		se		pr	sup		co	
		45	45	better usage of space because of merging of some systems	int			f	pr	sup		co	
	32	0	15	let's go to third stage	p		st		pr	sys	sub		
	33	15	75	we have to find the improvements of solved problems and check the possibility of using it again	p		st		pr	sys	sub		
	34	10	55	what technical parameter is improved by no-frost technology?	p		se		pr	sys	sub		
		20	10	when we had frost, the efficiency was less	p		se		pr	sys	sub		
		35	15	also we had to turn off the fridge to clean it periodically	p		se		pa	sys	sub		
	35	50	75	so both efficiency and continuty of usage improved	p		se		pr	sys	sub		
	36	5	15	what else was not let it to be improved?	p		st		pr	sys	sub		
		30	25	humidity of inside fridge was the reason for frost	p		se		pa	sys	sub		
	37	10	40	now we are bringing out the humidity and we have fluidity of air inside fridge	p		se		pr	sys	sub		
		35	25	we don't send air inside because if we send air inside, when we open the door, the air comes out with pressure and we can feel it	p		se		pr	sys	sub		
	38	5	30	so the main reason was the humidity of air inside the fridge	p		se		pa	sys	sub		
		35	30	or even entering the new air with humidity inside fridge every time we open the fridge door	p		se		pa	sys	sub		
		50	15	the next improving parameter?	p		st		pr	sys	sub		
	39	55	65	ease of usage and less time to access	p		se		pr	sys	sub		
	40	10	15	in opposite we have?	p		st		pr	sys	sub		
		30	20	we wanted to reach sooner to the food, what were the barriers?	p		st		pr	sys	sub		
		45	15	the benefit is that for example for smaller door, we loose less cold air	p		se		pr	sys	sub		
	41	0	15	yes, but we couldn't produce the smaller door before?	p		se		pa	sys	sub		
	42	0	60	the design and production became more complex and complicated	p		se		pr	sys	sub		
		40	40	different door for different boxes is more complicated	p		se		pr	sys	sub		
		50	10	for the next problem?	p		st		pr	sys	sub		
	43	10	20	we were not measuring the temperature before, just adjusting it from inside	p		se		pa	sys	sub		
		20	10	we didn't know the real temperature	p		se		pa	sys	sub		
		50	30	now the fridge informs us the temperature and humidity	p		se		pr	sys	sub		
	44	35	45	the system of information board is for controlling energy usage	p		se		pr	sys	sub		
	45	0	25	what was the barrier for that?	p		st		pa	sys	sub		
		50	50	new components are added & risk of failure of electronic board added	p		se		pr	sys	sub		
	46	0	10	also it becomes more expensive	p		se		pr	sys	sub		
		35	35	for the space: the volume of fridge is improved and also better access	p		se		pr	sys	sub		
	47	45	70	but the movement and space needed in kitchens are worsened	int			f	pr	sup		co	
	48	0	15	specially for tenants	p		se		pr	sup		user	
		45	45	now we have to select among the improved ones, which one do we want to improve more?	p		st		fu	sys	sub		
	49	20	35	efficiency of energy, space, more ease of usage	p		se		fu	sys	sub		
	50	45	85	it seems still the needs of user is more capacity with less space	p		se		fu	sys	sub		
	51	35	50	check if still the barriers are the same?	p		st		pr	sup		co	
	52	40	65	yes. The barriers are the same	p		se		pr	sup		co	
	53	0	20	we are out of time. So it is better to propose idea just for the space	*								
		30	30	we want big fridge as it is like now, but it can be moved more easily	int			f	fu	sys	sub		
	54	45	75	the idea for disport the engine from the fridge and combine it with air conditioner can solve the problem of space. This was our idea in first part	id	dev			fu	sup		co	

7. Team 7/ Session 1: without stimulus, Session 2: trend as a stimulus

Part	Time (end)	Sentences	Concept	Idea	Precedent	Interpreter	Time	Space	Sys	Sup	Si

	Min	Sec	interval		(idea, precedent, interpreter)	(initial, developed)	(episodic, semantic, stimuli)	(given, find)	(past, present, future)	(system, super system, sub system)	(subsystem, object)	(co-systems, user)	(alternative, analogy)
1	0	10	10	what are the elements of a simple fridge?	p		ep		pr	sys	sub		
		25	15	fridge, freezer, layers inside the container,	p		ep		pr	sys	sub		
		35	10	the fridge must be lighter	id	in			fu	sys	sub		
		45	10	yes. The problem is that the fridge is heavy	int			f	fu	sys	sub		
		55	10	the different layers could be dedicated for different food	id	in			fu	sys	obj		
	1	5	10	it has a device for cooling water	p		ep		pr	sys	sub		
		15	10	it is too detail now	p		ep		pr	sys	sub		
		25	10	what is the main task of fridge? Cooling	p		ep		pr	sys	sub		
		30	5	it is expensive so we can consider it as part of lifestyle	p		se		pr	sup		user	
		40	10	we want to propose a better fridge so we have to focus on main task	p		se		pr	sys	sub		
		55	15	the main task is keeping food fresh by cooling and ice making	id	in			fu	sys	obj		
	2	10	15	there are devices for different degree of temperature	p		ep		pr	sys	sub		
		25	15	new fridge provides many various degrees	p		ep		pr	sys	sub		
		35	10	what is the lowest degree for freezer	p		ep		pr	sys	sub		
	3	0	25	I think the temperature is among minus 20 to 0 for freezer	p		ep		pr	sys	sub		
		30	30	we have to consider 2 parts; freezer and fridge separately	p		ep		pr	sys	sub		
		55	25	one is for freezing and keeping for long time and the other is for cooling and keeping short time	p		ep		pr	sys	sub		
	4	15	20	if we want to propose an improvement?	p		se		pr	sys	sub		
		45	30	in past we had a small fridge inside home that they had even an external lock	p		ep		pa	sys	sub		
	5	5	20	they had always ice in their internal walls	p		ep		pa	sys	sub		
		15	10	also the engines were being broken a lot	p		ep		pa	sys	sub		
		25	10	we can consider the changes and improvements from past to present	p		se		pa	sys	sub		
		40	15	the user store more inside fridge and they need bigger fridge	p		se		pr	sup		user	
		50	10	so if we want to make it lighter, we have to consider the capacity too	int			f	fu	sys	sub		
	6	10	20	the size is related to design	p		se		pr	sys	sub		
		25	15	no. the size can be technical too when we want to improve other characteristics	p		se		pr	sys	sub		
		40	15	it is one of our constraints	int			f	fu	sys	sub		
	7	0	20	do we have filtration in the fridge?	p		se		pr	sys	sub		
		25	25	we can propose to filter water and provide drinking water	id	in			fu	sys	sub		
		35	10	I think that there is such this mechanism in current generation	p		ep		pr	sys	sub		
		45	10	we can propose to change the temperature of water	id	dev			fu	sys	sub		
	8	10	25	the board of current fridges are smart with lots of options	p		ep		pr	sys	sub		
		25	15	it shows the level of energy consumption	p		ep		pr	sys	sub		
		35	10	still the energy consumption needs more attention	int			f	fu	sys	sub		
		50	15	board is related to device of water cooling, ice making, the temperature of fridge, …	p		ep		pr	sys	sub		
	9	5	15	actually it is so complicated	p		se		pr	sys	sub		
		20	15	as energy is so important, we have to concentrate on that too	int			f	fu	sys	sub		
		30	10	we can use the solar energy	id	in			fu	sys	sub		
		40	10	it is more possible for air conditioner	p		se		pr	si			an
		50	10	we can think about a fridge which is an air conditioner too	id	dev			fu	sup		co	
	10	0	10	one device for both	p		se		fu	sys	sub		
		15	15	opening fridge door frequently is the problem	p		ep		pr	sys	sub		
		25	10	we can propose more doors instead of single door	id	dev			fu	sys	sub		
		35	10	just open a small door to reach the part needed	p		se		fu	sys	sub		
		45	10	also we have to educated our children not to open the door so often	p		se		pr	sup		user	
	11	5	20	we can not limit user in number of opening the fridge door	p		se		pr	sup		user	
		25	20	do you know how does fridge work?	p		ep		pr	sys	sub		
	12	50	85	they are not turn on always; they usually work around 8 hours in a day because they have a trans	p		ep		pr	sys	sub		
	13	5	15	we can use its pump for other usage at home then	id	dev			fu	sup		co	
		15	10	the pump, moves the gas inside the condensor	p		ep		pr	sys	sub		
		25	10	the invention can be like this; the fridge works like an air conditioner	p		se		fu	si			an
		30	5	from the other hand we have to consider the real time of working of fridge for future	p		se		fu	sys	sub		
		55	25	also the light of fridge must be LED	id	dev			fu	sys	sub		
	14	5	10	what else?	p		se		fu	sys	sub		
		25	20	I think that we can propose ice cream making as also	id	dev			fu	sup		co	
		50	25	also we can see proposed classification in the layers of both fridge and freezer	id	dev			fu	sys	sub		
	15	5	15	it is difficult to classify the food before putting them inside fridge	p		se		pr	sys	sub		
		15	10	lower parts are usually for vegetables	p		ep		pr	sys	sub		
		45	30	and upper parts for meat	p		ep		pr	sys	sub		

	16	0	15	and the upsets part for ice	p		ep		pr	sys	sub		
		20	20	what else we can consider?	p		se		fu	sys	sub		
		35	15	do we have frost in new fridge?	p		ep		pr	sys	sub		
		45	10	very well. No. the new fridges are no-frost	p		ep		pr	sys	sub		
		50	5	maybe by changing the gas	p		se		pr	sys	sub		
	17	0	10	do you see the back of fridge?	p		ep		pr	sys	sub		
		10	10	it is like the previous generation	p		ep		pr	sys	sub		
		20	10	shall we change this part?	p		se		pr	sys	sub		
		35	15	I don't know its mechanism well	p		ep		pr	sys	sub		
		45	10	so what we can propose for next generation?	p		se		pr	sys	sub		
	18	0	15	we have to propose a technical improvement	int			g	pr	sys	sub		
		25	25	it is better to think a little	p		se		fu	sys	sub		
	19	15	50	I think about a horizontal fridge	id	dev			fu	sys	sub		
		35	20	the problem is that we don't know the last technology of fridge	p		se		pr	sys	sub		
		45	10	we can think about the motto of "nice, enough space and reliable" for Emerson	int			f	fu	sys	sub		
	20	0	15	maybe we can consider reliable, what does it mean technically?	p		se		fu	sys	sub		
		10	10	it must work for a long time	int			f	fu	sys	sub		
		30	20	we can think to add an option to fridge	p		se		fu	sys	sub		
		40	10	a fridge that can remove the smell of food	id	dev			fu	sys	sub		
	21	0	20	we analyzed lots of problems, now we can propose solutions for them	p		se		pr	sys	sub		
		15	15	what are the problems?	p		se		pr	sys	sub		
		35	20	some times we have a problem that we want to propose solution for it. Some times we just want to propose improvements	p		se		pr	sys	sub		
		45	10	please mention one of the problems	p		se		pr	sys	sub		
		55	10	we want less consumption of energy, while no limitation for opening the door	int			f	fu	sys	sub		
	23	10	75	a fridge without door	id	dev			fu	sys	sub		
		15	5	like an industrial fridge	p		ep		pr	si			an
		30	15	some fridge just pumps the air from bottom in a semi-closed container in the shops	p		ep		pr	si			an
		40	10	some part without door	id	dev			fu	sys	sub		
		50	10	it can also cool the home but the waste of energy is higher	id	dev			fu	sup		co	
	24	0	10	it is a trade-off among cool down home and energy waste	p		se		fu	sup		co	
		20	20	I think that we have to reduce the working time of trans up to 6 hours from 8 hours	p		se		fu	sys	sub		
		40	20	we have to minimize the temperature exchange	p		se		fu	sys	sub		
		55	15	we have to collect the cold air which comes out, and transfer it again inside fridge	id	dev			fu	sys	sub		
	25	15	20	by using a container or box in the direction of distribution of cold air in the kitchen	p		se		fu	sys	sub		
		45	30	also we can make the door transparent by using glass	id	dev			fu	sys	sub		
		55	10	we can select the food by a button	id	dev			fu	sys	sub		
	26	10	15	like the fridge of purchasing chocolate and cookies in public places	p		ep		pr	si			an
		25	15	there is a tendency to open the door of fridge by users at home and this solution removes this habit	p		se		pr	sup		user	
		35	10	even we don't want to pick up any thing	p		se		pr	sup		user	
		45	10	and also we are sure that there is not anything inside	p		se		pr	sup		user	
	27	5	20	also we consider it as a bad pattern of food consuming	p		se		pr	sup		user	
		20	15	so if we buy less, we open the door less: just I am kidding	p		se		pr	sup		user	
	28	0	40	you are changing the direction of thinking from energy consumption to user behavior	p		se		pr	sup		user	
		55	55	we are analyzing the reason for opening the door	p		se		pr	sup		user	
	29	55	60	opening the door too much, means that the door must be regulated in a good way to tolerate this amount of opening	p		se		pr	sys	sub		
	30	30	35	it means we have both energy consumptions because of air exchange, and also erosion in elements of fridge	p		se		pr	sys	sub		
		55	25	also we can show the patterns of consumption to help the users to change their behavior	id	dev			fu	sys	sub		
	31	10	15	I think it is not related to technology	p		se		pr	sys	sub		
		20	10	it could lead us to innovation	p		se		fu	sys	sub		
	32	10	50	I am thinking of transparent door for energy saving as you told before	p		se		fu	sys	sub		
		20	10	it means more productivity	p		se		fu	sys	sub		
	33	0	40	what is the advantage of this solution beside energy consumption?	p		se		fu	sys	sub		
		55	55	less times of opening the door	p		se		fu	sys	sub		
	34	15	20	if we had a fridge in the room, we could think better	p		se		pr	sys	sub		
		45	30	less opening means less erosion of elements	p		se		fu	sys	sub		
	35	5	20	we cannot propose a better gas, because it is not inside our expertise	p		se		fu	sys	sub		

		45	40	still we can propose solutions for classification of shelves and filtering water, or the light of fridge, …	p		se		fu	sys	sub		
	36	0	15	for example, we can use the rotating of fridge door to produce light for inside fridge	id	dev			fu	sys	sub		
		10	10	also one of the problem is related to cleaning of fridge and the shelves	int			f	pr	sys	sub		
		25	15	every time we have to bring out everything from fridge, clean it and put them again inside fridge	p		ep		pr	sys	sub		
		35	10	we can think about self-cleaning	id	int			fu	sys	sub		
	37	5	30	even the alarm for expiring date of food, so we don't have dirty food	id	dev			fu	sys	obj		
		25	20	it can realize the spoiling by smell, gases,	id	dev			fu	sys	sub		
		35	10	it seems you have experiences with fridge	p		ep		pr	sup		user	
		45	10	I don't go in front of fridge and I usually forget to eat fruit	p		ep		pr	sup		user	
		55	10	and it spoils after a while	p		ep		pr	sys	sub		
	38	5	10	so it is helpful to have alarms	p		se		pr	sys	sub		
		15	10	what about self-cleaning, we cannot wash inside fridge with water	p		ep		pr	sys	sub		
		40	25	we can think about a degree of rotation for shelves, to let wash them easily	id	dev			fu	sys	sub		
		50	10	we can think of suction like a vacuum cleaner for shelves	id	dev			fu	sys	sub		
	39	20	30	for the alarm we can use sensors	p		se		fu	sys	sub		
		55	35	we want sensor alarms for eating not spoiling	id	dev			fu	sup		user	
	40	55	60	one of my friends in dormitory, had such this experience that bad smell of spoiled food cannot be removed easily and he had to use lots of different smells to remove it after a long procedure	p		ep		pa	sys	sub		
	41	30	35	special fridge with lots of boxes for dormitories	id	dev			fu	sup		co	
	42	15	45	the fridge can remove the spoiled food and by using a chemical material clean the surface	id	dev			fu	sys	sub		
		35	20	I think it is enough	p		se		pr	sys	sub		
		55	20	how many we can propose in 45 min?	p		se		pr	sys	sub		
	43	0	5	end	p		se		pr	sys	sub		
2	0	15	15	first the people put their food inside soil under ground	p		se		pa	si			alt
		30	15	we have to first look at the examples carefully	p		st		pr	si			an
	1	0	30	looking the examples	p		st		pr	si			an
		30	30	the gramophone, we have better sound but the durability has decreased	p		st		pa	si			an
		45	15	the example of umbrella is so nice	p		st		pa	si			an
		55	10	we can use exactly for fridge	p		st		fu	sys	sub		
	2	10	15	we can propose fridge without door	id	dev			fu	sys	sub		
		25	15	it produces wind in direction according to a pattern	id	dev			fu	sys	sub		
		35	10	the technology is not advanced just the idea is new	p		se		pr	sys	sub		
		55	20	the eye glasses are so strange, there is no handle and no nose case	p		st		pa	si			an
	3	5	10	technology after some point is not nice any more, we have to do something in our life	p		se		fu	sys	sub		
		15	10	so let see the trend for fridge	p		se		pa	sys	sub		
		25	10	first it was a well	p		ep		pa	si			alt
		35	10	then a place in the basement	p		ep		pa	si			alt
		50	15	then Coleman	p		ep		pa	si			alt
	4	10	20	then first generation of fridge	p		ep		pa	sys	sub		
		25	15	it was a cube form	p		ep		pa	sys	sub		
		45	20	it was working with oil	p		ep		pa	sys	sub		
		55	10	it became bigger, when it became electrical	p		se		pa	sys	sub		
	5	20	25	we had a electrical shock for every device	p		ep		pa	sys	sub		
		50	30	then we had fridge and freezer together	p		ep		pa	sys	sub		
	6	15	25	then we see also drinking water providing	p		ep		pa	sys	sub		
		30	15	then we see also ice making	p		ep		pa	sys	sub		
	7	30	60	what do you think for the next?	p		se		fu	sys	sub		
		40	10	I think the common is the container, that it must remain	p		se		fu	sys	sub		
		50	10	I am thinking about distance control	id	dev			fu	sys	sub		
		55	5	to open the fridge and deliver food	id	dev			fu	sys	sub		
	8	5	10	in a cartoon it was a alarm for a thief	p		ep		pr	si			an
		10	5	and if the thief does not close the door, it shocks by electricity shocker	p		ep		pr	si			an
		20	10	it can be a alarm for open door	id	dev			fu	sys	sub		
		40	20	in the umbrella, we see that they changed the frame totally	p		st		fu	si			an
		50	10	we can think so radical like the example of umbrella	p		se		fu	sys	sub		
	9	0	10	but the function is performed in another way	p		se		fu	sys	sub		
		10	10	shall we think of removing something in fridge	p		se		fu	sys	sub		
		35	25	shall we remove the engine or pump?	p		se		fu	sys	sub		
		55	20	or changes the gas to more friendly to the environment	p		se		fu	sys	sub		
	10	0	5	I think it is not possible by available technology	p		se		fu	sys	sub		
		5	5	what else?	p		se		fu	sys	sub		

		10	5	can it produce fruit juice for us?	id	dev			fu	sup		co	
		20	10	we have to consider different fruits	p		se		fu	sys	obj		
		30	10	also we have to consider cleaning it very often	p		se		fu	sys	sub		
		40	10	we can think of making water gaseous and tasty	id	dev			fu	sup		co	
	11	0	20	also add ice cream maker to the fridge	id	dev			fu	sup		co	
		15	15	also we can think of customizing fridge	id	dev			fu	sys	sub		
		50	35	we want fridge according to each user needs and requirements	p		se		fu	sup		user	
	12	0	10	think about the place of fridge inside kitchen	p		se		pr	sup		co	
		20	20	we have limitation of space in kitchen	int			f	pr	sup		co	
		35	15	also one of the big problems of fridge is related to its moving	int			f	pr	sys	sub		
		50	15	we have to think of lighter fridge	p		se		fu	sys	sub		
	13	20	30	using lighter material like aluminum	id	dev			fu	sys	sub		
		45	25	we can add wheel under fridge for easier movement	id	dev			fu	sys	sub		
	14	0	15	to have a special basis for movement that can be activated by a button	id	dev			fu	sys	sub		
		15	15	like the wheel of airplane	p		ep		fu	si			an
		30	15	I think the frost is important but we are talking about other options	int			f	pr	sys	sub		
		40	10	what I can see in the examples, is the changing in the scales to have higher productivity	p		se		fu	sys	sub		
		50	10	we can propose some central system in buildings to provide fridge for all apartments centrally	id	dev			fu	sup		co	
	15	0	10	it can be like central air conditioner	p		se		fu	si			an
		15	15	and also it can be more efficient because of bigger scale	p		se		fu	sys	sub		
		30	15	maybe it needs more gas	p		se		fu	sys	sub		
		45	15	let's look again at examples	p		st		pa	si			an
	16	55	70	we have some different classes of changes	p		se		pa	si			an
	17	55	60	for ship for example we saw not only changes in technology, we also see changes in application	p		st		pa	si			an
	18	30	35	I mean we can concentrate of application too	p		se		fu	sys	sub		
	19	0	30	a fridge for dormitories, for hospitals, for hotels, …	p		se		fu	sup		co	
		15	15	think about different users	p		se		pr	sup		user	
		55	40	it means we focus on requirements	p		se		pr	sup		user	
	20	25	30	I don't have new idea	p		se		fu	sys	sub		
		45	20	I think when we face a new technology, we change our system to adapt or benefit new technology	p		se		fu	sys	sub		
	21	0	15	I mean that if there is a new kind of pump, we can bring it inside fridge, otherwise I don't have any idea	p		se		fu	sys	sub		
		15	15	why do we have to improve technology in the direction of working less?	p		se		fu	sys	sub		
		45	30	the quality of fridge is really important	p		se		fu	sys	sub		
	22	10	25	which kind of surprise can we propose more? Speaking	id	dev			fu	sys	sub		
		30	20	the fridge that can store electricity for the time of losing electricity	id	dev			fu	sys	sub		
		40	10	like the battery for computer	p		ep		pr	si			an
		50	10	it is not related to main function of fridge	p		se		pr	sys	sub		
	23	20	30	we want to go trip for one month, we want to control the fridge by SMS from distance	id	dev			fu	sys	sub		
	24	10	50	idea generation is so difficult	*								
		20	10	I think we propose good idea up to here	*								
		30	10	we can think also about safety	int			f	fu	sys	sub		
		40	10	especially for electrical shocks by anti-electrical shocks	id	in			fu	sys	sub		
	25	20	40	design a hidden box inside fridge for jewelries	id	dev			fu	sys	sub		
	26	0	40	I don't have any new idea	p		se		fu	sys	sub		
		15	15	we can think again about the movement	p		se		fu	sys	sub		
		30	15	we can propose a structure for moving it on the stairs	id	dev			fu	sys	sub		
		45	15	what else?	p		se		fu	sys	sub		
	27	10	25	it is better to put the fridge in the kitchen in the way to have access to the back	p		se		fu	sys	sub		
		15	5	why?	p		se		fu	sys	sub		
		35	20	to clean it easily	p		se		fu	sup		co	
	28	30	55	let look at the examples again	p		st		pa	si			an
		45	15	I don't have any idea	p		se		fu	sys	sub		
	29	0	15	please let finish	p		se		fu	sys	sub		

