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LESSONS ON THE DESIGN OF GAMING SIMULATIONS FOR CONVERGENCE AND DIVERGENCE IN VOLATILE INNOVATION ENVIRONMENTS

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ABSTRACT

Gaming simulation allows innovation stakeholders to experiment with innovations in a shielded environment. The main contribution to innovation processes is not solely the provision of knowledge to stakeholders but also the manipulation of process volatility. Volatility is the speed and magnitude by which innovations, stakeholders and institutions change during the process, creating unpredictability and uncontrollability. This paper posits that a more even distribution of volatility over time is beneficial and that gaming simulation is able to contribute to this. The use of games allows innovation managers to front-load volatility beforehand or diminish it when it occurs. Crucial is that both effects demand from games qualitatively different design choices. This paper distills, from a multitude of gaming experiments in the U.K. and Dutch railroad sector, a set of design choices to consider. This enables game designers and innovation managers to improve the impact of gaming simulation on innovation processes.

1 INTRODUCTION

Since 2009, the Dutch railroad sector has deployed a plethora of gaming simulations as a step in innovation processes (Meijer 2012). The sector, and certainly the public infrastructure manager ProRail, have embraced the method as it does justice to both the complexity and the sociotechnical properties of railroad systems. At a time when innovations were tackling both the technical infrastructure (signaling, tracks, switches, software) and the social components (operator procedures, roles, rules), the method provided a welcome addition to computer simulation and to costly field trials. For instance, in 2012 ProRail, the infrastructure manager responsible for infrastructure expansions, station redesigns and traffic control wished to test to what extent a separation of railroad corridors around a large hub-station would impact the robustness of the network. A gaming simulation was developed, paper-based and low-tech, with all processes validly portrayed within the game. Trains ran according to realistic time-tables, albeit moved by facilitators, and representatives of many operational processes were part of the game model such as personnel planning of train drivers, traffic control, and train control. The simulation provided the innovation managers more certainty that separating corridors by removing switches would be beneficial.

The current paper aims to shed light on this type of gaming simulations. They are often designed ad-hoc to answer very particular questions and often involve low-tech game elements. We thus exclude simulation suites such as simulators and realistic driving environments. The fact that these games are designed ad-hoc is problematic for its intended impact. If not carefully designed, gaming simulation runs the risk of having no impact on the subsequent process. Its local use could result in locality of its impact.

The core of the paper is twofold: firstly, we provide a summary of our empirical work on innovation processes in the railroad domain to extract what the impact of employing gaming simulation should be.

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Secondly, given our experience in ensuring, or failing to ensure, this impact we provide an overview of a set of design parameters by which gaming simulation designers can improve the practical use of their tool. This paper addresses especially the notion that gaming simulation's value is much more multi-dimensional then solely providing decision makers with additional knowledge, analogous to the argumentation on policy games and games for learning (see Duke and Geurts, 2004). This impacts the way we design, execute, debrief and analyze effective gaming simulations for innovation processes.

2 INNOVATION PROCESSES

To define innovation, we first bound ourselves to the study of the process, rather then the product. Hence we adhere to Van de Ven's definition of innovation as: "the development and implementation of new ideas by people who over time engage in transactions with others in an institutional context" (Van de Ven 1986: 604). The definition leaves open the distinction between product and process innovation and technical and administrative innovations (Daft 1978). However, taking into account that most innovations in the railroad domain focus on process innovations, and process innovations are less easily adopted than product innovations (Damanpour and Gopalakrishnan 2001), it is worthwhile to investigate these so-called process innovation processes.

2.1 Linear and Non-linear Perspectives

Although empirical studies on innovation processes have often shown a different picture, linear perspectives are still abound (Godin 2006). Linear perspectives portray innovation processes to move from an idea-generation phase through development to an implementation phase. Contemporary perspectives are for instance stage-gate models (Cooper 2011) and funnel models (Wheelwright and Clark 1992). Stage-gate models focus on individual innovation processes and given the increasing costs of adaptations advocates the use of gates to screen innovation progress and terminate those that do not seem promising enough. Funnel models are similar but portray the multitude of innovations that go through these gates and shows how gates work as funnels to weed out unpromising innovations.

Both empirical work within the management sciences (see Van de Ven 1986) and theorizing from the system sciences led to the development of a range of different theoretical frameworks on innovation processes. Chaos theory to explain otherwise seemingly randomness in innovation processes proved to be valuable (Cheng and Van de Ven 1996). Additionally evolutionary economics (see Nelson and Winter, 1982) provided new models and nomenclature to describe innovation processes. For instance the innovation systems literature (Carlsson and Stankiewicz 1991; Hekkert et al. 2007) and the Sociotechnical systems literature (Rip and Kemp 1998; Geels 2002) all portray innovations as the constant coevolution of technologies, actors and institutions.

Although both perspectives differ to a large extent on what drives these innovation processes, they do usually agree on one common phenomena: processes tend to move from a fuzzy front-end (Smith and Reinertsen 1998) towards stability over time. Funnels result in a dominant design, the interaction between learning processes, building of actor-networks and vision setting create momentum (Rotmans and Loorbach 2009) and chaos diminishes over time (Cheng and Van de Ven 1996).

2.2 PSI-Framework

We used the PSI framework from the fields of engineering design (Meijer et al. 2014) to analyze dynamics in the innovation process for a range of different innovations in the Dutch and U.K. railroad sectors. The framework serves as a linking pin between micro-level theory on design and decision making and macro-level theories such as linear, chaotic and evolutionary models on innovation processes. The PSI framework conceptualizes design as taking place in three related but qualitatively different spaces: a product space, a social space, and an institutional space. The product space describes what is being designed, whereas the social space and institutional space characterize the people involved in designing and the coordination mechanisms used respectively. It does so by characterizing these spaces using three dimensions. For instance, if we would like to describe the P-space, we use the dimensions of structural complexity, amount of disciplines involved and the knowledge availability to describe how complex the design task is. Key to this framework is that these spaces impact each other constantly: changes in the design in the product (P-space) create the need to include new actors with different perspectives and languages (S-space) and instigate the design of suitable institutions for effective coordination of design activities (I-space). In table 1 we provide an overview of the three spaces and their three dimensions.

Table 1: PSI framework.

Space	**Populated by:**	**Dimension**	**Explanation**
P (product)	Technical infrastructure, software, operators, operational procedures	Structural Complexity	Interdependence between system components
		Amount of Disciplines	Amount of qualitatively different disciplines involved in designing the artifact
		Knowledge Availability	Completeness of knowledge needed to design the artifact
S (social)	Designers, decision makers, stakeholders	Amount of Languages	Amount of different vocabularies used to describe the artifact
		Amount of Perspectives	Amount of different perspectives on artifact and its functions
		Inclusion	Ease by which actors can enter the S-space
I (institutional)	Rules, Organizational structures, contracts	Strength of ties	Weak versus strong ties
		Coordination Mechanism	Market versus hierarchy
		Knowledge Accessibility	Ease by which knowledge can be accessed

Similar conceptions of innovation processes as taking place on a technological level, social level and institutional level can be found in the sociotechnical systems literature (Rip and Kemp 1998; Geels 2002) and innovation systems literature (Carlsson and Stankiewicz 1991; Hekkert et al. 2007). However, the PSI framework allows for defining more accurately the specific structure in the three levels. In addition to a positivistic stance, allowing for mere description of processes, the PSI is also normative in that it postulates that good innovation processes are processes were the three spaces remain aligned. When an innovation becomes structurally more complex and multi-disciplinary, then the S-space should expand accordingly allowing many more designers and decision makers to enter the