8. Team 8/ Session 1: without stimulus, Session 2: trend as a stimulus

Part	Time (end)	Sentences	Concept	Idea	Precedent	Interpreter	Time	Space	Sys	Sup	Si

	Min	Sec	interval		(idea, precedent, interpreter)	(initial, developed)	(episodic, semantic, stimuli)	(given, find)	(past, present, future)	(system, super system, sub system)	(subsystem, object)	(co-systems, user)	(alternative, analogy)
	0	15	15	we have to propose technical changes	int			g	fu	sys	sub		
		25	10	what is function of fridge?	p		ep		pr	sys	sub		
		35	10	cooling	p		ep		pr	sys	sub		
		45	10	keeping food healthy	id	in			fu	sys	obj		
	1	0	15	cooling for some of the food	p		ep		pr	sys	obj		
		15	15	cooling is preventing of growing of bacteria	p		se		pr	sys	obj		
		30	15	we also want to keep healthy some food but simultaneously warm	id	dev			fu	sys	obj		
		40	10	we are talking about keeping for long period	id	dev			fu	sys	sub		
		55	15	it provides ice and cold water too	p		ep		pr	sys	sub		
	2	5	10	they are lateral. At the beginning it was just cooling	p		se		pr	sys	sub		
		15	10	it keeps fruit, dairy	p		ep		pr	sys	sub		
		20	5	it provides less temperature	p		ep		pr	sys	sub		
		35	15	what does the low temperature do?	p		se		pr	sys	sub		
		45	10	coldness decreases the activation of bacteria	p		se		pr	sys	obj		
	3	5	20	the picture shows a side-by-side fridge while there are fridges for car	int			g	pr	sys	sub		
		15	10	do we have to work also on freezer?	int			g	pr	sys	sub		
		25	10	I think we have to concentrate on fridge	int			g	pr	sys	sub		
		35	10	so what are our directions? Two directions	p		se		fu	sys	sub		
		50	15	a new way for cooling	id	in			fu	sys	sub		
	4	10	20	or a way to reduce the activation of bacteria	id	dev			fu	sys	obj		
		25	15	the second one is chemical	p		se		pr	sys	sub		
		35	10	we have another function for fridge too	p		ep		pr	sys	sub		
		45	10	I think the cabinet and being all food in one place is important too	p		ep		pr	sup		co	
	5	0	15	I mean any other way for cooling must consider to keep food in one cabinet	int			f	pr	sup		co	
		10	10	maybe it is better to not limited to the space	id	in			fu	sys	sub		
		25	15	I think of lots of small boxes in every where	id	dev			fu	sys	sub		
		35	10	but I think maybe it can be good even	p		se		fu	sys	sub		
	6	0	25	imagine that we don't have fridge in kitchen, but we can keep the food in every other cabinet	p		se		fu	sys	sub		
		30	30	so for trips, there are lots of dishes that can keep the food healthy and we can take them with ourselves	p		se		fu	sup		co	
	7	10	40	so we can propose a portable device for cooling	id	dev			fu	sys	sub		
		50	40	from black and white TV to color ones, we have more quality in images	p		ep		pa	si			an
	8	10	20	so in the fridge we have to consider cooling with higher quality	p		se		fu	sys	sub		
		20	10	what is the quality here?	p		se		fu	sys	sub		
	9	0	40	in TV, the first generation had a defect from the beginning	p		se		pa	si			an
		15	15	it was not the natural image	p		se		pa	si			an
		25	10	even in future they are going to become 3D to become more real	p		se		fu	si			an
		35	10	In fridge we have a food that we first cool it down and again warm it, the quality of food is changing	p		se		pr	sys	obj		
		45	10	so we can consider that we want the fresh food with original color, taste, smell without drying up	int			f	pr	sys	obj		
	10	0	15	they are related to bacteria	p		se		pr	sys	obj		
		30	30	from this point of view, we can think of performance improvement	p		se		fu	sys	sub		
		45	15	in Walkman we change the storing of voice from tape to digital	p		ep		pa	si			an
	11	0	15	in car, the engine has not changed but we have less usage of energy, higher speed, less noise, …	p		ep		pa	si			an
		10	10	fridge is not like that	p		se		pr	sys	sub		
		15	5	we can think of flying car. Is there?	p		se		fu	si			an
		25	10	just idea and working on prototypes	p		se		fu	si			an
		40	15	changing in TV from lamp to LED and LCD, can be considered as technical radical changes?	p		se		pa	si			an
	12	15	35	I think so. It is from color to plasma and LCD, …	p		se		pa	si			an
		30	15	LG has a new TV with curve to inside	p		se		pr	si			an
		45	15	the transition form 2d to 3d and 4d	p		se		fu	si			an
	13	0	15	so we can improve the functions of fridge	p		se		fu	sys	sub		
		50	50	I remember a memory that the very ancient doctors can distinguish the disease from the smell of urine	p		ep		pa	si			an
	14	20	30	if the fridge could distinguish the spoiling food	id	dev			fu	sys	sub		
		40	20	you mean we can add some functions to the fridge too	p		se		fu	sys	sub		
		50	10	the fridge can act like a laboratory	p		ep		fu	si			an
	15	15	25	It shows the characteristics of food, smell, ingredients, calories	id	dev			fu	sys	sub		
		30	15	shall we think about the form?	p		se		fu	sys	sub		

		45	15	I think it is related to design not technology	p		se		fu	sys	sub		
	16	5	20	we have to concentrate on problems and defects to improve it technically	int			g	pr	sys	sub		
		15	10	we want preventing people of becoming ill by eating spoiled food	int			f	pr	sup		user	
		25	10	and also we want to let the people to eat food with more quality to be healthy	p		se		pr	sup		user	
		35	10	the question is if we know a technology for testing the quality of food in a trade and business scale?	p		se		pr	sys	sub		
		45	10	otherwise it become so costy and expensive	p		se		pr	sys	sub		
	17	0	15	also the fridge are also so heavy	int			f	pr	sys	sub		
		15	15	I think this one is related to design again	p		se		pr	sys	sub		
		30	15	the question is that among mentioned directions, which one is more accessible?	p		se		fu	sys	sub		
	18	5	35	new function like laboratory, new way for cooling, the way for reducing growth of bacteria, or improving current functions	p		se		fu	sys	sub		
		15	10	I prefer adding new function	p		se		fu	sys	sub		
		25	10	is it accessible? I don't know about its related technologies	p		se		fu	sys	sub		
		35	10	we can think of this direction by technologies we know	p		se		fu	sys	sub		
		45	10	for example, the fridge that can act according to some pre plans for ordering point for food	id	dev			fu	sys	sub		
	19	0	15	it can be connected to super market	id	dev			fu	sup		co	
		10	10	it is so advance	p		se		pr	sys	sub		
		20	10	we usually use the last version of sytems in Iran before the people of developed countries	p		ep		pr	sup		user	
	20	0	40	one of my friend said that when he had gone to one of developed countries, he saw that still there are very first version of monitors in the factories while here we changed all monitors to LCD ones	p		ep		pr	sup		user	
		10	10	for drinking water, we have to think of anti-bacterial glass that it becomes anti-bacterial after each usage	id	dev			fu	sup		co	
		20	10	so everybody can use the glass without becoming ill	p		se		fu	sup		user	
		30	10	it is another new function	p		se		fu	sys	sub		
	21	10	40	the ordering point can be planned according to weight so it is possible	id	dev			fu	sys	sub		
		35	25	when we open the door of fridge, the smell comes out	p		ep		pr	sys	sub		
		40	5	smell of food	p		ep		pr	sys	sub		
		50	10	what is our solution?	p		se		pr	sys	sub		
	22	0	10	in the laboratory, we prevent entering of dust	p		ep		pr	si			an
		20	20	there is positive pressure inside lab so when the door becomes open, the new air cannot enter the room	p		se		pr	si			an
		30	10	is it expensive?	p		se		pr	si			an
		45	15	all the laboratories are like this and it is easy	p		se		pr	si			an
		55	10	we can have it diverse in the fridge	p		se		fu	sys	sub		
	23	5	10	if we add a suction, so the air comes inside instead of going outside and the smell doesn't go out	id	dev			fu	sys	sub		
		15	10	maybe it ruins the function and also bring pollution from outside to inside	p		se		fu	sys	obj		
		50	35	what other function can we add?	p		se		fu	sys	sub		
	24	20	30	we give idea, but we have to be aware that maybe they want us to construct them. So give simple ideas. just kidding	p		se		pr	sys	sub		
		50	30	there was an idea about anti-bacterial	p		se		fu	sys	sub		
	25	20	30	the fridge that act as an anti-bacterial device for food	id	dev			fu	sys	sub		
		35	15	do we have to just propose ideas? yes	p		se		pr	sys	sub		
		45	10	in TV from black and white to color, we had a better performance, so here	p		ep		pa	si			an
	26	0	15	more coldness with less energy for fridge	int			f	fu	sys	sub		
		15	15	and it keep the coldness even we open the door of fridge	id	in			fu	sys	sub		
		25	10	the food must be more accessible to save time (less time for door when it is open)	id	dev			fu	sys	sub		
		35	10	like the car that park itself by pushing a button	p		ep		pr	si			an
		45	10	the food comes out by pushing the number of place	id	dev			fu	sys	sub		
	27	35	50	it is like automatic store working by codes and robots	p		ep		pr	si			an
	28	5	30	we saw the content on a monitor and we select the food and it gives to us according to our order	id	dev			fu	sup		co	
		35	30	when the complexity goes higher, the risk of usage goes higher too	p		se		pr	sup		user	
		50	15	it happens at the end	p		se		pr	sys	sub		
	29	30	40	the old version of car, they didn't have computer and PCU. But it became computerized and we used to it	p		ep		pr	sys	sub		
		55	25	we can see that all the products around us became more complex but we use them	p		se		pr	sup		user	
	30	5	10	there are some other problems	int			f	pr	sys	sub		
		25	20	it is very difficult to move the fridge in stairs	int			f	pr	sys	sub		
		35	10	because it is big and heavy	p		ep		pr	sys	sub		

		50	15	may be using Nano material makes the fridge lighter and also stronger	id	dev			fu	sys	sub		
	31	5	15	also we can think of modular fridge that can be assembled at home	id	dev			fu	sys	sub		
		35	30	like a bed or furniture of IKEA	p		ep		pr	si			an
	32	30	55	and also if we propose small boxes for cooling, it solves this problem	p		se		fu	sys	sub		
		45	15	I am thinking about pre plans for women working	p		se		fu	sup		user	
	33	0	15	like a level of accessibility?	p		se		fu	sup		user	
		35	35	I mean to propose the food to the family members according to the plan	id	dev			fu	sup		co	
		45	10	also we can think about level of accessibility	id	dev			fu	sup		user	
		55	10	especially for medicine	p		se		fu	sys	obj		
	34	15	20	lock for some parts that kids can access only some parts	id	dev			fu	sys	sub		
		30	15	the kids are better in digital than adults	p		se		pr	sup		user	
	35	10	40	Italy is one of the countries advanced in home appliances	p		se		pr	sys	sub		
	36	0	50	I think we can finish, we had enough ideas	p		se		pr	sys	sub		
2	0	45	45	for coffee maker, first some improvements in the initial device, then changes in ingredients, then different tastes	p		st		pa	si			an
	1	20	35	you put the ingredients from one side and in the other side you choose the kind of coffee and it provide it for you	p		st		pr	si			an
		35	15	it is so advance for us	p		se		pr	si			an
	2	35	60	the second one is gramophone: it is about the quality of sound	p		st		pa	si			an
		45	10	the coffee maker is more related	p		se		pr	si			an
		50	5	we cannot change ingredients	p		se		pr	si			an
	3	10	20	in our culture we buy food and freeze it for long time and then use it	p		ep		pr	sup		user	
		30	20	in Europe the people buy the meat in the day, they need it	p		se		pr	sup		user	
		40	10	the market and availability of raw food is like this	p		se		pr	sup		user	
		50	10	they don't need to buy and freeze food	p		se		pr	sup		user	
	4	20	30	it is related to the accessibility of food for people in the city	p		se		pr	sup		user	
		35	15	in modern city, there is differences among houses and commercial centers	p		se		pr	sup		user	
		45	10	so we buy at least for one week	p		se		pr	sup		user	
		55	10	in some cities everything is accessible by even walking	p		se		pr	sup		user	
	5	30	35	yes. There are differences among these two life styles	p		se		pr	sup		user	
		50	20	is there any difference among different kind of preparing coffee	p		st		pr	si			an
	6	20	30	completely different. Different processes provide different tastes	p		se		pr	si			an
		35	15	the third example is about a boat	p		st		pa	si			an
	7	15	40	first it was wooden by paddle, then with sail and wind, then steam, disel and jet engine	p		st		pa	si			an
		40	25	then we see lots of branches for each main part	p		st		pa	si			an
		55	15	for example, the sub-marines are atomic and they are under water for more than 3 months	p		st		pa	si			an
	8	15	20	I remember the central vacuum cleaner	p		ep		pr	si			an
		25	10	do we have central fridge?	p		se		pr	sys	sub		
		35	10	like dormitories? It has own problems	id	dev			fu	sys	sub		
		45	10	each apartment has its fridge but the engine and condenser is common for whole building	id	dev			fu	sys	sub		
		50	5	the fourth example is an umbrella	p		st		pa	si			an
	9	10	20	I haven't see a good umbrella at all	p		se		pa	si			an
		20	10	there is also umbrella for 2 people, very big one	p		ep		pa	si			an
		30	10	they are usually expensive and strong	p		ep		pa	si			an
		40	10	what is the last one?	p		ep		pa	si			an
	10	0	20	it works with wind	p		st		fu	si			an
		15	15	before it, we had a new one with water proof cloth and then the version that doesn't reverse in the wind	p		se		pa	si			an
		45	30	I cannot understand the last one	p		st		fu	si			an
	11	0	15	the last example is eye glasses	p		st		pa	si			an
		10	10	one of them, doesn't have handle	p		st		pa	si			an
		30	20	the last one is google eye glasses that provide information	p		st		fu	si			an
		40	10	it needs connectivity to the internet	p		st		fu	si			an
		50	10	doesn't bother you by information or makes you to fell down?	p		st		fu	si			an
	12	5	15	it provides information, when they are needed	p		st		fu	si			an
		15	10	so after all, what we can propose?	p		se		fu	sys	sub		
		30	15	for example, to make it lighter, why not using plastic for body?	id	dev			fu	sys	sub		
		40	10	we proposed to make it modular	p		se		fu	sys	sub		
		50	10	I proposed to use Nano materials	p		se		fu	sys	sub		
	13	5	15	why not completely plastic?	p		se		fu	sys	sub		
		15	10	it becomes very lighter	p		se		fu	sys	sub		

		30	15	Nano also is useful for smell	p		se		fu	sys	sub		
		50	20	Nano doesn't let that different smells merged together	p		se		fu	sys	sub		
	14	20	30	it also doesn't let the different smell change the small and taste of other food	p		se		fu	sys	sub		
	15	10	50	also in the ship we see that new functions added to the ship	p		st		pa	si			an
		25	15	I think that it brought the technical changes of other fields to the ship	p		se		pa	si			an
	16	0	35	the ice breaker is new application	p		se		pa	si			an
		20	20	yes. I think the idea was available and they add it to the ship	p		se		pa	si			an
		35	15	also the atomic ship is for providing energy for longer period	p		se		pa	si			an
		45	10	shall we think of chargeable batteries for fridge?	id	dev			fu	sys	sub		
	17	0	15	like cell phones without wires	p		ep		pr	si			an
		10	10	using chargeable engines	id	dev			fu	sys	sub		
		45	35	also thinking about the fridge that can pack the entering food by some foils and plastics	id	dev			fu	sup		co	
	18	10	25	like coffee maker that changed the coffee	p		se		pr	si			an
		45	35	so we can add the capability of classification to the fridge after packing	id	dev			fu	sup		co	
	19	15	30	ancient people processed food differently to keep them for longer period	p		se		pa	sup		user	
		25	10	did they have ice?	p		se		pa	si			alt
		35	10	yes. They had both natural ice from mountain and also factories for making ice	p		se		pa	si			alt
		45	10	so we can think of processing food	id	dev			fu	sup		co	
	20	0	15	the difficulty for fridge is the variety of food. It is not just coffee	p		se		pr	sys	obj		
		20	20	also we have lots of processes in the other hand; to make the salty, to dry them, to cut them, to freeze them, …	p		se		pr	sup		co	
		30	10	so we don't have existing kind of fridge any more, it is like a transformable of food	p		se		fu	sys	sub		
		40	10	the big problem is that we want fridge to keep the original quality of food	p		se		fu	sys	obj		
		50	10	can we add new functions?	p		se		fu	sys	sub		
	21	0	10	I don't have any idea	p		se		fu	sys	sub		
		10	10	let's look at the example of ship again	p		st		pa	si			an
		50	40	the applications are added	p		st		pa	si			an
	22	15	25	for example, thinking of keeping food even warm, keeping it with original quality without cooling, …	p		se		fu	sys	sub		
		50	35	so what we have to do for growth of bacteria?	p		se		fu	sys	obj		
	23	20	30	I am thinking of 2 different containers one for cold food and one for warm food (like a flask)	id	dev			fu	sup		co	
		50	30	merging of fridge with oven for example	id	dev			fu	sup		co	
	24	35	45	so with pre-plan, the oven receives ingredients from fridge and cook food	id	dev			fu	sys	sub		
	25	30	55	what else?	p		se		fu	sys	sub		
		50	20	also adding a monitor on the door of fridge that it can be TV too	id	dev			fu	sup		co	
	26	10	20	transparent door or even some part transparent	id	dev			fu	sys	sub		
		35	25	even the light of inside can use in the kitchen in the night	p		se		fu	sup		co	
	27	15	40	it is like the google eye glasses that there is a monitor on the glass	p		st		pr	si			an
	28	0	45	what else?	p		se		fu	sys	sub		
		20	20	all the fridges are cube; do you see any other form?	p		se		pr	sys	sub		
		25	5	no. I haven't seen	p		ep		pr	sys	sub		
		50	25	why not cylindrical in the middle of kitchen?	id	dev			fu	sup		co	
	29	40	50	a fridge with lots of doors in all directions	id	dev			fu	sys	sub		
		55	15	or semi-cylindrical or for a corner	id	dev			fu	sup		co	
	30	15	20	it needs some changes in architecture of houses	p		se		fu	sup		co	
		30	15	to have sliding door	id	dev			fu	sys	sub		
		40	10	it is good for small kitchens	p		se		fu	sup		co	
		55	15	or the flexible semicircular doors	id	dev			fu	sys	sub		
	31	10	15	what is the cover of these walls?	*								
		15	5	Belka	*								
		25	10	how about its durability?	*								
		55	30	very long. And it is very good for repairing by every person	*								
	32	15	20	it is like a paper and it becomes ready by adding water	*								
		25	10	it is so fast also	*								
		35	10	it also doesn't absorb the pollution and dust and soot	*								
		45	10	It is also cheap compare to the painting	*								
	33	0	15	what else?	p		se		fu	sys	sub		
		45	45	the fridge was using oil, then they became electrical	p		ep		pa	sys	sub		
		55	10	is it possible to become atomic?	id	dev			fu	sys	sub		
	34	0	5	it is so expensive	p		se		pr	sys	sub		
		35	35	but in Alaska that they are small cities, every city has a very small reactor, like this room and by a very small fuel it works for a one year	p		se		pr	si			an

	35	0	25	it could be in future	p		se		fu	sys	sub		
		10	10	thinking is so difficult	*								
		25	15	for any idea, we have some constraints	*								
		45	20	let's look at the examples again	p		st		pa	si			an
	36	30	45	we can just construct diesel ships and airplanes	p		se		pr	si			an
		40	10	we even buy diesel engines	p		se		pr	si			an
	37	0	20	I have no more idea	p		se		fu	sys	sub		
		30	30	the time of playing is usually fly fast but thinking is difficult	*								
		45	15	we don't know technology for reduction of growth of bacteria instead of cooling	p		se		pr	sys	sub		
	38	0	15	let's finish	*								

9. Team 9/ Session 1: without stimulus, Session 2: engineering procedure as a stimulus

Part	Time (end)			Sentences	Concept	Idea	Precedent	Interpreter	Time	Space	Sys	Sup	Si
	Min	Sec	interval		(idea, precedent, interpreter)	(initial, developed)	(episodic, semantic, stimuli)	(given, find)	(past, present, future)	(system, super system, sub system)	(subsystem, object)	(co-systems, user)	(alternative, analogy)
1	0	30	30	we have to propose new technology, new set of materials and physical principles for solving the problems	int			g	fu	sys	sub		
		45	15	just think that what requirements the fridge does satisfy?	p		se		pr	sup		user	
		55	10	then see what fridge exactly does	p		se		pr	sys	sub		
	1	5	10	and then what are the gaps?	p		se		pr	sys	sub		
		20	15	so what requirements the fridge does satisfy?	p		se		pr	sup		user	
		30	10	we can think also about functions and the ideal way for them	p		se		fu	sys	sub		
		45	15	in past there were some needs like preventing spoiling food	p		ep		pa	sys	obj		
		55	10	so they used basements and wells	p		ep		pa	si			alt
	2	5	10	they are about needs and fridge was produced to satisfy this need	p		ep		pa	sys	sub		
		20	15	so the function of fridge, keeping food healthy for long period	id	in			fu	sys	obj		
		30	10	keep the quality of food	id	dev			fu	sys	obj		
		45	15	also compare to the past, everybody has its own fridge in his home	p		ep		pa	sys	sub		
		55	10	it means it is more accessible	p		se		pr	sys	sub		
	3	10	15	first it was fridge and keeping for short periods and then the freezer added and it became possible to keep food for longer period	p		ep		pa	sys	sub		
		25	15	now a day we have seen fridge and freezer in one device	p		ep		pr	sys	sub		
		35	10	it took less space for users	p		se		pr	sup		co	
		45	10	now the devices for cooling water and ice making are added too	p		ep		pa	sys	sub		
		55	10	now they are connected to the tap	p		ep		pr	sys	sub		
	4	5	10	also there is a small door for bar to access drinking faster	p		ep		pr	sys	sub		
		15	10	we can think about other requirements	p		se		pr	sup		user	
		30	15	the bar is for reducing energy consumption by saving the cold air inside fridge	p		se		pr	sys	sub		
		55	25	one of the problems of fridge is related to its size	int			f	pr	sys	sub		
	5	5	10	people are living in small apartments	p		ep		pr	sup		user	
		15	10	the size of side-by-side is big compare to the kitchens	p		se		pr	sup		co	
		30	15	most of devices are becoming smaller and smaller like ovens and microwaves	p		se		fu	si			an
		40	10	we need fridge that occupy less space	int			f	fu	sys	sub		
		50	10	it must be also lighter for movements	int			f	fu	sys	sub		
	6	20	30	I have such this experience that I forgot some food in some part of fridge and after spoiling, I become aware by smell	int			f	pa	sup		user	
		30	10	if the fridge has an alarm for that, which there is a spoiled food in some part	id	in			fu	sys	sub		
		40	10	by its color or smell	id	dev			fu	sys	sub		
		55	15	or maybe a timer like oven that can be set when we put each food inside fridge	id	dev			fu	sys	sub		
	7	20	25	it is better because it is even preventing spoiling	p		se		fu	sys	obj		
		35	15	so we reviewed the past and we mentioned some concerns like size and alarm for using food	int			f	fu	sys	sub		
	8	5	30	I think the competition among companies of fridge is about energy consumption and durability of fridge	p		se		fu	sys	sub		
		20	15	they propose more layers, boxes and doors for less energy consumption	p		se		pr	sys	sub		

		40	20	every company is in one way and with various kind of design	p		se		pr	sys	sub		
		50	10	so we can also think about these issues or think about other issues	int			f	fu	sys	sub		
	9	10	20	we can consider it and propose ideas for that	int			f	fu	sys	sub		
		20	10	new freezers that there are completely like a drawer	id	in			fu	sys	sub		
		30	10	we just open the drawer that we need not open all the doors	p		se		fu	sys	sub		
		40	10	for the part of ice and water, we usually first select ice button and then we select button of water	p		ep		pr	sys	sub		
		50	10	I am thinking of third button for mix of them	id	dev			fu	sys	sub		
		55	5	this option must not change the occupied space. In the same space, new option	int			f	fu	sys	sub		
	10	10	15	we want smaller fridge at the end	int			f	fu	sys	sub		
		20	10	also we can think of cleaning of internal part of fridge	int			f	fu	sys	sub		
		30	10	some people use some foils or covers on the layers for just changing them for cleaning	p		ep		pr	sup		co	
		40	10	because the cleaning of layers is time consuming	p		ep		pr	sup		user	
		50	10	but these covers affect the performance of fridge negatively	p		se		pr	sys	sub		
	11	0	10	I have such this experience too. The fridge is not cold anymore and removed all the covers then	p		ep		pr	sys	sub		
		10	10	so it gets more energy or working load to the engine	p		se		pr	sys	sub		
		25	15	you mean it reduce the durability of fridge?	p		se		pr	sys	sub		
		45	20	I think so	p		se		pr	sys	sub		
	12	10	25	if you remember, in past the layers of fridge were fixed and we had to turn off the fridge and make it empty and then wash it	p		ep		pa	sys	sub		
		20	10	but now it is possible to bring the layers out and wash them	p		ep		pr	sys	sub		
		35	15	this improvement is so incremental but we expect a radical improvement	p		se		pa	sys	sub		
	13	0	25	we can discard the incremental changes	p		se		fu	sys	sub		
	14	0	60	or find radical changes in the same issue	p		se		fu	sys	sub		
		30	30	how can we find radical changes?	int			g	fu	sys	sub		
	15	10	40	let's focus more on some of the issues	p		se		fu	sys	sub		
		25	15	first the energy consumption	int			f	fu	sys	sub		
		40	15	and also flexibility of size and weight	int			f	fu	sys	sub		
	16	10	30	design a fix fridge like a cabinet inside kitchen	id	dev			fu	sup		co	
		20	10	it is not just hiding fridge inside furniture. This takes more space	p		se		pr	sys	sub		
		35	15	it is a fixed fridge in kitchen	p		se		fu	sys	sub		
		45	10	it occupies less space	p		se		fu	sys	sub		
		55	10	and it is easier for tenants	p		se		fu	sup		user	
	17	15	20	like fix open in the kitchen	p		ep		pr	si			an
		30	15	thinking about fix appliances at homes	p		ep		pr	si			an
		45	15	the tubes of water and electricity are inside the walls	p		se		fu	sys	sub		
	18	0	15	the normal fridge must have some distance with wall for exchanging air around condenser	p		ep		pr	sup		co	
		15	15	yes. They have ventilators	p		ep		pr	sys	sub		
		40	25	we have to consider independent fridge also because it is needed for many different usages and conditions	int			f	pr	sys	sub		
	19	15	35	even this idea doesn't seem radical idea	p		se		fu	sys	sub		
		25	10	I think all of our ideas were not radical up to here	p		se		fu	sys	sub		
		40	15	we can consider this idea as one of ideas	p		se		fu	sys	sub		
	20	0	20	another issue	p		se		fu	sys	sub		
		20	20	we usually have some frozen food with ourselves in trips that we are worry about them if they become unfrozen before we want	int			f	pr	sup		user	
		35	15	if we have cover that can cool down the contents inside	id	dev			fu	sys	sub		
		45	10	like a some polimeric material	id	dev			fu	sys	sub		
		55	10	you are changing technology from fridge to cover	p		se		fu	sys	sub		
	21	10	15	yes. I am considering same function with new system	p		se		fu	sys	sub		
		20	10	just we need to charge the cover you proposed	id	dev			fu	sys	sub		
		35	15	like a small polimeric balls that when they add to the salt of water, they can absorb heat and release coldness	id	dev			fu	sys	sub		
		45	10	so you mean that we remove the fridge and there are small packages	p		se		fu	sys	sub		
		55	10	this packages are rechargable	p		se		fu	sys	sub		
	22	15	20	also they can be in different sizes and different temperature for different kind of food	id	dev			fu	sys	obj		
		25	10	we put these packages inside the cabinets	p		se		fu	sup		co	
		45	20	what about some foods that we put in the freezer for longer period?	p		se		fu	sys	obj		
		55	10	fridge solved our problems that we couldn't go shopping every day and we need to buy at least for one wek and in some cases more	p		se		pr	sup		user	
	23	10	15	we are so busy because we are working outside and even we buy bread for one week	p		se		pr	sup		user	

		30	20	for some food it can be considered as one of the cabinet of the kitchen but this new material that they must be charged automatically after regular periods	p		se		pr	sys	sub		
		50	20	this is similar to the idea of preservatives for food	p		ep		pr	si			alt
	24	15	25	it seems that we have special covers for every food	p		se		fu	sys	obj		
		55	40	this is different by preservatives; we don't add something inside food	p		se		pr	si			alt
	25	5	10	I want fresh food without any additives to be fresh inside this cover	int			f	fu	sys	obj		
		30	25	there are some covers even now, that they isolate the food	p		ep		pr	si			alt
		55	25	they keep food for 12 to 18 hours	p		ep		pr	si			alt
	26	10	15	they prevent growth of bacteria	p		ep		pr	si			alt
		30	20	we have some polimeric material which release coldness	p		ep		pr	si			an
		40	10	do they need electricity?	p		ep		pr	si			an
	27	10	30	for some food we can think of reaction of food and polimeric material for cooling but for some others we have to think of covers	id	dev			fu	sys	sub		
		30	20	and for covers we need electrisity to recharge it	p		se		fu	sys	sub		
	28	10	40	we have to consider original and fresh food without peservaties	int			f	fu	sys	obj		
		25	15	this direction can be seen again in industries	p		se		fu	sys	obj		
		50	25	we bought a new split air conditioner recently	p		ep		pr	si			an
	29	5	15	it uses more electrisity but less water compare to the previous version of air conditioners	p		ep		pr	si			an
		20	15	which is better for Iran according to our resources	p		ep		pr	si			an
		30	10	I am thinking of integrating the engine of these two devices	id	dev			fu	sup		co	
		40	10	or the engines of many electrical devices using at home	id	dev			fu	sup		co	
		50	10	to reduce energy consumption	p		se		fu	sys	sub		
	30	0	10	we have to consider the one that is working constantly and charging the batteries of the others according to the different usage time of the others	p		se		fu	sup		co	
		15	15	the fridge is working constantly and it can have considered as the main one	p		se		fu	sys	sub		
		50	35	also it worth to remember that the gas of fridge is not completely environment friendly	int			f	pr	sys	sub		
	31	30	40	the idea of cover can be considered as a radical idea and also feasible because there are polymeric materials	p		se		fu	sys	sub		
		55	25	something like hot water bag but act inversely, when we put it inside microwave, it becomes cool and can use for cooling food	id	dev			fu	sys	sub		
	32	15	20	we cannot go more in detail for this idea	p		se		pr	si			an
		45	30	it is better to follow another issue	p		se		pr	sys	sub		
	33	10	25	if we remove the fridge by the idea of cover, the devices for water and ice making is removing also	p		se		fu	sys	sub		
		55	45	I really like to come back to the life style of ancient people, buy each day for that day and prepare and eat it	p		ep		fu	sup		user	
	34	15	20	I mean if the devices were compatible with this changes	p		se		fu	sup		user	
		30	15	some people are changing to this direction but it is difficult for ordinary life	p		ep		fu	sup		user	
		50	20	we can have a labor instead fridge at home to prepare food for us	p		ep		pr	si			alt
	35	0	10	what about cooling. We like to eat some food cold	p		se		pr	sup		user	
		25	25	we need something like a microwave only for cooling	id	dev			fu	sys	sub		
	36	10	45	we have lots of brands of producing fridge in Iran but I think all of them work under license	*								
		25	15	my research is also is about home appliances factories	*								
		55	30	I want to find the relations among these factories and their patents and patterns for inventions	*								
	37	15	20	I want to propose a model for R&D activities for these companies	*								
		25	10	R&D is responsible for invention and new product development	*								
		40	15	I want to use some concepts of TRIZ in analyzing the situation of companies and their new product development processes	*								
	38	20	40	let's come back to the project	*								
		30	10	we first reviewed past. Which one do you think as the radical changes in the past?	p		se		pa	sys	sub		
		45	15	coming fridge for the first time	p		se		pa	sys	sub		
	39	0	15	then merging with freezer	p		se		pa	sys	sub		
		20	20	I mean we saw small number of radical changes compare to the lots of continuous improvements	p		se		pa	sys	sub		
		45	25	or maybe even adding some functions like providing cold water and ice making can considered as radical changes	p		se		pa	sys	sub		
	40	10	25	how much time we have more?	*								
		20	10	I think around 5 min	*								

	41	20	60	we just propose one radical idea and some improvements; covers instead of fridge and working on movements or cleaning	p		se		fu	sys			
	42	20	60	review detail of idea	p		se		fu	sys			
		35	15	also it is better that one of the cabinet becomes more isolated for putting the covers to not let the insects to come inside	id	dev			fu	sup		co	
		55	20	some chemical processes are endothermic that they can be used too	id	dev			fu	sys	sub		
	43	15	20	the idea for fridge is more feasible compare to the freezer	p		se		fu	sys	sub		
		30	15	and we need more R&D development for that	p		se		fu	sys	sub		
	44	0	30	I am thinking also that fridge provide us hot water too	id	in			fu	sup		co	
		25	25	like the devices of providing cold and hot water in offices	p		ep		pr	si			an
		45	20	did we propose any idea for size?	p		se		fu	sys	sub		
	45	0	15	we just referred to fix fridge for kitchens	p		se		fu	sys	sub		
		15	15	can we have flexible size?	id	dev			fu	sys	sub		
		30	15	if we can make it bigger by bring out some drawers that they are inside when we don't need them	id	dev			fu	sys	sub		
		45	15	what about the engine?	p		se		fu	sys	sub		
		55	10	it can be in less length but taller	p		se		fu	sys	sub		
	46	20	25	we can reach the upper parts by a lift or sliding	id	dev			fu	sys	sub		
	47	30	70	we solve the problem of space and accessibility by this way	p		se		fu	sup		co	
	48	10	40	it also can be like a machine that we can receive our food by a button	id	dev			fu	sys	sub		
		30	20	it can be even like a automatic layers instead of drawers	id	dev			fu	sys	sub		
		45	15	it can be also transparent that we can see inside	id	dev			fu	sys	sub		
	49	0	15	end	*								
2	0	15	15	we have to consider both fridge and freezer. They have different functions	p		se		pr	sys	sub		
		25	10	they are five steps that we have to follow	p		st		pr	sys	sub		
	1	20	55	the task of fridge: to keep food healthy for longer periods	p		ep		pr	sys	sub		
		45	25	then the people even wanted cooling food	p		ep		pr	sys	sub		
	2	10	25	then they added freezer	p		ep		pa	sys	sub		
		20	10	Is there separated fridge and freezer even now?	p		ep		pa	sys	sub		
		30	10	yes. I have seen	p		ep		pa	sys	sub		
		40	10	then the device for water added	p		ep		pa	sys	sub		
		55	15	then the device for ice making	p		ep		pa	sys	sub		
	3	20	25	also we can see more accessibility to room for keeping food healthy	p		se		pr	sys	sub		
		30	10	and also less spaces compare to the basement or a complete room	p		se		pr	sup		co	
	4	15	45	now we have to find the problems	p		st		pr	sys	sub		
		40	25	I think it is about 70 years that we have similar fridge in market	p		se		pr	sys	sub		
	5	15	35	we have to consider the elements	p		st		pr	sys	sub		
		25	10	like the engine	p		st		pr	sys	sub		
		45	20	and the bigger systems that our system is part of them	p		st		pr	sup		co	
	6	10	25	like kitchen	p		st		pr	sup		co	
	7	10	60	also the home can be considered as super-system	p		st		pr	sup		co	
		30	20	a little difficult to realize the super-systems	p		se		pr	sup		co	
		45	15	is the electricity or water tap parts of super systems?	p		se		pr	sup		co	
	8	10	25	can we consider factories of steel and plastic part of super-systems?	p		se		pr	sup		co	
		30	20	I don't think so	p		se		pr	sup		co	
		45	15	what are the elements and sub-systems?	p		st		pr	sys	sub		
	9	45	60	like engine and container, …, we call them systems with special function	p		st		pr	sys	sub		
	10	35	50	now we have to compare the system of present with the old version in terms of elements and also super-systems	p		st		pr	sys	sub		
	11	45	70	past and old version means, the first version of system or when there is not this type of system at all?	p		st		pa	sys	sub		
	12	0	15	I think we can consider the basement for the old version	p		ep		pa	sys	sub		
		10	10	what are the elements of water reservoire	p		ep		pa	sys	sub		
		55	45	water, dark room, the soil and thatch, the position under ground	p		ep		pa	sys	sub		
	13	15	20	what were super-systems then?	p		st		pa	sup		co	
	14	30	75	difficult to say, maybe season, buildings, air, wind, climate, ...	p		ep		pa	sup		co	
		55	25	now we can shift to present	p		st		pr	sys	sub		
	15	20	25	sub system of current fridge	p		ep		pr	sys	sub		
	17	50	150	engine, layers, doors, condensor, …	p		ep		pr	sys	sub		
	20	20	150	super-systems can be considered as electricy, house, kitchen, cabinet, water tap, compressor, condenser, gas, body, glass, …	p		ep		pr	sup		co	
	21	0	40	can we find some problems solved by these two versions?	p		st		pr	sys	sub		
		50	50	how to find the problems?	p		st		pr	sys	sub		

	22	15	25	we can first list the problems of both situations	p		se		pr	sys	sub		
	23	15	60	let's start by comparing sub-systems	p		se		pr	sys	sub		
	24	55	100	it is difficult to compare these two situation because they are totally different	p		se		pr	sys	sub		
	25	5	10	I think about the health issues and pollution	p		se		pr	sys	obj		
		15	10	also about the accessibility	p		se		pr	sys	sub		
		25	10	and it depended to the city and country	p		se		pr	sup		co	
		35	10	it means the fridge was dependent to the season and air condition	p		se		pr	sup		co	
		50	15	today the fridge is independent to the air condition	p		se		pr	sup		co	
	26	10	20	so we can list the problems like this:	p		se		pr	sys	sub		
		25	15	1. it is less polluted for food now	int			f	pr	sys	obj		
		35	10	2. it is less space for fridge	int			f	pr	sys	sub		
		50	15	3. independent to the air condition	int			f	pr	sup		co	
	27	25	35	4. less dependent to the home architecture (because the related room must be dark and cold naturally)	int			f	pr	sup		co	
		55	30	5. longer durability for food	int			f	pr	sys	obj		
	28	30	35	6. possibility to have cold food beyond healthy food	int			f	pr	sys	sub		
		40	10	7. more accessibility	int			f	pr	sys	sub		
		50	10	by using fridge, we can have fruit and vegatables from other cities	p		se		pr	sup		co	
	29	0	10	it means that we have fresh fruit and vegetables out of season	p		se		pr	sup		co	
		55	55	so 8. accessibility to varity of food out of season	int			f	pr	sup		co	
	30	5	10	do we see any other problem?	int			f	pr	sys	sub		
		20	15	let us to find solved problems	p		st		pr	sys	sub		
		50	30	the food are not polluted by the fridge	p		se		pr	sys	obj		
	31	15	25	and the durability increased	p		se		pr	sys	obj		
		40	25	but still they are not healthy as we expected	p		se		pr	sys	obj		
		50	10	what else?	p		ep		pr	sys	sub		
	32	0	10	I think all other problems has solved	p		se		pr	sys	sub		
		20	20	for example, fridge occupy less space compare the entire room	p		se		pr	sup		co	
	33	0	40	but not completely. In the past the houses were bigger also but now the houses are smaller and we need to deal with the problem of space too	p		se		pr	sup		co	
		15	15	also freedom to the air condition for varity of food	p		se		pr	sup		co	
		25	10	possibility of cooling more rapidly	p		se		pr	sys	sub		
		35	10	easier access to the fridge	p		se		pr	sys	sub		
		45	10	also the fridge is helpful for keeping medicine	p		se		pr	sys	sub		
	34	10	25	so we finished second step	p		st		pr	sys	sub		
	36	45	155	we have to analyze the problems to see what are the bariers for the third step	p		st		pr	sys	sub		
	37	20	35	so let start	p		st		pr	sys	sub		
		55	35	still I have doubt about the version we selected for analysis	p		se		pa	sys	sub		
	38	25	30	I think every version we select, we will see more or less similare problems	p		se		pa	sys	sub		
		55	30	less consider the following parameters as improved ones	p		se		pr	sys	sub		
	39	15	20	1. quality of food	p		se		pr	sys	obj		
		25	10	2. duration of keeping	p		se		pr	sys	obj		
		35	10	3. in less space	p		se		pr	sys	sub		
		45	10	and the others are similar	p		se		pr	sys	sub		
	40	15	30	may be we have to make them more measurable	p		se		pr	sys	sub		
		35	20	or maybe we have to focus more on the technologies were used	p		se		pr	sys	sub		
	41	0	25	we had totally different technologies (without technology to technology)	p		se		pr	sys	sub		
	42	20	80	I think that we have to make them just measurable	p		se		pr	sys	sub		
		45	25	in past we had the technology inside houses to let wind came to the home and make the dark room cold	p		se		pa	sys	sub		
	43	5	20	it was an advanced technology	p		se		pa	sys	sub		
		25	20	also they considered special material for the room	p		se		pa	sys	sub		
	44	20	55	but for the fridge we can consider instead the gas circulation in condensor, …	p		se		pr	sys	sub		
	45	15	55	now we have to say the bariers	p		st		pr	sys	sub		
		55	40	we don't have time so let to compact all other steps together	*								
	46	15	20	still we can work on less space	p		se		pr	sup		co	
		45	30	Barrier in past can be considered as difficulty to have a dark isolated cold small place in houses	p		se		pa	sys	sub		
	47	15	30	and it was bigger	p		se		pa	sys	sub		
		40	25	and also it was not accessible	p		se		pa	sys	sub		
	48	55	75	and the barriers for present can be considered still the size of engine and compressor, external condensor are big	p		se		pr	sys	sub		
	51	40	165	the problem of past to presnt has solved completely but from present to future has not solved completely yet	int			f	fu	sys	sub		
		50	10	we are out of time	*								
	52	5	15	but let's to have an idea at least	*								

	53	45	100	our previous idea about central engine for house can solve the problem	id	dev			fu	sys	sub		
	54	0	15	let's finish	*								

10. Team 10/ Session 1: without stimulus, Session 2: without stimulus

Part	Time (end)			Sentences	Concept	Idea	Precedent	Interpreter	Time	Space	Sys	Sup	Si
	Min	Sec	interval		(idea, precedent, interpreter)	(initial, developed)	(episodic, semantic, stimuli)	(given, find)	(past, present, future)	(system, super system, sub system)	(subsystem, object)	(co-systems, user)	(alternative, analogy)
1	0	55	55	we have to propose new fridge that there are some radical technological changes	int			g	fu	sys	sub		
	1	25	30	we can start by looking at the function of the fridge	p		se		pr	sys	obj		
		45	20	what do you mean by function?	p		se		pr	sys	obj		
		55	10	main reason that we need fridge	p		se		pr	sys	obj		
	2	25	30	it cools down food	p		ep		pr	sys	obj		
		45	20	it cools down food for what?	p		se		pr	sys	obj		
		55	10	to keep food healthy	p		se		pr	sys	obj		
	3	20	25	we cool down to decrease the growth of bacteria	p		se		pr	sys	obj		
		30	10	it also freezes food	p		ep		pr	sys	obj		
		40	10	to keep it for longer period	p		ep		pr	sys	obj		
		50	10	also it cools down food to let us enjoy of cold food	p		ep		pr	sup		user	
	4	0	10	like water and drinking	p		ep		pr	sup		user	
		10	10	but I think the main task of fridge is keeping food healthy	p		se		pr	sys	obj		
		20	10	so we can focus on the main task	p		se		pr	sys	obj		
		30	10	we can think of removing reasons of spoiling food	id	in			fu	sys	obj		
		35	5	like fridge for preventing them like killing bacteria	id	dev			fu	sys	obj		
		45	10	like an isolated box that doesn't let transferring of food with outside	id	dev			fu	sys	sub		
		55	10	it is difficult to make it isolated because we open its door so often to put new food or takeout food	p		se		pr	sys	sub		
	5	25	30	we can use a classification and for very less using food, using more isolated container	id	dev			fu	sys	obj		
		50	25	we can have a mediator container. Every food automatically store in some part of fridge and selected food can be accessed in the mediator container	id	dev			fu	sys	sub		
	6	5	15	it is like some laboratories	p		ep		pr	si			an
		15	10	I think this idea increases the price of fridge and it is not affordable for many people	p		se		pr	sup		user	
		30	15	a smart robot can bring food for us	id	dev			fu	sys	sub		
		55	25	maybe we can think of special gloves like the gloves inside laboratories to choose and bring out to the mediator container	id	dev			fu	sys	sub		
	7	15	20	I think also the rate of exchange of bacteria from out to inside of fridge is not so high when we open the door	p		se		pr	sys	sub		
		25	10	and if the fridge repeats the process of killing bacteria regularly, it can be enough	id	dev			fu	sys	sub		
		30	5	how can we kill bacteria? Do we know any technology?	p		ep		pr	si			an
		40	10	can sound kill the bacteria?	id	dev			fu	sys	sub		
		45	5	it can be	p		se		fu	sys	sub		
		55	10	but may be they also increase temperature too	p		se		fu	sys	sub		
	8	5	10	or may be some changes in the food and we don't want these changes	p		se		fu	sys	obj		
		10	5	maybe we can think of filtering air	id	dev			fu	sys	sub		
		20	10	that small portion of bacteria are inside air	p		se		pr	sys	sub		
		30	10	where are the bacteria for example for an apple?	p		se		pr	sys	obj		
	9	0	30	both inside and outside, because some food spoil from inside	p		se		pr	sys	obj		
		15	15	so we can think of waves that kill the bacteria	id	dev			fu	sys	sub		
		40	25	also we can think of using vacuum for decreasing of bacteria	id	dev			fu	sys	sub		
	10	0	20	like a drawer that vacuum air when we close it	p		se		pr	si			an
		25	25	there are some small packages for vacuuming to reduce the growth of bacteria	p		ep		pr	si			alt
		45	20	and we don't have frost in this way at all	p		se		fu	sys	sub		
	11	15	30	but this way doesn't kill bacteria and it just reduce their growth	p		se		pr	sys	obj		
		30	15	can we think about other ways?	p		se		fu	sys	sub		
		55	25	may be we can change also the topic. Instead of thinking about killing bacteria, thinking about increasing the durability of food	p		se		pr	sys	obj		
	12	15	20	or also increasing the accessibility to the food	int			f	fu	sys	sub		
		25	10	or adding the capicity of fridge without increasing size	int			f	fu	sys	sub		
		30	5	also less energy consumption	int			f	fu	sys	sub		

		40	10	they say that we open the door, the energy consumption increases	p		se		pr	sys	sub		
		55	15	using two layer doors for decreasing waste of energy	id	in			fu	sys	sub		
	13	5	10	by this way, we are changing the direction	p		se		pr	sys	sub		
		15	10	come back to the bacteria	p		se		pr	sys	sub		
		25	10	there 2 issues, one preventing spoiling food	p		se		pr	sys	sub		
		35	10	the other is related to quality of food especially for the food were kept inside freezer	p		ep		pr	sys	sub		
		45	10	you are referring to nutritional value	p		se		pr	sys	obj		
		55	10	even more, the changes in tissue and tastes	p		se		pr	sys	obj		
	15	15	80	you are proposing to produce idea for keeping food for longer period with saving original quality	int			f	fu	sys	obj		
		25	10	even for freezer, the final target is keeping longer period not freezing	int			f	pr	sys	sub		
		40	15	maybe the bacteria for spoiling of different kind of food, are different also so we need a fridge that can realize type of food and keep them in a special situation	id	dev			fu	sys	obj		
		55	15	and we can control them in different temerature	p		se		fu	sys	obj		
	16	25	30	do we have to develop our idea in details or even general idea is enough	int			f	pr	sys	sub		
		45	20	no I think we have to just propose ideas that we think that they can be feasible with some technologies	int			f	pr	sys	sub		
	17	0	15	we can think of ultrasonic for killing bacteria	id	dev			fu	sys	sub		
		35	35	or even we can think of some gases that can kill bacteria if it does not damage the food	id	dev			fu	sys	sub		
		50	15	these ideas are related to the fridge	p		se		fu	sys	sub		
	18	5	15	for freezer we can think of working on process of freezing to keep the quality of food	p		se		fu	sys	sub		
		20	15	in scientific documentaries I saw that there are some ways of cooling that don't damage the organic tissues	p		ep		pr	si			an
		30	10	after DE freezing the organic tissues work as an alive cell	p		ep		pr	si			an
	19	25	55	for example, we can use very fast freezing that save the tissue	id	dev			fu	sys	sub		
	20	0	35	quality can be considered as taste, nutritional value, color, smell, tissue, …	p		se		pr	sys	obj		
		15	15	can this direction also produce radical ideas?	p		se		pr	sys	sub		
		45	30	in most of the previous ideas, we proposed radical ideas	p		se		pr	sys	sub		
	21	25	40	we change materials and physical principles	int			g	pr	sys	sub		
		40	15	what about changing the gen of food?	id	dev			fu	sys	obj		
		50	10	now we are working on the fridge	p		se		pr	sys	sub		
	22	0	10	by genetic, the fridge is removing completely	p		se		fu	sys	sub		
		15	15	let's work on fridge	p		se		pr	sys	sub		
		30	15	I heard that special geometric shape has special energy that can keep food safe	p		se		pr	si			an
	23	15	45	it is metaphysic and it is not trustable and there is no evidence for that	p		se		pr	si			an
		25	10	let's adjust ourselves again to the task	p		se		pr	sys	sub		
		35	10	we have to propose new solutions and idea for problem by new materials and physical principles	int			f	pr	sys	sub		
		45	10	it means all fridges try to keep food by cooling	p		se		pr	sys	sub		
		55	10	but we are proposing ideas by new principles	p		se		fu	sys	sub		
	24	15	20	by waves, vacuum, gas, …	p		se		fu	sys	sub		
		25	10	light is wave also?	p		ep		pr	sys	sub		
		50	25	yes. It is kind of waves	p		ep		pr	sys	sub		
	25	0	10	in past we use to dry food	p		ep		pa	si			alt
		10	10	shall we use it again	id	in			fu	sys	sub		
		20	10	the factory prepares dried food and we buy it, why do we have to dry at home?	p		se		pr	sup		co	
		30	10	some part of fridge for drying	id	dev			fu	sys	sub		
		40	10	I think we can think of some ideas related to software also	p		se		fu	sys	sub		
		50	10	the fridge that reports the content of inside and a sensor to alarm spoiling	id	dev			fu	sys	sub		
	26	0	10	the fridge alarms the ordering point according to the usage pattern	id	dev			fu	sys	sub		
		15	15	to show the calories of food	id	dev			fu	sys	sub		
		20	5	for what?	p		se		fu	sup		user	
		25	5	for the people who have diet	p		se		fu	sup		user	
		45	20	wireless fridge that can be moved easily	id	in			fu	sys	sub		
		50	5	why do you want to move fridge?	p		se		pr	sup		user	
		55	5	to wash it	p		se		pr	sup		user	
	27	20	25	chargeable battery for time of out of electricity	id	dev			fu	sys	sub		
		40	20	ups can store the electricity and release it when the electricity is out of circuit	id	dev			fu	sys	sub		
	28	10	30	can the bacteria be killed by pressure?	p		se		pr	sys	sub		
		25	15	I think it damages food more than bacteria	p		se		pr	sys	obj		
		55	30	can pressure affect the energy consumption?	p		se		pr	sys	sub		

	29	15	20	I mean shall we use pressure to decrease the energy consumption?	id	dev			fu	sys	sub		
		50	35	if we decrease the pressure, the temperature decreases	p		se		pr	sys	sub		
	30	20	30	so if we vacuum inside the fridge, we need less energy to cool it	id	dev			fu	sys	sub		
	31	20	60	the fridge is working according to the same physical principle for gas inside condenser	p		ep		pr	sys	sub		
		40	20	that mechanism is outside fridge but I am proposing for inside fridge	p		se		pr	sys	sub		
		50	10	but when we open the door, the pressure of inside and outside become the same	p		se		pr	sys	sub		
		55	5	so we use mediator for bringing out food	id	dev			fu	sys	sub		
	32	10	15	but a woman at home uses fridge so much and it is not feasible I think	p		se		pr	sup		user	
		25	15	it is like a small laboratory	p		ep		pr	si			an
	33	45	80	a flexible cover and we can take the food by cover and bring them in mediator box and then take them out from that box	id	dev			fu	sys	sub		
	34	30	45	it is so difficult because the fridge has different shelves and the food are in the different depth in each shelf	p		se		pr	sys	sub		
	38	0	210	draw the picture	p		se		fu	sys	sub		
2	0	20	20	please let to review our approach in previous	p		se		pr	sys	sub		
		45	25	we started with the function of system and we realized 3 different functions	p		se		pr	sys	sub		
	1	5	20	keeping food for short period, long period, cooling	p		se		pr	sys	sub		
		20	15	then we distinguished the bacteria for spoiling food	p		se		pr	sys	obj		
		55	25	and we realized cooling as one of possible way for reducing the growth of bacteria	p		se		pr	sys	sub		
		15	20	then we proposed some new way for killing or paralyzing bacteria	p		se		pr	sys	sub		
	2	5	50	such as gas, vacuuming, waves, light, ultrasonic, and even pressure	p		se		pr	sys	sub		
		30	25	what were the other approaches?	*								
	3	0	30	we also mentioned the quality of food especially for long period	p		se		pr	sys	sub		
		45	15	the quality can be seen in color, tissue, smell, nutritional values, taste	p		se		pr	sys	obj		
	4	5	20	even something like softness and brightness	p		se		pr	sys	obj		
		35	30	I think brightness is part of color and softness is part of tissue	p		se		pr	sys	obj		
	5	0	25	some times when the degree of fridge is high, some fruits even freeze in the fridge, we can distinguish it from the brightness of surface	p		ep		pr	sys	obj		
		25	25	and the taste is mixing with water, like the taste is water with some essence of the fruit	p		ep		pr	sys	obj		
		50	25	some people like the taste like iced-sour cherry	p		ep		pr	sup		user	
	6	0	10	why we talked about the quality of food?	p		se		pr	sup		user	
		15	15	every technology for keeping food, must not change the quality	int			f	fu	sys	obj		
		35	20	for example, gas and pressure will change the quality	p		se		pr	sys	sub		
		50	15	but maybe they change the quality but they must be better than the current fridge	int			f	fu	sys	obj		
	7	10	20	also we talked about the durability	p		se		fu	sys	obj		
		20	10	that we can propose a fridge that can increase the durability of food	p		se		fu	sys	obj		
		35	15	but we didn't propose a special idea related to that	p		se		fu	sys	sub		
		45	10	I don't remember. May be we consider it as part of quality	p		se		fu	sys	sub		
		50	5	no	p		se		fu	sys	sub		
	8	10	20	what else we discussed?	p		se		pr	sys	sub		
		35	25	2 other issues we entered but we didn't discuss completely	p		se		pr	sys	sub		
		50	15	one to add software to fridge	p		se		pr	sys	sub		
	9	5	15	the second one, were talking about energy consumption	p		se		pr	sys	sub		
		15	10	let's follow these 2 directions first and then something else	p		se		pr	sys	sub		
		25	10	I think we can propose good ideas for the first one	p		se		pr	sys	sub		
		45	20	the software is an important part of technology	p		se		pr	si			an
		55	10	and we see lots of changes in this part now a day	p		ep		pr	si			an
	10	15	20	we see only the electronical board as software	p		ep		pr	sys	sub		
		30	15	what does the board do?	p		ep		pr	sys	sub		
		40	10	we adjust the time of fridge, freezer and water by that	p		ep		pr	sys	sub		
		55	15	also we choose the water or ice mode by that	p		ep		pr	sys	sub		
	11	10	15	does it change the temperature automatically according to usage?	p		ep		pr	sys	sub		
		15	5	I don't think so	p		ep		pr	sys	sub		
		45	30	when the temperature is adjusted, if we use the fridge less, the engine works less and the energy consumption is less	p		ep		pr	sys	sub		
	12	5	20	it is based on the circulation of gas in condenser	p		ep		pr	sys	sub		
		20	15	we proposed the fridge show the calories of food for diet users	p		se		fu	sys	sub		
		35	15	we also proposed the sensor for spoiling food	p		se		fu	sys	sub		
		45	10	how does this sensor work?	p		se		fu	sys	sub		

	13	0	15	can this sensor distinguish the spoiling food?	p		se		fu	sys	sub		
		35	35	maybe we can use code for food when we put them in the fridge like the barcode of food	id	dev			fu	sys	sub		
		55	20	the alarm works according to the time we adjust for the code	p		se		fu	sys	sub		
	14	25	30	I think there are some sensors in laboratories that they can distinguish the vapors and smells of spoiling food	p		ep		pr	si			an
	15	0	35	why do we want to know the spoiling of food? It is better fridge propose the time for eating the food.	id	dev			fu	sys	sub		
		10	10	so I think using code is more logical	p		se		fu	sys	sub		
		25	15	also these codes can be used for knowing the amount of food to know the ordering time	p		se		fu	sys	sub		
		35	10	it was one of our idea in previous session	p		se		fu	sys	sub		
		55	20	what about if fridge show us the previous pattern of usage?	id	dev			fu	sys	sub		
	16	10	15	why is it helpful when we have ordering time?	p		se		fu	sup		user	
		20	10	information is important	p		se		pr	sup		user	
	17	5	45	now a day we are interested in healthy family. We can improve life style by showing the pattern and compare it with a best practice for such these families	p		ep		pr	sup		user	
		35	30	the fridge can be connected to the doctor to give new prescription	id	dev			fu	sup		co	
		55	20	also if it shows the previous function, we can manage our children even when we are not at home	id	dev			fu	sys	sub		
	18	25	30	may be instead, a mother from outside can be connected to the fridge and order it to propose food the children	id	dev			fu	sys	sub		
		35	10	I mean controlling from distance	p		se		fu	sys	sub		
		50	15	specially for the medicine of children	p		se		fu	sys	sub		
	19	0	10	what else we can propose?	p		se		fu	sys	sub		
		10	10	I think it is better to change discussion to second issue	p		se		pr	sys	sub		
		25	15	to propose some idea for energy consumption	p		se		pr	sys	sub		
		40	15	we propose 2 layer doors which is not very radical idea	p		se		pr	sys	sub		
	20	0	20	but also we talked about relation of pressure and vacuuming to the energy consumption	p		se		pr	sys	sub		
		15	15	yes. Also vacuuming is effective in reducing the growth of bacteria	p		se		pr	sys	sub		
		35	20	there are some covers for vacuuming the food to reduce the growth of bacteria	p		ep		pr	si			alt
		55	20	is it possible to have special boxes by vacuuming instead of fridge?	id	dev			fu	sys	sub		
	21	15	20	but we still need fridge for cooling or freezing	p		se		fu	sys	sub		
		35	20	idea of vacuum box can solve the problem of weight of fridge	p		se		fu	sys	sub		
		50	15	fridge is really heavy and it is one of problems of users	p		ep		fu	sys	sub		
	22	5	15	most of us are tenants and we have to move the fridge every year to new house	p		ep		pr	sup		user	
		20	15	we have to think about the lighter fridge	int			f	fu	sys	sub		
		35	15	actually it must be portable	int			f	fu	sys	sub		
		55	20	I mean it can be portable even if it is heavy	int			f	fu	sys	sub		
	23	15	20	there are some special wheels for fridges	p		ep		pr	sys	sub		
		35	20	but they are good for small movements inside kitchen and they are not useful for moving in stairs	p		se		pr	sys	sub		
	24	10	35	if we could pack the fridge and make it as small as possible for movement	id	in			fu	sys	sub		
	25	5	55	why not a flexible fridge that can be packed in different sizes	p		se		fu	sys	sub		
		50	45	so we can use the fridge in different sizes according to need	id	dev			fu	sys	obj		
	26	15	25	it means that we need special material for body and some joints	p		se		fu	sys	sub		
		40	25	the body must be isolated	p		se		fu	sys	sub		
	27	15	35	why not the body from water proof clothing material	id	dev			fu	sys	sub		
		55	40	it is good for portable fridge for picnics like a Coleman	id	dev			fu	sys	sub		
	28	25	30	for easier movement let's analyze first	p		se		fu	sys	sub		
		35	10	which part of fridge is heavier?	p		se		fu	sys	sub		
		50	15	body. it is from steel	p		ep		fu	sys	sub		
	29	10	20	now a day their different kind of polymer and plastics, why they don't change the material of body	id	dev			fu	sys	sub		
		30	20	the body is thinner compare to the past	p		se		fu	sys	sub		
		45	15	I think the engine and compressor are the heaviest parts	p		ep		fu	sys	sub		
	30	0	15	is it possible to separate them from fridge?	id	dev			fu	sys	sub		
		25	25	I mean if we can disassemble and assemble the engine before movement and after that	p		se		fu	sys	sub		
		40	15	maybe the engine is sensitive part that this can damage it more	p		se		pr	sys	sub		
	31	5	20	it could be with new strong cover	p		se		fu	sys	sub		
		45	40	also we can position the engine and compressor everywhere in the kitchen that is cooler	p		se		fu	sys	sub		
	32	0	15	this idea is like the idea of split air conditioner	p		ep		pr	si			an
		15	15	we can merge the engine of these two device	id	dev			fu	sys	sub		
		25	10	I like this idea	p		se		fu	sys	sub		
		45	20	this is both radical and feasible	p		se		fu	sys	sub		
	33	0	15	let's finish	p		se		fu	sys	sub		

11. Team 11/ Session 1: without stimulus, Session 2: trend as a stimulus

Part	Time (end)			Sentences	Concept	Idea	Precedent	Interpreter	Time	Space	Sys	Sup	Si
	Min	Sec	interval		(idea, precedent, interpreter)	(initial, developed)	(episodic, semantic, stimuli)	(given, find)	(past, present, future)	(system, super system, sub system)	(subsystem, object)	(co-systems, user)	(alternative, analogy)
1	0	25	25	in management of technology we talk about technology push and market pull	p		se		pr	sup		user	
		45	20	I am not agreeing that technology is responding a problem. I think after emerging of some technologies, the new problems emerge	p		se		pr	sup		user	
		55	10	most of technologies are like this	p		se		pr	sup		user	
	1	5	10	but in today's market, I am not agreeing with you	p		se		pr	sup		user	
		25	20	some new theories for producing technologies, discuss differently	p		se		pr	sup		user	
	2	0	35	so we see synthesis of both in the real market	p		se		pr	sup		user	
		15	15	I think technology push is dominant	p		se		pr	sup		user	
		25	10	what do we want to reach by this issue?	p		se		pr	sup		user	
		35	10	some times the market is surprising by new solution of a new radical technology and then accept it	p		se		pr	sup		user	
		45	10	but we have to consider the need and problems of users in the market	p		se		pr	sup		user	
		55	10	in the industry of home appliences, I belive on technology push	p		se		pr	sup		user	
	3	10	15	we didn't expect some device for grilling chiken, it comes to the market and then we bought it	p		ep		pr	si			an
		30	20	may be in oil industry, it is more problem base	p		ep		pr	si			an
	4	0	30	the problems of digging, excavation, transfering, … are clear	p		ep		pr	si			an
		10	10	we have to propose radical technological ideas	int			g	fu	sys	sub		
		25	15	it means that we have focus on technology	int			g	fu	sys	sub		
		45	20	by some changes materials, physical principles, ...	int			f	fu	sys	sub		
		55	10	maybe this kind of changes are incremental or radical	p		se		fu	sys	sub		
	5	5	10	but if we changes both materials and principles together, I think we can expect radical ideas	p		se		fu	sys	sub		
		30	25	like recording voice; from gramaphone to tape and then digital on CD	p		ep		pr	si			an
		55	25	we see a radical changes in paradigm; in both gramaphone and tape, we see electromagnetic changes in material and see differences of wave of the material but CD and DVD are working based on laser and optic	p		se		pa	si			an
	6	5	10	this is radical paradigm	p		se		pa	si			an
		25	20	may be one day we change optic with new field again	p		se		fu	si			an
		35	10	now for fridge we can see in this way	p		se		pr	sys	sub		
		50	15	check the materials and physical principles to study the possibility of changes in them	p		se		pr	sys	sub		
	7	0	10	circulation of gas, condensation, evaporation, ...	p		ep		pr	sys	sub		
		10	10	I don't know the technical knowledge of fridge	p		ep		pr	sys	sub		
		25	15	we see compressor and pressure change also	p		ep		pa	sys	sub		
		35	10	we have to cool the container	p		ep		pr	sys	sub		
		45	10	we can try to propose changes for these parts	int			f	fu	sys	sub		
	8	10	25	we have to think first about the new generation of system	p		se		fu	sys	sub		
		35	25	that we have to propose technical ideas	int			g	fu	sys	sub		
	9	15	40	we can think first separately and then share our opinions	p		se		pr	sys	sub		
		25	10	first we can list the elements of fridge	p		ep		pr	sys	sub		
		45	20	and if we tell in following the function of each element	p		ep		pr	sys	sub		
	10	10	25	we want to propose the next generation so we have to review frist the current generation like a good literature review	p		ep		pr	sys	sub		
	11	10	60	I think we have to consider the problems of fridge, materials and physical principles	p		se		pr	sys	sub		
		25	15	the fridge works based on termodynamic law with a gas	p		ep		pr	sys	sub		
		40	15	we can think about changing termodynamic law	id	in			fu	sys	sub		
		50	10	also changes of gas to be more efficent	id	dev			fu	sys	sub		
		55	5	also more environment friendly gas	id	dev			fu	sys	sub		
	12	10	15	the system consists of compressor, condensor, container, tubes, engine,	p		ep		pr	sys	sub		
		25	15	these elements are similar in termodynamic systems with some different	p		ep		pr	sys	sub		
		45	20	if we cahange or improve the termodynamic system, we can expect radical changes	p		se		pr	sys	sub		
	13	45	60	the gas is compressed by a compressor and it become liquid and realease the heat, then it guided to the tubes of condensor and as	p		ep		pr	sys	sub		

				the pressure is low, it becomes gas again and absorbs the heat to receive the heat of food inside the condensor									
		55	10	this cycle repeats to cool down the food	p		ep		pr	sys	sub		
	14	5	10	if we improve the system of thermodynamic, we are improving the curren fridge but if we propose a new law, we can expect radical changes	p		se		pr	sys	sub		
		40	35	by this changes we can see more productivity, less consumption of energy, less cost, …	int			f	pr	sys	sub		
	15	0	20	if there are some harms by gas, changes of that part can be considered as next generation too	int			f	pr	sys	sub		
		15	15	also the quality and durability of food is important	int			f	pr	sys	sub		
		25	10	or think about processing food according to our needs	id	in			fu	sys	obj		
		35	10	we can analyze the functions	p		se		pr	sys	sub		
		45	10	the function of fridge seems cooling food	p		ep		pr	sys	sub		
		50	5	but we can change it to keep food fresh according to your idea	id	dev			fu	sys	obj		
		55	5	it helps us to new ideas	p		se		fu	sys	sub		
	16	10	15	we can work on the gens of food and seeds	id	dev			fu	sys	obj		
		40	30	it is possible but we have to consider the boundaries of system	p		se		pr	sys	sub		
	17	40	60	I mean if we consider the fridge as the system, we have to generate ideas for that not for seeds	p		se		pr	sys	sub		
		55	15	changing the scope, is misleading us to wrong situation	p		se		pr	sys	sub		
	18	30	35	can we propose ideas and solutions for different time periods, for 20 years, for 15 years, for 10 and 5 years	p		se		pr	sys	sub		
		40	10	and consider seeds as very long period	id	dev			fu	sys	obj		
	19	20	40	forecasting is also related to map of technology of each company	p		se		fu	sys	sub		
		45	25	when we study the map of technology, we also think about the strengths and threats	p		se		fu	sys	sub		
	20	30	45	that is so huge task and we don't need to work on	p		se		fu	sys	sub		
		45	15	we are in the position of R&D engineer and we are proposing our visions about possible technologies for future	int			f	fu	sys	sub		
	21	15	30	we don't consider now the investment and constraints for example	p		se		fu	sys	sub		
		25	10	so let works on the technology	p		se		fu	sys	sub		
		50	25	we can also try to be inspired by nature to propose idea	p		ep		fu	si			an
	22	5	15	it means that we think about other animals and plants that look for or need coldness and try to learn their mechanism	p		ep		fu	si			an
		15	10	try to propose technology according to what is happening in the nature	p		ep		fu	si			an
		45	30	the materials of fridge can be related to the cabin and keeping cold air inside and some others related to the mechanism of cooling	p		ep		pr	sys	sub		
		55	10	some materials can be effective in radical changes and some others not like the plastics around the door	p		se		pr	sys	sub		
	23	5	10	the thickness of walls of fridge are so high	p		se		pr	sys	sub		
		15	10	and waste lot of spaces and the transfering is so difficult	p		se		pr	sup		co	
		25	10	so if we propose a new insulator, we can propose next generation	id	in			fu	sys	sub		
		35	10	I am thinking of a fridge that can be diassembled for movements	id	in			fu	sys	sub		
		50	15	this solves the problem of movement radically	p		se		pr	sys	sub		
	24	10	20	so you mean that we are proposing ideas in 2 levels	p		se		fu	sys	sub		
		35	25	in one level we proposing ideas for technical improvements in the system	p		se		fu	sys	sub		
	25	0	25	in one other level we are proposing ideas to change the main mechanism	p		se		fu	sys	sub		
		20	20	we can propose new systems for cooling according to the nature	p		se		fu	si			an
		45	25	always the aqueduct is very cold and the water of that is cold too	p		ep		pr	si			an
	26	0	15	why is it cold?	p		se		pr	si			an
		20	20	maybe there is not the effect of sun under ground	p		se		pr	si			an
		55	35	maybe it is the matter of soil and clay	p		se		pr	si			an
	27	20	25	usually 25 meters under ground even in the desert	p		se		pr	si			an
		35	15	let's think separately for 3 minutes	*								
	31	40	24 5	let's share now	*								
		55	15	I was thinking to synthesize and multi-functional system	p		se		fu	sup		co	
	32	15	20	I mean that we want the fridge to harvest, pick, cool down and transfer them from farm	id	in			fu	sup		co	
		30	15	we have new application for the system and we have to add new function to it	p		se		fu	sys	sub		
	33	0	30	but we had to propose idea for fridge for home	p		se		fu	sys	sub		
		10	10	but I like your idea	p		se		fu	sys	sub		
		25	15	when an idea makes the people laugh, it means that it has some potential for radical changes	p		se		fu	sys	sub		
		45	20	can you predict the approximate time for that too?	p		se		fu	sys	sub		
		55	10	is there any market for that?	p		se		fu	sys	sub		

	34	15	20	I think the farmers need it	p		se		fu	sup		user	
	35	5	50	but the scope has cahnged totally from home to agriculture	p		se		fu	sup		user	
		20	15	my father has a one-hectar farm of fruit	p		ep		pr	si			an
		45	25	he needs also a fridge to store fruit before sending to the market	id	dev			fu	sup		co	
	36	0	15	this idea merge the store and car for transfring	p		se		fu	sup		co	
		10	10	how big can it be?	p		se		fu	sys	sub		
		30	20	also it needs a packing system	id	dev			fu	sup		co	
		50	20	I also thought about another direction to find a conflict	p		se		fu	sys	sub		
	37	30	40	but I was thinking to list the weaknesses of fridge to improve them	p		se		fu	sys	sub		
	38	0	30	or thinking about more optimum solutions that we need very technical information	p		se		fu	sys	sub		
		30	30	we can also think different generations	p		se		fu	sys	sub		
	39	5	35	but for starting we need to know how mature is the current version of fridge on its s-curve	p		se		fu	sys	sub		
		15	10	if it is close to the end or we have time to develop it in the curent version	p		se		fu	sys	sub		
		25	10	it is long time that we can not see radical changes in fridge	p		se		pr	sys	sub		
		30	5	the energy changed from oil to the electricity	p		ep		pa	sys	sub		
		45	15	the devices for cold water and ice making are added to that	p		ep		pa	sys	sub		
	40	0	15	maybe we can see some little improvements on the freshness of food	p		ep		pr	sys	sub		
		15	15	my idea was to check the weakness of the last version of fridge	p		se		pr	sys	sub		
		55	40	to check which element can we eliminate and give its function to the other parts	p		se		fu	sys	sub		
	41	30	35	shall we remove the engine and compressor?	id	dev			fu	sys	sub		
		55	25	in car it is like this that if we use engine for air conditioner, we use the engine of the car	p		ep		pr	si			an
	42	5	10	they use each part for different tasks	p		ep		pr	si			an
		20	15	this direction doesn't seem to lead to radical changes, they reduce the costs	p		se		fu	sys	sub		
		35	15	if we remove some elements, the reliability is increasing significantly	p		se		fu	sys	sub		
		55	20	usually the engine of fridge is one of the elements that is breaking	p		ep		pr	sys	sub		
	43	15	20	we have to consider the weaknesses that they have potentiality for radical changes	p		se		pr	sys	sub		
		30	15	let's finish and the discussion is longer to finish in 2 remaing minutes	*								
2	0	20	20	look at the examples	p		st		pr	si			an
	1	0	40	we have to propose an idea for new s-curve according to the dominant technology of future	int			g	fu	sys	sub		
		30	30	do we know what is the dominant technology of future?	p		se		fu	sys	sub		
	2	10	40	let's find the answer to the examples	p		se		pr	si			an
	9	20	430	I think just 2 of examples are related	p		st		pr	si			an
		40	20	we can learn more about coffee machine and ship	p		st		pr	si			an
	10	10	30	the picture of ship shows the available versions, future versiona and the removed version from the application	p		st		pr	si			an
		45	35	it shows that for different generations, there are some changes in main functions	p		st		pr	si			an
	11	15	30	the moving mechanism (engine and fuel) has changes; sail, steam, disel, …	p		st		pa	si			an
		50	35	also the applications changes or added	p		st		pa	si			an
	12	20	30	load and people, tourist, pulling other ships, breaking ice, …	p		st		pa	si			an
		50	30	and each one is a branch with lots of sub-branches	p		st		pa	si			an
	13	10	20	even we can think of a ship with a main body that can be completed by various devices for different applications according to the need	p		se		fu	si			an
		25	15	some times for sport races, sometimes for defending targets, …	p		se		fu	si			an
		35	10	but this picture is not complete and we cannot see all versions of ship on that	p		se		pr	si			an
		50	15	all the versions except hovercraft are based on Archimedes law	p		se		pr	si			an
	14	20	30	but the example of coffee machine has more information inside	p		st		pr	si			an
		35	15	it is in the field of home appliances	p		st		pr	si			an
		45	10	it is evolving through more automation	p		se		pr	si			an
	15	35	50	first they boiled coffee with water then they change it to brew the coffee by steam	p		st		pa	si			an
		45	10	also we can see different tastes	p		st		pa	si			an
	16	0	15	we see that the devices for brewing coffee and tea, were merged	p		st		pa	si			an
		25	25	then we see the device for coffee making that can add milk and gas inside coffee	p		st		pa	si			an
		35	10	we see the multi-functions	p		se		pa	si			an
		55	20	we see that quality of preparing food has improved	p		se		pa	si			an
	17	35	40	after while the technology changed from boiling to brewing by steam	p		se		pa	si			an

		55	20	quality of coffee was under improvement	p		se		pa	si			an
	18	15	20	then make the process easy to combine all part of process in one device	p		se		pr	si			an
		30	15	so the time is decreased too	p		se		pr	si			an
		50	20	how we can bring this direction to the fridge?	p		se		pr	sys	sub		
	19	15	25	also the price is reasonable for individual user to buy it	p		se		pr	si			an
		30	15	no body buy kettle these days for making coffee, they prefer coffee maker	p		se		pr	si			an
		45	15	the coffee maker does some process on the coffee that we cannot have it by kettle. It is not only the matter of comfort	p		st		pr	si			an
	20	0	15	so for fridge?	p		se		pr	sys	sub		
		20	20	also we can see differences in related industries; producer of coffee, producers of cups, …	p		st		pa	si			an
		45	25	we consider function of fridge as: keeping food fresh	p		se		fu	sys	sub		
	21	0	15	we can add functions	p		se		fu	sys	sub		
		25	25	I am thinking of considering fridge as the main device at home for cooling and heating	id	dev			fu	sup		co	
		35	10	to remove air conditioner and cool down even the house by fridge	p		se		fu	sup		co	
	22	20	45	and also to warm house or devices according to the plan	p		se		fu	sup		co	
		35	15	or another kind of fridge that can cool down the food locally specially for each food	id	dev			fu	sys	sub		
		45	10	also the fridges that can act as anti-bacterial device	id	dev			fu	sup		co	
		55	10	a fridge to alarm the spoiling	id	dev			fu	sys	sub		
	23	25	30	even possibility to transfer the spoiled food to the fresh food	id	dev			fu	sup		co	
		35	10	is Mrs. Salimi, the student of POLIMI?	*								
		45	10	why she is working on this subject?	*								
	24	20	35	I don't know but she said she is studying the group of methods and tools for design	*								
		40	20	they are proposing tools. It is good. It means they go in details not just study the models	*								
		55	15	come back to the task	*								
	25	10	15	if the fridge wants to transfer spoiled food to the fresh food, do we know any natural process for that?	id	dev			fu	sys	obj		
		25	15	some fridges have fan to circulate air	p		ep		pr	sys	sub		
		35	10	there are different degrees of coldness in different parts of freezers	p		ep		pr	sys	sub		
		50	15	I mean we can add new functions to the fridge like transferring the spoiled food to the fresh food	p		se		fu	sys	sub		
	26	15	25	that the company can add the function to its motto	p		se		fu	sys	sub		
		30	15	this idea needs a new technology	p		se		fu	sys	sub		
		45	15	and it can lead to radical technological changes	p		se		fu	sys	sub		
	27	25	40	we are changing from keeping fresh to the making fresh	p		se		fu	sys	sub		
		50	25	we have to analyze the process of spoiling	p		se		fu	sys	sub		
	28	0	10	I think that we have to consider also the cost	int			f	fu	sys	sub		
		30	30	the new idea must be cheaper or reasonable otherwise the idea cannot come to the market	p		se		fu	sup		user	
		55	25	imagine we are working at the R&D of Emerson. The question is, what do we have to produce to be the first in the market	p		se		fu	sys	sub		
	29	10	15	first the completion in the market is in the function	p		se		pr	sys	sub		
		25	15	I think the people prefer to buy one device for lots of function. Fridge and air conditioner in one device	p		se		pr	sup		user	
		45	20	then the completion is on the cost; same function with less price	p		se		fu	sys	sub		
	30	0	15	let review	p		se		fu	sys	sub		
		5	5	we predict two direction of radical changes	p		se		fu	sys	sub		
		15	10	first on the increasing the quality of food	p		se		fu	sys	obj		
		30	15	second one on the structure and productivity	p		se		fu	sys	sub		
		45	15	means using fridge for cooling and heating	p		se		fu	sys	sub		
	31	10	25	but in the first one we use cooling for quality	p		se		pr	sys	sub		
		20	10	it is like a store for a period	p		se		pr	sys	sub		
		35	15	we can substitute any new technology for that even in front of sun, if we can keep food for a desire period	p		se		pr	sys	sub		
		55	20	we use cooling to kill bacteria	p		se		pr	sys	obj		
	32	10	15	are they killed by cooling?	p		se		pr	sys	obj		
		30	20	I think just we can reduce the growth of bacteria by cooling	p		se		pr	sys	obj		
		40	10	there are two different issues	p		se		pr	sys	sub		
		50	10	first we are preventing of spoiling	p		se		fu	sys	obj		
	33	5	15	second we are curing the spoiled food	p		se		fu	sys	obj		
		20	15	one of the methods for forecasting is looking from past to present	p		se		pr	sys	sub		
		35	15	at least there are more 30 methods	p		se		pr	sys	sub		
		45	10	which direction do we want to follow?	p		se		fu	sys	sub		
		55	10	ideas for increasing the quality of food or on the productivity of fridge?	p		se		fu	sys	sub		
	34	5	10	do we have to go further? We don't propose solution. We just want to say the new generation	p		se		fu	sys	sub		

		40	35	we have to realize the radical feasible ones among the possible directions	p		se		fu	sys	sub		
	35	0	20	we can propose lots of ideas and then assess according to the costs and benefits	*								
		25	25	in previous step I was thinking that I cannot be involve well because I don't have enough technical knowledge in the field	*								
		45	20	now I want to say that I can be effective in technology forecasting	*								
	36	0	15	I was just thinking about the current technology in details	*								
		15	15	but when I came upper, I could see the system better and have good questions and some directions	*								
		35	20	for designing for sure I need technical knowledge and expertise	*								
		50	15	we talked 36 min up to here	*								
	37	5	15	I like this session more than the first session	*								
		15	10	maybe because of peach we eat in break	*								
		40	25	we can follow idea generation and we don't need to assess the generated ideas	*								
	38	0	20	we can just prioritize the ideas	*								
		55	55	for eye glasses we can think of different jumps; eye glasses, contact lenses and eye surgery	p		st		pa	si			an
	39	45	50	in coffee we can see complete process of preparing different tastes of coffee	p		st		pr	si			an
	40	10	25	and it becomes a business out of a device	p		st		pr	si			an
		50	40	it means we consider different tastes of users and their interests	p		st		pr	si			an
	41	30	40	I think the users buy the fridge that can transfer spoiled food to the fresh food because if it was even so expensive, they benefit in time from not wasting food and also buying cheap food	p		se		fu	sup		user	
		45	15	this idea can solve the problems of markets of fruits and vegetables	p		se		fu	sys	obj		
	42	0	15	we have to propose fridges that can do lots of tasks for us	p		se		fu	sys	sub		
		10	10	lots of function with less cost such as washing, warming, cooling, …	id	dev			fu	sup		co	
		20	10	then reducing the energy consumption	p		se		fu	sys	sub		
		30	10	using free energy resources of nature or around at home	id	dev			fu	sys	sub		
		40	10	fridge that can produce energy by itself	id	dev			fu	sys	sub		
		50	10	give energy to other systems around or use the energies of the other engines	id	dev			fu	sys	sub		
	43	0	10	do you focus only on energy?	p		se		pr	sys	sub		
		10	10	no I am saying that next generation first becomes multi-functional	p		se		fu	sys	sub		
		20	10	then less resources and costs	p		se		fu	sys	sub		
		30	10	also solving the problems of other systems around	p		se		fu	sup		co	
		40	10	it is more coordinated to the environment	p		se		fu	sup		co	
		50	10	can it be instead of internet?	id	dev			fu	sup		co	
	44	0	10	it can be	p		se		fu	sys	sub		
		25	25	we proposed more or less the next options	*								
	45	0	35	the time is also over	*								

12. Team 12/ Session 1: without stimulus, Session 2: patent as a stimulus

Part	Time (end)			Sentences	Concept	Idea	Precedent	Interpreter	Time	Space	Sys	Sup	Si
	Min	Sec	interval		(idea, precedent, interpreter)	(initial, developed)	(episodic, semantic, stimuli)	(given, find)	(past, present, future)	(system, super system, sub system)	(subsystem, object)	(co-systems, user)	(alternative, analogy)
1	0	20	0	I think it is better to start with physical elements of fridge and finding the problems	p		se		pr	sys	sub		
		45	1	technology of cooling, technology of saving coldness (isolation), energy consumption,	p		ep		pr	sys	sub		
		55	1	dividing in 2 parts; internal size and external size	p		ep		pr	sys	sub		
	1	15	1	also weight	p		ep		pr	sys	sub		
		25	1	then energy consumption	p		ep		pr	sys	sub		
		35	2	also form and shape	p		ep		pr	sys	sub		
		55	2	technology of cooling can be the gas as the main material and also the system	p		ep		pr	sys	sub		
	2	5	2	for example, the gas changes to something else	id	in			fu	sys	sub		
		15	2	we have to see which one has more important problem	p		se		pr	sys	sub		
		25	2	what other issue?	p		se		pr	sys	sub		
		40	3	also we can think of application	p		se		pr	sup		user	

	3	30	4	we see fridges for home, industries, shops, … also in the oil industries	p		ep		pr	sup		user	
		40	4	what about the function?	p		se		pr	sys	sub		
		50	4	we want completely automatic adjusting temperature	id	in			fu	sys	sub		
	4	0	4	it can be completely smart to the need of food	id	dev			fu	sys	obj		
		15	4	we want different temperature for different parts of fridge	id	dev			fu	sys	sub		
		30	5	different speed for cooling for different food	id	dev			fu	sys	obj		
		45	5	different way of cooling for different kind of food according to their type and tissue	id	dev			fu	sys	obj		
	5	10	5	it is smart only for adjusting temperature or it can do other tasks?	p		se		fu	sup		user	
		20	5	connection to the user	id	dev			fu	sup		user	
		30	6	shall we produce fridge for animals?	id	in			fu	sup		user	
		45	6	I mean that instead of food, we put alive organic inside	id	dev			fu	sup		user	
		55	6	like an air conditioner for them?	p		se		pr	sup		user	
	6	5	6	to keep them in special temperature	p		se		pr	sup		user	
		15	6	like one of the movies of Jim Carry	p		ep		pr	sup		user	
		25	6	it can be considered as one of the applications	p		ep		pr	sup		user	
	7	10	7	if the fridge is bigger than a size it can be called cold-room and it can be seen in the industries	p		se		pr	si			an
		40	8	let's think about the problems	p		se		pr	sys	sub		
		50	8	we have lots of problems related to external shape	int			f	pr	sys	sub		
	8	10	8	also we see lots of spaces inside that we cannot use them	int			f	pr	sys	sub		
		20	8	if we can manage the layers flexibly in some way else, we use it more efficient	id	in			fu	sys	sub		
		35	9	the degree of flexibility of layers is so low	int			f	pr	sys	sub		
		45	9	the external shape can be flexible too	id	dev			fu	sys	sub		
		55	9	it is always like cube and rigid	p		ep		pr	sys	sub		
	9	20	9	the internal layers can move a little but it is not sufficient	p		ep		pr	sys	sub		
		45	10	we can think of a jelly material on the wall of fridge that you can put and sink food in them and they become cold, this gels are memory shape	id	dev			fu	sys	sub		
		50	10	you mean a container full of jelly material?	id	dev			fu	sys	sub		
	10	0	10	it can be different from current cube shape like a thick wall up to the desirable thickness	id	dev			fu	sys	sub		
		10	10	but I think must be in a special package	id	dev			fu	sys	sub		
		20	10	for external shape instead of cube, what we can propose?	int			f	fu	sys	sub		
		30	11	let's look at the s-curve of fridge	p		se		pr	sys	sub		
		40	11	it is a long time that it is more or less the same	p		se		pa	sys	sub		
		50	11	it became bigger and the freezer added to it	p		se		pa	sys	sub		
	11	0	11	but the technology is the same but the gas improved	p		se		pa	sys	sub		
		10	11	we also have the changes in smart board for adjusting temperature	p		se		pa	sys	sub		
		20	11	and also some changes in isolation system	p		se		pa	sys	sub		
		35	12	we see some improvements but not jumps of technology	p		se		pa	sys	sub		
		45	12	the TV for example changed from lamp to LED but we can see such this kind of improvements in the fridge	p		ep		pa	si			an
		55	12	we see compressor and condenser that are related to this technology	p		ep		pr	sys	sub		
	12	10	12	if we change energy from electrical to chemical, solar, what will happen?	id	in			fu	sys	sub		
		20	12	we change energy sources	p		se		fu	sys	sub		
		30	13	also we can think of new material like Nano for cooling instead of gas	id	dev			fu	sys	sub		
		40	13	there are some new materials that if we warm them, they radiate some light or activate a circuit	p		ep		pr	si			alt
		50	13	I am thinking of Nano materials to absorb heat and produce electricity	id	dev			fu	sys	sub		
	13	0	13	you changed the gas to the Nano material	p		se		fu	sys	sub		
		10	13	and then the technology of cooling is changing according to that	p		se		fu	sys	sub		
		35	14	we can think to any other chemical, nuclear or magnetic fields to use	id	dev			fu	sys	sub		
		50	14	electromagnetic is easier to design than the others because we don't need an expensive material for that but I don't have any idea	p		se		fu	si			alt
	14	50	15	we can also think of electro chemical, bio, …	id	dev			fu	sys	sub		
	15	10	15	let's proceed with other issues	*								
		25	15	I think isolation system is good enough, we don't lose energy from the door when it is closed	p		se		pr	sys	sub		
		40	16	the amount of hot or normal temperature food, increasing the energy consumption	p		se		pr	sys	sub		
	16	0	16	so it is better to change to another issue	p		se		pr	sys	sub		
		50	17	we are trying to find the problem	p		se		pr	sys	sub		
	17	0	17	what are the problems related to the function?	p		se		pr	sys	sub		
		10	17	I mean which are the constraints of current system?	p		se		pr	sys	sub		

		20	17	we have to transfer the food inside	p		se		pr	sys	obj		
		30	18	it does the same task for all food	int			f	pr	sys	sub		
		40	18	speed of coldness is limited	int			f	pr	sys	sub		
	18	10	18	one of the big problems is that the fridge needs external energy	int			f	pr	sys	sub		
		25	18	and it consume lots of energy	int			f	pr	sup		co	
		35	19	also the space which is occupied in the kitchen	int			f	pr	sup		co	
		50	19	the thickness of the wall is so high	int			f	pr	sys	sub		
	19	0	19	it is related to the isolation system	p		se		pr	sys	sub		
		30	20	so beside the form and shape the material and thickness of the body must be considered	p		se		pr	sys	sub		
	20	5	20	when we need more space we close the door of the oven and we use it as a free surface but fridge always occupies a space in the kitchen	p		se		pr	sup		co	
		25	20	thinking ideally, we want a flexible fridge	id	dev			fu	sys	sub		
		45	21	when we have less food, we pack or push the walls and make it smaller and shorter and opposite	id	dev			fu	sys	sub		
	21	0	21	also the weight and movements is an issue	int			f	fu	sys	sub		
		10	21	it is produced integrated and we could produce some boxes that can be connected or disconnected and the disconnected boxes can be folded	id	dev			fu	sys	sub		
		20	21	it is monolith and it can be divided in some parts	id	dev			fu	sys	sub		
		30	22	do we have to select one of them to proceed?	p		se		pr	sys	sub		
		45	22	I think if we want to propose the next generation, we have to select the problem that we think solving that, can lead to radical impact	p		se		pr	sys	sub		
	22	0	22	we saw that more or less the technology was the same	p		se		pr	sys	sub		
		15	22	before that we used the natural ice I think	p		se		pa	sys	sub		
		25	22	first the container was one part and now we have multi parts	p		se		pa	sys	sub		
		50	23	I think fridge and merges of fridge and freezer are 2 products but on one s-curve	p		se		pa	sys	sub		
	23	0	23	every one of the above mentioned that we improve, we have a new product	p		se		fu	sys	sub		
		10	23	we can see small door on the door for more accessibility	p		se		pa	sys	sub		
		25	23	2-layer door can save energy for less energy consumption	id	in			fu	sys	sub		
		35	24	we have more separated boxes	p		ep		pa	sys	sub		
		45	24	we can also think about some new applications	p		se		fu	sys	sub		
	24	10	24	there are lots of improvements in the cooling technology but they are not radical	p		se		fu	sys	sub		
		25	24	fridge that can manage its content as one smart fridge	id	dev			fu	sys	sub		
		45	25	a box that can be adjusted separately from the other part, speed up the cooling	id	dev			fu	sys	sub		
	25	0	25	for transferring heat, we can use convection or radiation	p		ep		pr	sys	sub		
		25	25	in fridge compressor compresses the gas and it becomes liquid and cold, in fridge it receives the heat and again becomes gas and hot. It releases it temperature again in the compressor in a circle	p		ep		pr	sys	sub		
		50	26	inside fridge we can see convection that cold air is cooling the food but in the compressor we have radiation	p		ep		pr	sys	sub		
	26	0	26	if we wanted to change all the mechanism to the radiation?	p		se		pr	sys	sub		
		10	26	with radiation we cannot absorb heat, we can just receive energy	p		se		pr	sys	sub		
		35	27	shall we think of waves	p		se		pr	sys	sub		
		50	27	we do some stimulus on food that can radiate its heat and becomes cold	id	dev			fu	sys	obj		
	27	0	27	something that can absorb the heat like a black hole	id	dev			fu	si			alt
		20	27	we also use the characteristics of gases that there is a relation among temperature, pressure and volume	p		ep		pr	sys	sub		
		55	28	when the liquid gas release in an open space the valve freezes because of very rapid drop of pressure	p		ep		pr	sys	sub		
	28	20	28	this is the mechanism that we can see in the fridge	p		ep		pr	sys	sub		
		50	29	in the fridge, there were some changes in the gases that make the process more efficient	p		se		pr	sys	sub		
	29	10	29	if we also use the technology of changing pressure in the fridge	p		se		pr	sys	sub		
		25	29	using vacuum in the fridge to decrease the temperature	id	dev			fu	sys	sub		
		35	30	also we have to consider the cost, if the idea is reasonable	int			f	fu	sys	sub		
		45	30	we need bigger compressor that can act on the all the air inside the fridge	id	dev			pr	sys	sub		
		50	30	I think just we have to propose idea and it is not necessary to analyze the cost	p		se		pr	sys	sub		
	30	5	30	we are proposing changes in technology of cooling by changing material, field or the system	p		ep		pr	sys	sub		
		20	30	Nano materials that receives electricity and become cold	id	dev			fu	sys	sub		
	31	20	31	so one of our suggestions is that using Nano materials instead of system of cooling	id	dev			fu	sys	sub		
	32	0	32	can we use radiation of cooling?	p		se		fu	sys	sub		

		20	32	it means absorbing energy. I think every mechanism, first absorb material and then energy. And it is not possible	p		se		pr	si			alt
		40	33	black hole is like this and main reason is high density. It absorbs everything to find enough space	p		se		pr	si			alt
	33	0	33	we can see it as changes of movements of molecules. The heat is increasing the movements and the coldness is decreasing the movements	p		se		pr	si			an
		10	33	radiation increases the movements	p		se		pr	si			an
		20	33	and if we know any way to decrease the movements of molecules	id	dev			fu	sys	obj		
		50	34	we can also think of a chemical reaction that absorbs heat	id	dev			fu	sys	sub		
	34	10	34	if it finishes, we need to start it again and we need energy for that and it becomes similar to the current fridge	p		se		pr	sys	sub		
		20	34	if we remove the convection? It means that the cold material is in direct connection of food	p		se		pr	sys	sub		
		30	35	the idea of jelly walls is like this	id	dev			fu	sys	sub		
	35	25	35	it works with electrical energy and the jelly Nano material become cold and they are in direct connection with food	id	dev			fu	sys	sub		
		35	36	we have some changes. Instead of air for absorbing heat we have jelly Nano material.	p		se		fu	sys	sub		
		50	36	and also the gas is replaced with jelly materials	p		se		fu	sys	sub		
	36	10	36	like when we put food inside the cold water of river	p		ep		pr	si			an
	37	45	37	so we generate some ideas. first we mentioned some problems and very rough solution for some of them. But then we concentrate on the cooling technology to propose the jump for that	p		se		pr	sys	sub		
	38	45	38	what are the sources of energy? Solar, wind, fossil, electrical, …	p		se		pr	si			an
	39	0	38	we had oil and electrical up to here	p		se		pa	sys	sub		
		50	39	I am thinking of a fridge that it is like a dark tunnel that always the air is passing rapidly	id	dev			fu	sys	sub		
	40	15	39	I mean that moving fresh cold air can help for better cooling	p		se		fu	sys	sub		
		35	40	what is the mechanism of fluidity of fresh air then?	p		se		fu	sys	sub		
		55	40	self-movement or using again a system for that that needs energy?	p		se		fu	sys	sub		
	41	45	41	if we make some groove on the surface of watermelon even in the desert, it becomes cold by passing air from inside	p		ep		pr	si			an
	42	0	41	inside of watermelon is like porous material	p		ep		pr	si			an
		30	42	shadow in the sunny day is less warm because of removing radiation	p		ep		pr	si			an
		55	42	like desert that is cold in the night when the sun sets	p		ep		pr	si			an
	43	30	43	if we remove sources of heat in a dark cube	id	dev			fu	sys	sub		
		45	43	the food are hot by themselves	p		se		pr	sys	obj		
		55	43	we want something to absorbs heat	p		se		fu	sys	sub		
	44	20	43	we are coming back to the first problem like a circle	*								
		30	44	the time is over	*								
	45	0	44	it was not so bad. We had some idea	*								
2	0	10	0	let's look at the patents	*								
	1	30	2	there are some special dishes for organizing food inside freezer	p		st		fu	sup		co	
		40	2	this patent is similar	p		st		fu	sup		co	
	2	0	2	it is about organizing food inside fridge	p		st		fu	sup		co	
		15	2	we can propose some special dishes for food which they can store very well inside the fridge and we have less unsable positions inside fridge/ better shelves	id	dev			fu	sup		co	
		35	3	read the second patent	p		st		fu	sys	sub		
	3	30	4	this patent use RFID for storing food inside fridge	p		st		fu	sys	sub		
		40	4	it is in the direction of smartness	p		se		fu	sys	sub		
		50	4	RFID is transfering data by radio waves	p		st		pr	si			an
	4	0	4	it is used in barcodes and sales systems now a days. even it is used in cars and permission to pass some places	p		st		pr	si			an
		15	4	this patent gives the information of food to the central processor	p		st		fu	sys	sub		
		35	5	information like the period of keeping, the required tempreture, …	p		st		fu	sys	sub		
		45	5	it is more useful for industrial fridges	p		se		pr	si			an
		55	5	even for home it can show the expire date, content of fridge,	p		se		fu	sys	obj		
	5	10	5	if we have smart surfaces that can distinguish the healtiness of food and fruit	id	dev			fu	sys	obj		
		25	5	the fridge must have the capability to accept and act according to these kind of orders	p		se		fu	sys	sub		
		35	6	read the third patent	p		st		fu	si			an
	6	50	7	it is about a ice cream maker	p		st		fu	si			an
	7	0	7	it can distinguish the hardness of ice cream and finish the process	p		st		fu	si			an

		15	7	we have fridge for keeping the food and some fridges are for preparing food	p		se		pr	sys	obj		
		25	7	it is kind of fridge that prepares food	p		se		fu	si			an
		35	8	it does not have relation to the home fridges	p		se		pr	si			an
		55	8	we can think of adding some applications to our fridge	p		se		fu	sup		user	
	8	20	8	it is not reffering to technology of cooling but it must be like the others	p		se		pr	si			an
		35	9	read the fourth patent	p		st		fu	sys	sub		
	9	30	9	it is about isolation system and the automation of closing of the door	p		st		fu	sys	sub		
	10	40	11	if the casing be broken, the door will open automatically	p		st		fu	sys	sub		
	11	20	11	we checked in previous session some of the problems of fridge and the patents show that in some of them, there are some related patents	p		se		pr	sys	sub		
		30	11	read the fifth patent	p		st		fu	sup		co	
	13	10	13	it is about a software for using RFID to buy food	p		st		fu	sup		co	
		20	13	we can develop a software for showing the ordering time	id	?			fu	sys	sub		
		30	13	we can say most of the patents are about adding functions and applications to the fridge	p		se		fu	sup		user	
	14	30	14	we can think of adding some processes to the fridge to be performed on the food	id	in			fu	sys	obj		
	15	10	15	also it means to do functions simultaneously like the ice cream maker. To make ice cream while it is cooling	p		se		fu	sys	sub		
		25	15	we can think some of processes that need cooling	id	dev			fu	sup		co	
		35	16	and then processes that need cooling after	id	dev			fu	sup		co	
		50	16	and if we find an endothermic reaction inside fridge	id	dev			fu	sys	sub		
	16	15	16	also if we find an endothermic reaction that is useful for other devices at home	id	dev			fu	si			an
		35	17	do we know any food that they need cooling for preparing like ice cream?	p		se		pr	sys	obj		
	17	5	17	the semi-prepared food need cold place for keeping	p		ep		pr	sys	obj		
		45	18	no. I mean the process of preparing food which need cooling	p		se		pr	sys	obj		
	18	0	18	for anti-bacterial we need cooling	p		ep		pr	si			an
		15	18	I think they first need heating for killing bacteria and then they keep in cold temperature to not let the bacteria to grow	p		se		pr	si			an
		30	18	for preparing jelly, we need cooling and we can add it to the fridge	id	dev			fu	sup		co	
	19	0	19	even we can add ice cream maker to the fridge	id	dev			fu	sup		co	
		55	20	none of the patents are related to the cooling technology directly	p		se		pr	sys	sub		
	20	20	20	it was better if we could search related patents to what we were talking about in previous session to see if there is related patents about cooling technology or not	p		se		fu	si			alt
	21	0	21	or even see something relevant in other systems. For example, the different technologies for cooling of the tire of airplane	p		se		fu	si			an
		10	21	these patents show that some other fields of application used knowledge of our field like some industrial fridges	p		se		fu	sup		co	
		45	22	for example, now a days the tire of cars is filled by nitrogen because it can cool down tire in hot weather	p		ep		pr	si			an
	22	0	22	nitrogen is known and used for cooling a lot and we can use it too in the dark tunnel	id	dev			fu	sys	sub		
		35	23	for decreasing the growth of bacteria, nitrogen is used too but it is not good for food	p		se		pr	sys	obj		
		45	23	is it environment friendly?	p		se		pr	sup		co	
	23	0	23	I think so. I don't think it be harmful	p		se		pr	sup		co	
		35	24	we need an endothermic material that is not limited	id	dev			fu	si			alt
	24	25	24	endothermic material must be recycled and we can use this fridge in cycles	id	dev			fu	si			alt
	25	20	25	it can be like temporary fridge that can be activated and used for a considered period like a Coleman (chargeable small fridge)	id	dev			fu	sys	sub		
		30	25	like the gas capsules	p		se		pr	si			an
	26	0	26	the Coleman are just saving the temperature of food and they don't cool down food	p		se		pr	sys	sub		
		30	26	there are some small fridges in the car. They are like normal fridges but just it uses the energy of car engine	p		ep		pr	si			an
	27	0	27	maybe it is just cool down up to some small degree changes and it cannot cool down more than 10 degrees	p		ep		pr	si			an
		30	27	can we think about fridge in the space or under water in the sea	id	dev			fu	sup		user	
		45	28	first we have to think about the real user and application	p		se		pr	sup		user	
	28	10	28	who need this kind of fridges	p		se		pr	sup		user	
		45	29	for the scientific journeys	p		se		pr	sup		user	
	29	20	29	I proposed this suggestion because the condition is completely different so maybe completely new technology can be used	p		se		pr	sup		user	

		30	29	maybe we have new technology but it is totally new product	p		se		pr	sup		user	
		45	30	and then we can just think about transferring new technology to the home fridge	p		ep		pr	sup		user	
	30	0	30	what is final task of us? We have to propose the next generation of home fridge?	p			g	pr	sys	sub		
		55	31	yes, but I think that Mrs. Salimi wants to see our directions of thinking and see the effects of training or some information on engineers	*								
	31	15	31	we can think of some fridges inside the body of human for some disease	id	dev			fu	si			an
	32	10	32	local coldness for some part from inside	id	dev			fu	si			an
	33	0	33	yes, we can expect totally new technology like some pills and external devices for leading the pill to the considered body	id	dev			fu	si			an
		15	33	if we have a special material that can cool down everything in every condition	id	dev			fu	si			alt
		30	33	when it releases into the target situation, it cools down the target	id	dev			fu	si			alt
	34	20	34	we completely came out of home fridge with completely new cooling technology	p		se		pr	sys	sub		
		35	35	I think that we can use the information of patents	p		se		pr	sys	sub		
	35	10	35	we can think of changing the other characteristics of food instead of temperature such as entropy, movement of molecules that the result is drop of temperature	id	dev			fu	sys	obj		
		25	35	we can add some functions like now that the fridge has device for cooling water and making ice	p		se		pr	sys	sub		
		35	36	let’s think that it prepares the food	p		se		pr	sys	obj		
		45	36	adding function of disinfection to fridge	id	dev			fu	sup		co	
	36	0	36	adding some processes of home to the fridge	p		se		fu	sup		co	
		10	36	fridge that can filter the water of home	id	dev			fu	sup		co	
		25	36	fridge that can be the water heater of home	id	dev			fu	sup		co	
		40	37	using the heat of back of the fridge for warming	p		se		fu	sup		co	
	37	0	37	even filtering the air because the engine changing the air	id	dev			fu	sup		co	
		20	37	so adding function of air conditioner to fridge (combine these two)	id	dev			fu	sup		co	
		40	38	even combining to the oven	id	dev			fu	sup		co	
	38	0	38	we can think of any of home devices and possibility to combine	p		se		fu	sup		co	
		35	39	the condenser be horizontal and acts as part of oven like electrical oven	id	dev			fu	sys	sub		
		55	39	and also a box for keeping the warm the desired food	id	dev			fu	sup		co	
	39	5	39	it is better to add something by using available resources	p		se		fu	sup		co	
		15	39	we can use the condenser as iron	id	dev			fu	sup		co	
		50	40	change the external form of fridge to be used as sofa, bed, TV and other stuff of living room	id	dev			fu	sup		co	
	40	0	40	I think we can add some similar ideas and we can finish	*								

Appendix 2: Generated ideas for the next generation of the fridge by all 12 teams of R&D engineers

Idea	Teams	**Novelty of idea** (please rank by one of No. 4, 3, 2, 1 based on meaning of them)			**Technical plausibility of idea** (please rank by one of No. 4, 3, 2, 1 based on meaning of them)			**Relevance of idea** (please rank by one of No. 4, 3, 2, 1 based on meaning of them)		
		Expert 1	**Expert 2**	**Expert 3**	**Expert 1**	**Expert 2**	**Expert 3**	**Expert 1**	**Expert 2**	**Expert 3**
so we focus on the role of fridge in keeping quality of current type of food for longer periods, even without cooling	2, 3, 4, 6, 7, 8, 9, 11	1			3					
if the fridge wants to transfer spoiled food to the fresh food, do we know any natural process for that?	11	4	3	4	2	2	3	4	2	4
the main task is keeping food fresh by cooling and ice making	3, 4, 6	1			4					
also I was thinking about ready to use food not just cooling	6			4			4			4
let's think another way, if we think that we use food in a way that we don't need fridge any more	4, 10, 11	1	2	1	4	4	4	2	4	4
the food must keep its quality by itself	2, 3, 10, 11	1	1	1	4	4	4	1	2	4
genetically modification of food	3, 11	1	1	1	4	4	4	1	2	4
we can think about something in our mouth that can prevent the side effect of spoiling food for body	2	3	2	3	4	3	4	2	2	4
we can think of removing reasons of spoiling food	4, 10	1			4			4		
or even decreasing the ability of bacteria or reducing its activation	2, 4, 8	1			3					
if we provide another kind of reaction with fridge that doesn't let it to have reaction with bacteria	3	4	4	4	2	2	2	3	2	4
not let food and air have chemical reaction by controlling the interaction of food and bacteria	3	1			3					
I think oxygen is more effective than bacteria and we have remove the presence of oxygen	3	3	2	2	3	4	3	2	4	4
we want special vacuuming, cover, box, ... for food to keep bacteria growing that doesn't let transferring of food with outside	2, 3, 4, 10	1			3					
special cover for the food like the shell of watermelon for lower growth of bacteria	2	3			3			3		
vacuuming boxes are manageable in every cabinet	4, 10	1			1					
we have also conservation for can in industry which means try to remove the connections that decay it and instead fill it or make shell somewhere to separate from the surrounding	3	1			3					
we can think about a new field for decreasing the growth of bacteria	2	3	1	2	2	3	3	4	3	4
maybe we can think of filtering air	10	1			1					
we can use a classification and for very less using food, using more isolated container	10			2			4			1
we can have a mediator container. Every food automatically store in some part of fridge and selected food can be accessed in the mediator container	10	3	4	1	4	3	4	3	3	4
maybe we can think of special gloves like the gloves inside laboratories to choose and bring out to the mediator container	10			2			4			1
substance like deodorant to attach it to food that attract the bacteria or protect food	2, 3	4	4	4	2	2	2	3	2	4
the ideal solution is that to have type of wax to cover food in whole stages	3	1			2					
like a capsule inside food that we can bring them out when we want using food. It is better not to inject something inside but have something inside to preserve it from there. Like small chips for cooling inside	3	4	4	4	2	2	2	3	2	4
like fridge for preventing them like killing bacteria	10	1			3					
can sound kill the bacteria?	10	1	2	2	3	3	4	3	4	15
we can think of ultrasonic for killing bacteria	2, 10	3	1	2	2	3	3	4	3	4
so we can think of waves that kill the bacteria	2, 10	3	1	2	2	3	3	4	3	4
or even we can think of some gases that can kill bacteria if it does not damage the food	10	2	1	2	3	4	4	4	4	4
maybe the bacteria for spoiling of different kind of food, are different also so we need a fridge that can realize type of food and keep them in a special situation	10	3	2	4	3	4	1	3	4	1
and if the fridge repeats the process of killing bacteria regularly, it can be enough	10	1								
a new way for cooling (changing thermodynamic law)	2, 3, 8, 11	3	2	4	3	4	1	3	4	1
so one solution is working for technology which can cool the system without heat	4	3	2	4	3	4	1	3	4	1
we can think of changing the other characteristics of food instead of temperature such as entropy, movement of molecules that the result is drop of temperature	12	3	2	4	3	4	1	3	4	1
and if we know any way to decrease the movements of molecules	12	3	2	4	3	4	1	3	4	1
we can think to any other chemical, nuclear or magnetic fields to use	12	3	–	4	2	–	1	3	–	4
we can also think of electro chemical, bio, …	12	3	–	4	2	–	1	3	–	4
we do some stimulus on food that can radiate its heat and becomes cold	12	3	–	4	2	–	1	3	–	4
something like hot water bag but act inversely, when we put it inside microwave, it becomes cool and can use for cooling food	9	3	–	4	2	–	1	3	–	4

we need something like a microwave only for cooling	2, 9	3	–	4	2	–	1	3	–	4
if we have cover that can cool down the contents inside	9	3	–	4	2	–	1	3	–	4
like some polymeric material	9, 10, 12	3	–	4	2	–	1	3	–	4
just we need to charge the cover you proposed	9	1								
like a small polymeric balls that when they add to the salt of water, they can absorb heat and release coldness	9	3	–	4	2	–	1	3	–	4
also they can be in different sizes and different temperature for different kind of food	9									
also it is better that one of the cabinet becomes more isolated for putting the covers to not let the insects to come inside	9	1			1					
for some food we can think of reaction of food and polymeric material for cooling	9	4	4	4	2	2	2	3	2	4
something that can absorb the heat like a black hole	12	3	–	4	2	–	1	3	–	4
I am thinking of a fridge that it is like a dark tunnel that always the air is passing rapidly	12	3	–	4	2	–	1	3	–	4
if we remove sources of heat in a dark cube	12	3	–	4	2	–	1	3	–	4
using some Nano materials for the body of fridge	4	3	3	4	1	3	2	4	3	4
this material is full of tiny hollows that let warm air go outside and just cool air come inside	4	3	3	4	1	3	2	4	3	4
also we can think of new material like Nano for cooling instead of gas	1, 12	4	3	1	1	2	4	3	3	4
I am thinking of Nano materials to absorb heat and produce electricity	12	4	3	1	1	2	4	3	3	4
Nano materials that receives electricity and become cold	12	4	3	1	1	2	4	3	3	4
so one of our suggestions is that using Nano materials instead of system of cooling	12	4	3	1	1	2	4	3	3	4
the idea of jelly walls is like this	12	4	3	1	1	2	4	3	3	4
it works with electrical energy and the jelly Nano material become cold and they are in direct connection with food	12	4	3	1	1	2	4	3	3	4
if we remove the gas	2	4	3	1	1	2	4	3	3	4
also we can substitute gas with new technology that is not harmful for environment	4, 12	4	3	1	1	2	4	3	3	4
this new material does not need to energy for its working	1	4	3	1	1	2	4	3	3	4
it must be rechargeable material or reusable material	1	4	3	1	1	2	4	3	3	4
also changes of gas to be more efficient	11	1			1					
also more environment friendly gas	11	1			1					
we can also think of a chemical reaction that absorbs heat	12	4	3	1	1	2	4	3	3	4
and if we find an endothermic reaction inside fridge	12	4	3	1	1	2	4	3	3	4
some chemical processes are endothermic that they can be used too at home	9, 12	4	3	1	1	2	4	3	3	4
we need an endothermic material that is not limited	12	4	3	1	1	2	4	3	3	4
endothermic material must be recycled and we can use this fridge in cycles	12	1								
it can be like temporary fridge that can be activated and used for a considered period like a Coleman (chargeable small fridge)	12	1								
to find a material that absorbs heat for its metabolism	4	4	4	3	3	3	3	4	3	3
imagine kind of material that can absorb heat and release it somewhere else	4	4	3	1	1	2	4	3	3	4
we are thinking that we don’t want the mediator (like a box of cold air)	6	3	3	1	2	2	2	2	3	4
so our new technology could remove mediator by being in touch with a cold material	6	3	3	1	2	2	2	2	3	4
a metal that become cold by waves	6	3	3	1	2	2	2	2	3	4
idea of using clay in the air conditioner	1	1			1					
use fan, clay, water and metal instead of gas and condenser	1	1			1					
something like a capacitor or paint	1	4	3	1	1	2	4	3	3	4
if we find a cool gas	4	4	3	1	1	2	4	4	2	4
nitrogen is known and used for cooling a lot and we can use it too in the dark tunnel	12	2	2	2	4	4	4	2	3	4
and it keep the coldness even we open the door of fridge	8	1			1					
using vacuum in the fridge to decrease the temperature	10, 12	1			1					
we need bigger compressor that can act on the all the air inside the fridge	12	1								
fridge doesn’t need compressor	3	1			1					
fridge with less components	3	1								
small fans on the back of fridge for circulating the air	1	4	1	1	4	4	4	1	3	4
mechanism of circulating the air and the direction of it	1	1								
the size of the fans is the same as fans of computer	1	1								
according to the temperature of back of fridge, different quantity of fans can be run automatically	1	1								
the fans can work when the load of engine is low	1	4	1	1	4	4	4	1	3	4
adjustability of various boxes for different temperature and humidity	1	2	1	1	4	4	4	4	4	4
a box that can be adjusted separately from the other part, speed up the cooling	1	1			1					
the different layers could be dedicated for different food	5, 7	1			1					
so we can divide the concept of keeping food before meals and after meals and we have waste also	2	2	1	1	4	4	4	4	4	4
so we can have a device to keep food for few hours to eat excessive food	2	2	1	1	4	4	4	4	4	4
also we can see proposed classification in the layers of both fridge and freezer	7	1			1					
we want completely automatic adjusting temperature for each food	11, 12									
it can be completely smart to the need of food	12									
adjust temperature for each kind of food manually	6, 12	1			4			4		
we can propose more doors instead of single door	7	2	1	1	4	4	4	3	4	4
a fridge without door	7	4	4	2	4	2	4	2	2	4
some part without door	7	3	2	3	4	4	4	2	3	4
multi doors	1	3	2	3	4	4	4	2	3	4
with various temperature for each door	1	2	1	1	4	4	4	4	4	4
different boxes for the various kind of food	1	2	1	1	4	4	4	4	4	4
using co2 for rapid cooling in a box which collects the co2 after finishing its performance	1	1			1					
different speed for cooling for different food	12									
different way of cooling for different kind of food according to their type and tissue	12									

we can think about rapid cooling as some available solutions that they are about changing the temperature in less time but still fresh food	3, 10	1			1					
what else can we propose? We can make fridge smart	4	2	1	1	4	4	4	4	4	4
also we can think of customizing fridge	7	3	3	1	4	4	4	3	4	2
fridge that can manage its content as one smart fridge	12	2	1	1	4	4	4	4	4	4
digital LCD on the door of fridge to show the information	2, 4, 8	1	1	1	4	4	4	3	4	4
it can be also transparent that we can see inside	1, 5, 7, 8, 9	3	1	3	4	4	4	3	4	4
transparent not whole door but just some part	1	3	1	3	4	4	4	3	4	4
smart fridge that declare the ordering time of food on a list on the door of fridge or in an application	4	2	1	1	4	4	4	4	4	4
and also to listen to our talks and complains like a live friend	2, 7	4	3	4	3	4	4	3	4	4
if our fridge can call our name and talk to us about the food inside and propose plan for eating them, is it a new technology?	2	4	3	4	3	4	4	3	4	4
the fridge alarms the spoiling time of food inside	2, 4, 7, 8, 9, 10, 11	2	3	4	3	3	4	4	4	4
a fridge to alarm the expiring and eating time	5, 7, 10	2	3	4	3	3	4	4	4	4
propose the food eating according the ones they are spoiling sooner	12	3	–	1	4	–	4	2	–	4
propose the ordering for using food based on FIFO	4	3	–	1	4	–	4	2	–	4
we can develop a software for showing the ordering time	2	3	–	1	4	–	4	2	–	4
fridge which can propose the food for cooking according to its content and cooking recepies	2	3	4	1	4	3	4	3	3	4
also we can show the patterns of consumption to help the users to change their behavior	7, 10	1	1	1	4	4	4	3	3	4
also if it shows the previous function, we can mange our children even when we are not at home	10	3	3	1	4	4	4	3	4	2
It shows the characteristics of food, smell, ingredients, calories	2, 4, 8, 10	3	3	4	3	3	3	3	4	4
if we have smart surfaces that can distinguish the healthiness of food and fruit	12	3	3	4	3	3	3	3	4	4
we can make it by barcodes. We get a barcode to each food before put it in the fridge that can control the inventory instead of user	5, 10	3	3	4	3	3	3	3	4	4
even some food must keep in special temperature and it can control that by RFID	9	3	3	4	3	3	3	3	4	4
even it can be some small devices on each food that can analyze the food (by smell, gases, colors)	5, 7, 9	3	3	4	3	3	3	3	4	4
or maybe a timer like oven that can be set when we put each food inside fridge	9	3	3	4	3	3	3	3	4	4
connection to the user and accept orders	7, 8, 12	2	1	1	4	4	4	3	3	4
I am thinking about distance control	2, 7, 8, 10, 11, 12	2	1	1	4	4	4	3	3	4
may be instead, a mother from outside can be connected to the fridge and order it to propose food the children	7, 8	3	–	1	4	–	4	2	–	4
the fridge can be connected to the doctor to give new prescription	10	3	–	1	4	–	4	2	–	4
it can be connected to super market to buy food automatically	8	1			1					
if the fridge can control the amount of food like a store	4, 5, 8, 10	1			1					
alarm for the maximum capacity for cooling when we fill it	4	3	2	4	4	4	3	3	4	4
also alarm for the bad positioning of food in front of the windows for cooling	4	3	2	4	4	4	3	3	4	4
it can be a alarm for open door	7	3	1	1	4	4	4	4	4	4
to open the fridge and deliver food	8, 9	4	4	2	4	2	4	2	2	4
it also can be like a machine that we can receive our food by a button	9, 10	4	4	2	4	2	4	2	2	4
it can be even like an automatic layers instead of drawers	7	4	4	2	4	2	4	2	2	4
adding something additional like cold water device	1	2	1	1	4	4	4	4	3	4
we can propose to change the temperature of water	7				1					
we can propose to filter water and provide drinking water	7	2	1	1	4	4	4	4	3	4
fridge that can filter the water of home	12	2	1	1	4	4	4	4	3	4
why not thinking about fridge that can add boiler to the fridge?	4	2	1	4	4	4	3	3	4	4
using the heat of back of fridge for boiling water. If we cannot change the cooling technology, why not using the heat for something useful?	4, 9, 12	2	1	4	4	4	3	3	4	4
the fridge can provide tasty water with essence of various fruit and gaseous	4, 7	3	1	4	4	4	4	3	4	4
add the juice maker to the fridge	4, 7	3	1	4	4	4	4	3	4	4
can the fridge also warm the food for us	2, 4, 8, 12	2	1	4	4	4	3	3	4	4
to use the heat of back of fridge	2, 6, 12	2	1	4	4	4	3	3	4	4
like the merge of fridge and oven which oven automatically receive the ingredients according to initial plan of user	2, 4, 8	3	3	3	4	4	3	2	3	2
and also a box for keeping the warm the desired food	12	2	1	4	4	4	3	3	4	4
this idea needs also a programmable oven	2, 8	3	3	3	4	4	3	2	3	2
fridge like a slow cooker which can be cook food, the user set it before living home in the morning and have cooked food in the evening by the heat of back of fridge	2	3	3	3	4	4	3	2	3	2
also possible to realize the condition of cooking food and manage it from distance	2	3	3	4	3	3	3	3	4	4
by video or photo with a camera in the fridge	2									
using RFID technology is easier	2									
we need a technology to work instead of our taste	2									
by transferring taste to codes	2									
we can merge fridge and air conditioner together	1, 4, 6, 7, 10, 12	3	2	4	4	4	4	3	3	1

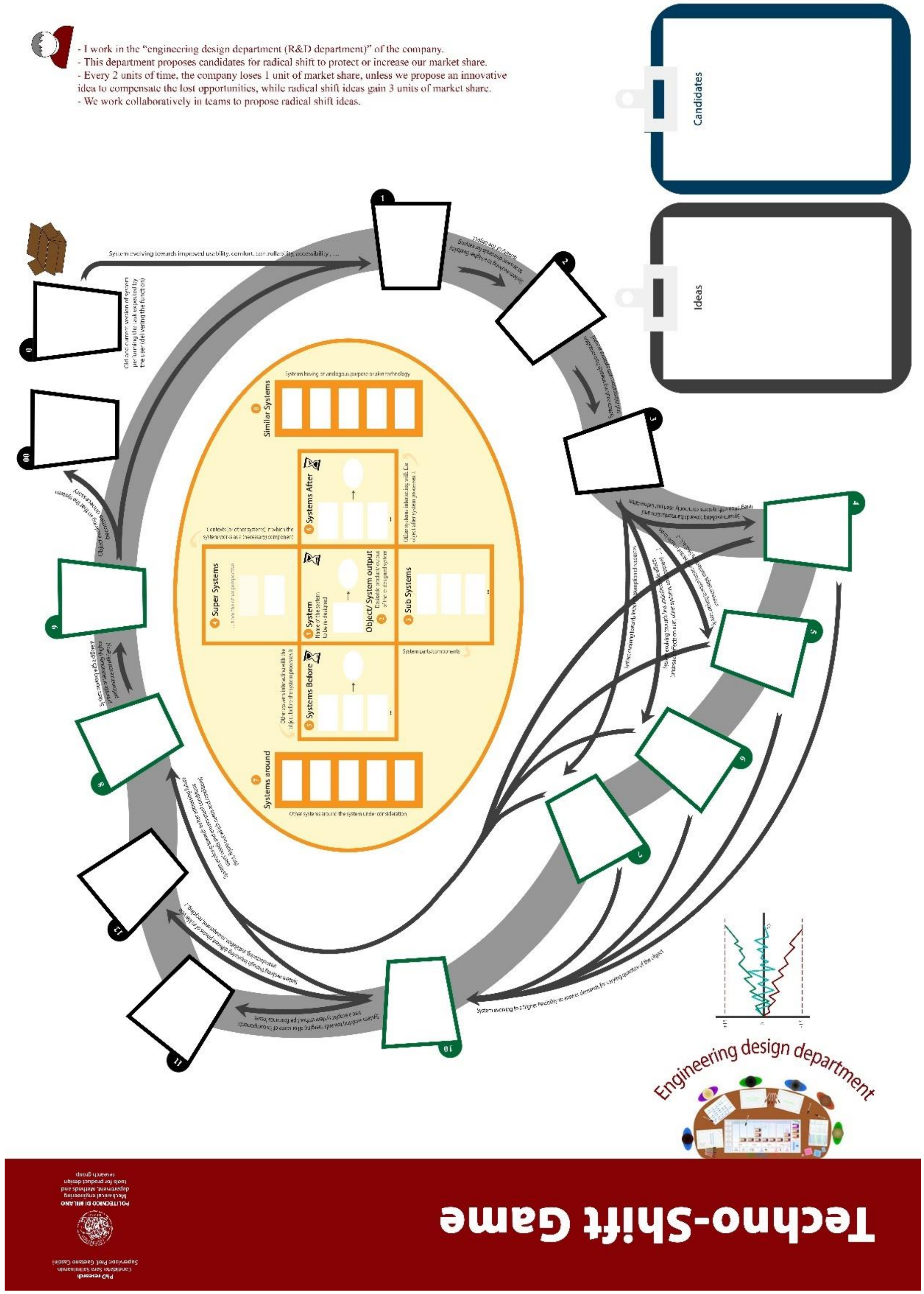
even filtering the air because the engine changing the air (like hood)	12	3	1	4	4	4	2	1	4	1
an special place for cooling system of all apartments of buildings	1	3	2	4	4	4	4	3	3	1
we need a system to get temperature of some parts of house to give it to water for make some other parts warmer	1	3	2	4	4	4	4	3	3	1
fridge is getting the temperature from the food and give it to the kitchen	1	3	2	4	4	4	4	3	3	1
I am thinking of considering fridge as the main device at home for cooling and heating	11	3	2	4	4	4	4	3	3	1
merging the system of cooling and warming of houses to each other	1	2	3	4	4	4	4	3	4	4
merging to water heater of home	4	2	3	4	4	4	4	3	4	4
we can add with anti-bacterial device too	6, 8, 11, 12	2	1	1	4	4	4	4	4	4
for drinking water, we have to think of anti-bacterial glass that it becomes anti-bacterial after each usage	8	2	1	1	4	4	4	4	4	4
lots of function with less cost such as washing, warming, cooling, …	11	2	3	4	4	4	3	4	3	3
we can concentrate more on the fridge can receive raw material and prepare them for the programed food and deliver it (processing food)	8, 11, 12			4			4			4
also thinking about the fridge that can pack the entering food by some foils and plastics	8, 11			4			4			4
so we can add the capability of classification to the fridge after packing	8			4			4			4
we can think some of processes that need cooling	12									
and then processes that need cooling after	12									
dry food	10	3	2	4	4	4	2	2	3	4
some part of fridge for drying	10	3	2	4	4	4	2	2	3	4
I mean that we want the fridge to harvest, pick, cool down and transfer them from farm	11	3	–	3	3	–	2	2	–	1
if we use the concept of JIT for the food, what will happen?	2	1	2	1	4	4	4	2	4	4
let's think about growing every food at home and have all resources at home	2	3	4	3	4	3	3	3	3	3
if we give the order to the fridge one day before and it give us the fruit or vegetables in the right time according to the seeds it have	2	3	4	3	4	3	3	3	3	3
for preparing jelly, we need cooling and we can add it to the fridge	12	3	1	4	4	4	2	2	3	4
I think that we can propose ice cream making as also	7, 12			3			4			3
also add ice cream maker to the fridge	7			3			4			3
a fridge that can remove the smell of food	7, 8	3	4	1	3	4	4	4	4	4
the fridge that can store electricity for the time of losing electricity	7	1			4			4		
we can use the condenser as iron	12									
design a hidden box inside fridge for jewelries	7	1								
lock for some parts that kids can access only some parts	8	1								
he needs also a fridge to store fruit before sending to the market	11									
shall we produce fridge for animals?	12									
I mean that instead of food, we put alive organic inside	12									
can we think about fridge in the space or under water in the sea	12									
we can think of some fridges inside the body of human for some disease	12									
local coldness for some part from inside	12									
yes, we can expect totally new technology like some pills and external devices for leading the pill to the considered body	12									
if we have a special material that can cool down everything in every condition	12	4	3	1	1	2	4	3	3	4
I am thinking of third button for mix of them	9	1			1					
so the ice making must be flexible to the consumption	5	1			1					
even we can order for more according to our need for parties	5	1			1					
a self-cleaning filter after some usage period	5	2	1	1	4	4	4	4	3	4
or even it doesn't become dirty	5	2	1	1	4	4	4	4	3	4
we have to consider using ultrasound	5	2	1	1	4	4	4	4	3	4
also we can use Gama waves	5	1			1					
when water comes to the fridge in different part, we use different ultrasound waves to separate different particles	5	1			1					
using ultra with different wavelength to separate particles from water	5	1			1					
it means that we use the structure of layers and try to remove particles in different layers by different temperature	5	1			1					
so we can first let the water to freeze and then melt it again to have drinking water	5	2	1	4	4	4	3	3	4	4
we can use the heat of condenser for melting	5	2	1	4	4	4	3	3	4	4
so we can also use condenser temperature to remove some different particles	5	3	3	4	3	4	3	4	2	4
the fridge can have also a tube for removing not drinking water	5	2	1	1	4	4	4	4	4	4
we can also add process of enriching water or vitaminize it	5			3			4			4
add pills or vitamin	5			3			4			4
or very cheap filter that users change by themselves	5	1			1	4	4	4	3	4
also we can think that the meshes are like a plate that can be brought out by user to wash it	5	1			1	4	4	4	3	4
the fridge can be smaller but more real capacity	5	2	4	1	4	1	4	4	4	4
also we can think about level of accessibility	8	2	4	1	4	1	4	4	4	4
thinking ideally, we want a flexible fridge	9, 12	3	4	4	3	3	2	3	3	3
to be flexible in body according to different houses, because we change our houses a lot and we move the fridge with ourselves	5, 12	3	4	4	3	3	2	3	3	3
we need that the size changes according to new place when we move our house	5, 6, 10	4	4	4	4	3	3	3	3	3
the fridge must be lighter	7	3	2	1	4	3	4	2	4	4
also we can think about moveable fridge to move it by yourself when you are in the living room, when you are in the study room, …	6	1			4			4		
small portable fridge	1	1			2					
chargeable small fridge	1, 8	1			2					
chargeable battery for time of out of electricity	8, 10	1			4			4		
fridge in 1 foot	1	1			2					

so we can propose a portable device for cooling	8	1			4			4		
maybe it is better to not limited to the space	6, 8	4	3	3	3	2	4	4	3	2
it is monolith and it can be divided in some parts	12	3	2	1	4	4	4	2	4	4
some part that we need for cooking, inside kitchen and some part for drinking and fruits inside living room	2, 6	3	2	1	4	4	4	2	4	4
we can move different parts to every part of house	2	3	3	4	4	4	4	2	3	3
the boxes that are conveying in home can work like a Coleman	2	2	1	4	4	4	4	3	4	4
I think of lots of small boxes in every where	8	3	3	4	4	4	4	2	3	3
dedicate some part of fridge to Coleman	1, 10	2	1	4	4	4	4	3	4	4
with the ammonia in the wall that can preserve the temperature	1	1			2					
to separate engine from the fridge to make it portable	1, 6, 10	3	3	3	4	4	4	1	3	4
if we could pack the fridge and make it as small as possible for movement	10, 12	4	4	4	4	3	3	3	3	3
if we can make it bigger by bring out some drawers that they are inside when we don't need them	9	4	4	4	4	3	3	3	3	3
I am thinking of a fridge that can be disassembled for movements	11	3	4	4	4	4	4	2	3	3
also we can think of modular fridge that can be assembled at home	8, 12	3	4	4	4	4	4	2	3	3
like dormitories? It has own problems	7, 8	3	2	1	4	4	4	2	3	4
so we can use everywhere as fridge like each cabinet by adjusting and controlling the temperature degree	1	2	4	4	4	3	4	2	3	4
something on the roof of the house that absorb the heat and convey it to water	1	4	3	1	1	2	4	3	3	4
with some water container on the ceiling	1	3	1	4	4	4	4	2	4	1
the container can be wide but with less depth in all over the ceiling	1	3	1	4	4	4	4	2	4	1
we can add the function we need to the cabinets	2, 9	2	4	4	4	3	4	2	3	4
each apartment has its fridge but the engine and condenser is common for whole building	7, 8	3	2	4	4	4	4	3	3	1
our previous idea about central engine for house can solve the problem	9	3	2	4	4	4	4	3	3	1
using lighter material like aluminum, plastic, polymer	7, 8, 10	3	2	1	4	3	4	2	4	4
why not the body from water proof cloth material	10	3	2	1	4	3	4	2	4	4
we can think of a jelly material on the wall of fridge that you can put and sink food in them and they become cold, this gels are memory shape	12	3	2	4	4	4	4	2	3	4
may be using Nano material makes the fridge lighter and also stronger	8	3	2	1	4	3	4	2	4	4
you mean a container full of jelly material?	12	3	1	4	4	4	4	2	4	1
it can be different from current cube shape like a thick wall up to the desirable thickness	12	3	1	4	4	4	4	2	4	1
but I think must be in a special package	12	3	1	4	4	4	4	2	4	1
we can add wheel under fridge for easier movement	7			1			4			4
to have a special basis for movement that can be activated by a button	7	3	3	4	4	2	3	2	2	2
we can propose a structure for moving it on the stairs	7	3	3	4	4	2	3	2	2	2
wireless fridge that can be moved easily	10	3	2	4	4	3	3	4	2	4
also it is better that depth of fridge be not so much to access that forest food easily	5, 8	1								
if we can manage the layers flexibly in some way else, we use it more efficient	12	2	1	1	4	4	4	3	3	4
we can propose some special dishes for food which they can store very well inside the fridge and we have less unusable positions inside fridge/ better shelves	12	2	4	1	4	1	4	4	4	4
or inside the fridge can be like a rotator to reach every part easily	5	2	2	2	4	4	4	3	4	4
for the ergonomic issues we can consider the up-down side fridge and freezer as the children cannot use fridge very well	5	1			1					
we can reach the upper parts by a lift or sliding	9	2	2	2	4	4	4	3	4	4
I think about a horizontal fridge	7	2	1	2	4	4	4	3	4	4
why not cylindrical in the middle of kitchen?	8	1			1					
a fridge with lots of doors in all directions	8	3	1	4	4	4	4	2	4	1
or semi-cylindrical or for a corner	8	3	1	4	4	4	4	2	4	1
to have sliding door	8	3	1	4	4	4	4	2	4	1
or the flexible semicircular doors	8	3	1	4	4	4	4	2	4	1
we can propose fridge without door	7	1			1					
it produces wind in direction according to a pattern	7	3	3	3	4	2	4	3	3	2
we have to collect the cold air which comes out, and transfer it again inside fridge	7	3	3	3	4	2	4	3	3	2
change the external form of fridge to be used as sofa, bed, TV and other stuff of living room	12	1			1					
also we like different color, flexibility in color	5	1								
each drawer of freezer can have its own door and plastic string to keep the cold air inside, so remove the external door of freezer	9	3	1	2	2	4	4	2	4	2
fridge without need energy	1, 3	3	3	4	1	3	1	4	4	4
fridge doesn't need engine	3, 11	1			1					
fridge that can produce energy by itself	11	3	3	4	1	4	2	1	4	1
fridge with less energy usage	3, 5	1								
I mean shall we use pressure to decrease the energy consumption?	10	1			1					
so we use mediator for bringing out food	10	1								
a flexible cover and we can take the food by cover and bring them in mediator box and then take them out from that box	10	1								
using more effective insulators in the body of fridge	1, 2, 11	1			3					
using two layer doors for decreasing waste of energy	10, 12	4	2	3	4	4	4	1	3	4
also the light of fridge must be LED	7	1								
for example, we can use the rotating of fridge door to produce light for inside fridge	7	3	3	4	1	4	2	1	4	1
or using other sources of energy	1, 3, 4, 8	1			4			3		
without using non-renewal energy	3	1			4			3		
using free energy resources of nature or around at home	3, 11	1			4			3		
using solar cell for energy	1, 6, 7, 12	1			4			3		

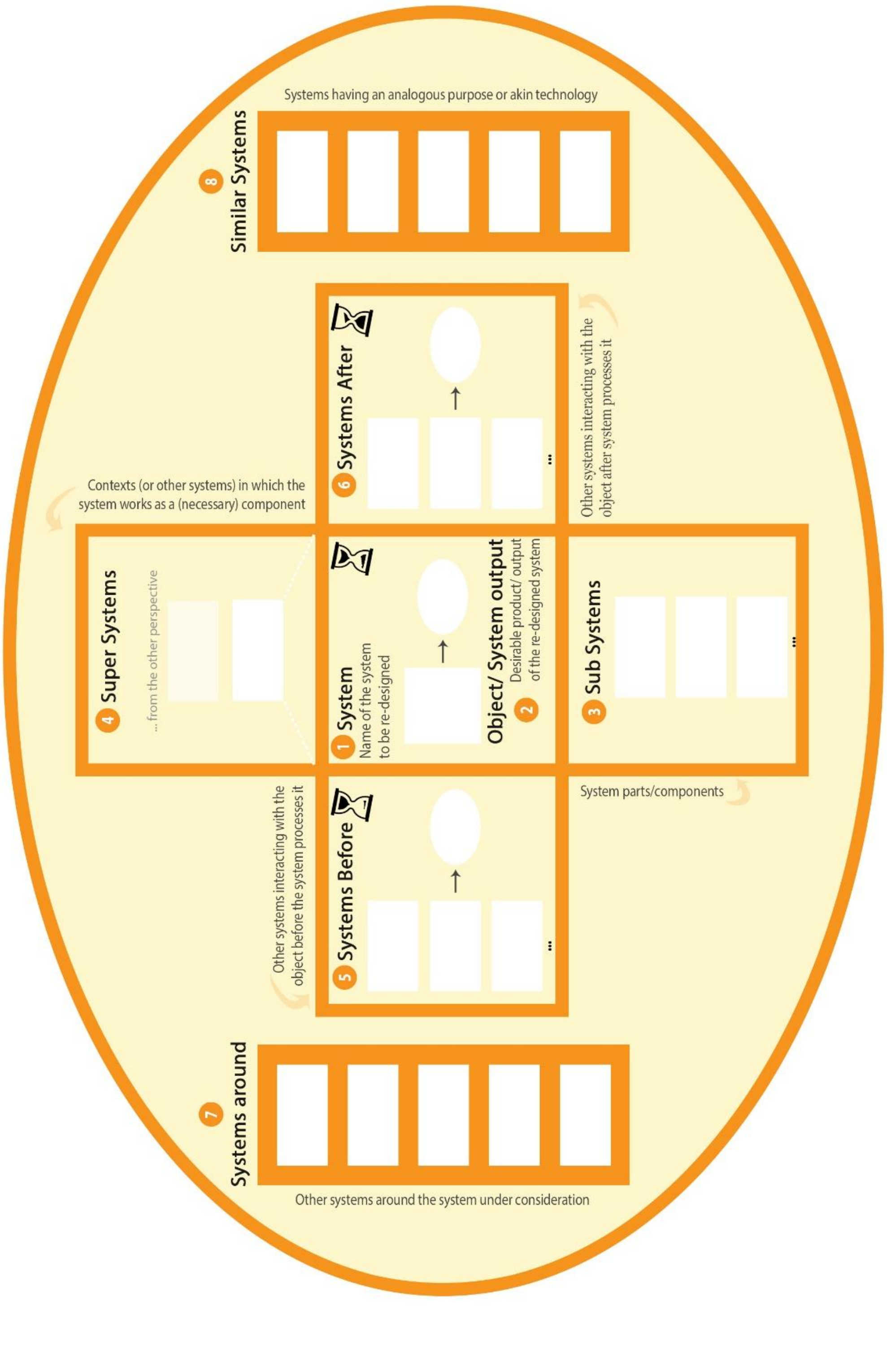
using the energy of wind by a turbine	1	1			4			3		
for example, we are using energy of reaction of food together as a source of energy	3	4	–	4	2	–	4	4	–	4
using magnetic field in new type of container	3	1			4			3		
we can use energy of wind, sun, magnetic, mechanical that can automatically work, chemical,	4	1			4			3		
to have chemical action that we need it for another purpose and use it to reduce the heat of food inside the fridge	4	3	3	2	4	3	3	3	3	4
one energy source for whole building and one cooling system also for whole building and just a container in each house	1, 7, 9	3	2	4	4	2	4	1	2	1
I am thinking of integrating the engine of these two devices	9, 11	3	2	4	4	2	4	1	2	1
using fridge as air conditioner of kitchen, it can also cool the home but the waste of energy is higher	7	1								
ups can store the electricity and release it when the electricity is out of circuit	5, 10	1								
especially for electrical shocks by anti-electrical shocks	5, 6, 7	1			4			4		
the fridge that can clean itself	4, 5, 7			3			3			2
fridge that can remove spoiled food	4, 7, 11			3			2			4
also easier way of cleaning	5, 7	3	1	3	4	4	3	4	4	4
fridge that clean itself by using Nano material	4	3	1	3	4	4	3	4	4	4
fridge that doesn't get bad smell	4	3	4	1	3	4	4	4	4	4
we have to think about ventilation inside fridge	5	1								
using materials for body of fridge that don't get smell	5	3	4	1	3	4	4	4	4	4
material of layers must be stronger to not broken by any kind of strike and self-cleaning	5	3	1	3	4	4	3	4	4	4
we can think about a degree of rotation for shelves, to let wash them easily	7			1			4			4
we can think of suction like a vacuum cleaner for shelves	7			1			4			4

Appendix 3: Techno-shift game stuff

1. Game board



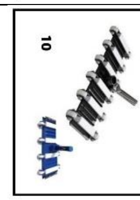
2. Table of resources



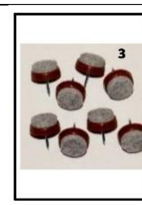
3. Example cards

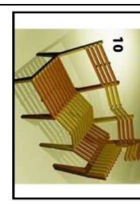
1. Vacuum cleaner

No.	Think stations heuristics	Back side of cards	Front side of cards
0	Old and current version of system performing the task expected by the user (delivering the function)	Techno-Shift Game An early hand-pumped vacuum cleaner	
1	System evolving towards improved usability, comfort, controllability, accessibility, …	Techno-Shift Game Portable Vacuum cleaner	
2	System evolving to a higher flexibility to answer demands for varying quality of the object	Techno-Shift Game Vacuum cleaner For different kind of floors	
3	System evolving towards harmonization and integration with systems around	Techno-Shift Game Soft vacuum cleaner body to not scratch home furniture	
4	System evolving towards harmonization and integration with systems commonly used just before/after	Techno-Shift Game Vacuum cleaner to wash carpets and furniture	
5	System evolving to reduce human involvement or easier to use (common usage, maintenance, feedback, ...)	Techno-Shift Game Vacuum cleaner with changeable bag	

6	System evolving towards less undesired side effects (undesired effects on user, other systems, environment, …)	Techno-Shift Game Cyclonic vacuum cleaner removing bag filter	
7	System evolving towards lower consumption of resources	Techno-Shift Game Cordless vacuum cleaner	
8	System evolving towards better addressing future users' needs and environment conditions (first, figure out which needs and conditions)	Techno-Shift Game Automated vacuum cleaner to start by detecting rubbish	
9	System working with a different principle or technology (higher performance and efficiency)	Techno-Shift Game Sticky Buddy Carpet Cleaner	
10	System evolving to a higher flexibility to answer demands for varying quantity (of the object)	Techno-Shift Game Vacuum cleaner with extendable brush	
11	System evolving towards merging all or some of its components into a simpler system without performance losses	Techno-Shift Game Power bed vacuum cleaner	
12	System evolving through improving different phases of its lifecycle (manufacturing, installation, management, recycling, ...)	Techno-Shift Game Vacuum cleaner made by carton and paper	
00	Object evolving so that the system becomes unnecessary		

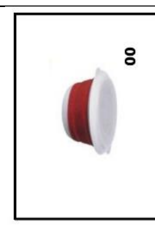
2. Chair

No.	Think stations heuristics	Back side of cards	Front side of cards
0	Old and current version of system performing the task expected by the user (delivering the function)	Techno-Shift Game Normal chair	
1	System evolving towards improved usability, comfort, controllability, accessibility, …	Techno-Shift Game More comfortable chair by reclining back and wheels	
2	System evolving to a higher flexibility to answer demands for varying quality of the object	Techno-Shift Game Chair adjustable in height to allow different people to be seated	
3	System evolving towards harmonization and integration with systems around	Techno-Shift Game Harmonization to the floor by using casters	
4	System evolving towards harmonization and integration with systems commonly used just before/after	Techno-Shift Game Desk attached to chair	
5	System evolving to reduce human involvement or easier to use (common usage, maintenance, feedback, ...)	Techno-Shift Game Automatic foldable chair for cinema and restaurants	
6	System evolving towards less undesired side effects (undesired effects on user, other systems, environment, …)	Techno-Shift Game Chair vibrating to massage back of person after long sitting period	

7	System evolving towards lower consumption of resources	Techno-Shift Game Mesh material instead of monolith	
8	System evolving towards better addressing future users' needs and environment conditions (first, figure out which needs and conditions)	Techno-Shift Game Foldable chair like a divider wall	
9	System working with a different principle or technology (higher performance and efficiency)	Techno-Shift Game Bean Bag Chair	
10	System evolving to a higher flexibility to answer demands for varying quantity (of the object)	Techno-Shift Game Extendable chair	
11	System evolving towards merging all or some of its components into a simpler system without performance losses	Techno-Shift Game Wearable chair just the necessary part for sitting	
12	System evolving through improving different phases of its lifecycle (manufacturing, installation, management, recycling, ...)	Techno-Shift Game Outdoor chairs	
00	Object evolving so that the system becomes unnecessary		

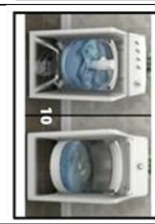
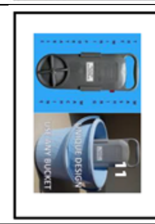
3. Coffee maker

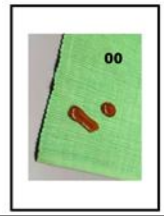
No.	Think stations heuristics	Back side of cards	Front side of cards
0	Old and current version of system performing the task expected by the user (delivering the function)	Techno-Shift Game Iron vessel placed on hot charcoal	
1	System evolving towards improved usability, comfort, controllability, accessibility, …	Techno-Shift Game Coffee pot with a lid and a whistle for boiled water	
2	System evolving to a higher flexibility to answer demands for varying quality of the object	Techno-Shift Game Coffee maker to brew both coffee and cappuccino	
3	System evolving towards harmonization and integration with systems around	Techno-Shift Game Coffee maker to brew both coffee and cappuccino	
4	System evolving towards harmonization and integration with systems commonly used just before/after	Techno-Shift Game Coffee maker that first grinds and then brews coffee	
5	System evolving to reduce human involvement or easier to use (common usage, maintenance, feedback, ...)	Techno-Shift Game Coffee maker with capsule to allow customizing taste instead of user	
6	System evolving towards less undesired side effects (undesired effects on user, other systems, environment, …)	Techno-Shift Game Coffee maker filter for using tap water	

7	System evolving towards lower consumption of resources	Techno-Shift Game Coffee machine for 12 people to-gether with same amount of energy consumption	
8	System evolving towards better addressing future users' needs and environment conditions (first, figure out which needs and conditions)	Techno-Shift Game Smart coffee maker to deliver coffee according to preset patterns	
9	System working with a different principle or technology (higher performance and efficiency)	Techno-Shift Game Soluble coffee pills (various coffee blends)	
10	System evolving to a higher flexibility to answer demands for varying quantity (of the object)	Techno-Shift Game Coffee maker with flexible capacity for 1 to 20	
11	System evolving towards merging all or some of its components into a simpler system without performance losses	Techno-Shift Game Pocket coffee maker	
12	System evolving through improving different phases of its lifecycle (manufacturing, installation, management, recycling, ...)	Techno-Shift Game Possibility of recycling coffee maker for other usage	
00	Object evolving so that the system becomes unnecessary	Techno-Shift Game A folded glass (like a lid) which can be activated to make coffee	

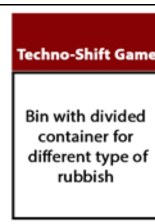
4. Washing machine

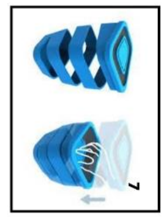
No.	Think stations heuristics	Back side of cards	Front side of cards
0	Old and current version of system performing the task expected by the user (delivering the function)	Techno-Shift Game A pot of water and rolls	
1	System evolving towards improved usability, comfort, controllability, accessibility, …	Techno-Shift Game Automated washing machine with rotating drum	
2	System evolving to a higher flexibility to answer demands for varying quality of the object	Techno-Shift Game Washing machine treating different textiles	
3	System evolving towards harmonization and integration with systems around	Techno-Shift Game Washing machine connected to the home water boiler	
4	System evolving towards harmonization and integration with systems commonly used just before/after	Techno-Shift Game Device for refreshing clothes (a steam flow both cleans and iron clothes)	
5	System evolving to reduce human involvement or easier to use (common usage, maintenance, feedback, ...)	Techno-Shift Game Wi-Fi Control for washing machine	

6	System evolving towards less undesired side effects (undesired effects on user, other systems, environment, …)	**Techno-Shift Game** Washing machine using reusable chips rather than a liquid detergent	
7	System evolving towards lower consumption of resources	**Techno-Shift Game** Washing machine dosing water according to the amount of loaded clothes	
8	System evolving towards better addressing future users' needs and environment conditions (first, figure out which needs and conditions)	**Techno-Shift Game** Washing machine using reusable fish shape chips instead detergent	
9	System working with a different principle or technology (higher performance and efficiency)	**Techno-Shift Game** Using ultraviolet-C light for the cleaning	
10	System evolving to a higher flexibility to answer demands for varying quantity (of the object)	**Techno-Shift Game** half load for washing machine	
11	System evolving towards merging all or some of its components into a simpler system without performance losses	**Techno-Shift Game** Mini portable washing machine	
12	System evolving through improving different phases of its lifecycle (manufacturing, installation, management, recycling, ...)	**Techno-Shift Game** BBQ made of Washing machine drum	

00	Object evolving so that the system becomes unnecessary		

5. Bin

No.	Think stations heuristics	Back side of cards	Front side of cards
0	Old and current version of system performing the task expected by the user (delivering the function)		
1	System evolving towards improved usability, comfort, controllability, accessibility, …		
2	System evolving to a higher flexibility to answer demands for varying quality of the object		
3	System evolving towards harmonization and integration with systems around		
4	System evolving towards harmonization and integration with systems commonly used just before/after		

5	System evolving to reduce human involvement or easier to use (common usage, maintenance, feedback, ...)	Techno-Shift Game Bin to alarm errors in type of rubbish in to the basket	
6	System evolving towards less undesired side effects (undesired effects on user, other systems, environment, …)	Techno-Shift Game Trash cans using a process called vacuum ionization, it sterilizes all the waste and pre-vents the garbage from decaying	
7	System evolving towards lower consumption of resources	Techno-Shift Game Press the trash to release more bag capacity	
8	System evolving towards better addressing future users' needs and environment conditions (first, figure out which needs and conditions)	Techno-Shift Game Device to produce pencil by using used papers	
9	System working with a different principle or technology (higher performance and efficiency)	Techno-Shift Game Compost bin to transform garbage into organic fertilizer	
10	System evolving to a higher flexibility to answer demands for varying quantity (of the object)	Techno-Shift Game Flexible bin for amount of garbage	
11	System evolving towards merging all or some of its components into a simpler system without performance losses	Techno-Shift Game Trash bag holder instead of bin	

12	System evolving through improving different phases of its lifecycle (manufacturing, installation, management, recycling, ...)	Techno-Shift Game Foldable trash bin	
00	Object evolving so that the system becomes unnecessary	Techno-Shift Game Edible package	

4. Cards of Tips & Tricks

Techno-Shift Game

Think of

you and your relatives' future needs

Techno-Shift Game

Think of

other systems that could share one of their components with the system. What evolution they might have?

Techno-Shift Game

Think of

potentialities of new or future manufacturing systems (Such as diffusion, adoption, manufacturing processes, ...)

Techno-Shift Game

Think of

trimming some of the system components and transfer their performance to something else

Techno-Shift Game

Think of

splitting contradictory performances, desires of users, desired quality or quantity of the object, ... and address them one by one through the different system parts (Splitting system to its components or even each component to smaller parts)

Techno-Shift Game

Think of

Split contradictory performances, desires of users, desired quality or quantity of the object and try to address them during different time fractions (within the system working time)

Techno-Shift Game

Think of

Split contradictory performances, desires of users, quality or quantity of the object, ... and try to address them By designing a system that works with improved versatility in different conditions

Techno-Shift Game

Think of

Define two contradictory requirements of the system and try to address them so that the whole system addresses one of them and one of the system component addresses the second one

Techno-Shift Game

Think of

Split one of conditions of user, object or environment in two conditions while each one need one contradictory requirements respect to other part and try to cover by adjusting system for both

5. Idea card

Techno-Shift Game	Group No. ………… Idea No. …………… Station No. ………. Idea description ……………………………… ……………………………… ……………………………… ……………………………… ……………………………… ……………	Criterion	Score	Description
		Novelty	1	Existing in the market/Already in use
			2	Existing concept, not available on the market
			3	Existing feature or trait in other fields of application never applied to the domain of this product
			4	Novel feature or trait
		Technical plausibility	1	Against laws of physics
			2	Not against laws of physics, but it sounds infeasible
			3	It sounds infeasible with current knowledge but presumably achievable with further research in the field
			4	It sounds feasible with current knowledge
		Relevance	1	No benefits foresee neither for the current usage of the system nor potential interpretations for the future society
			2	No benefits foresee for the current usage of the system in the current society, but potential relevance in specific (narrow) niches of members of future society
			3	No benefit for the current usage of the system in the current society but potential benefits (interpretation) perceived for different usage in a future society
			4	Benefits also for the current society

6. Score card

Techno-Shift Game

Group No.: ……………………………………………………………………

Number of players: ……………………………………………………………………

Name of system: ……………………………………………………………………

Time dedicated to table of resources: ……………………………………………………………………

Time dedicated to line of idea generation: ……………………………………………………………………

No. of think stations passed: ……………………………………………………………………

No. of ideas generated: ……………………………………………………………………

Time dedicated to complete score card: ……………………………………………………………………

Final score: ……………………………………………………………………

Idea No.	Idea	Station No.	Idea score			candidates
			Novelty	Technical plausibility	Relevance	
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						

Final score formula:

-15 (corresponding to the factory lost opportunities in 30 minutes) + total numbers of idea + 2 * number of candidates (for radical shift)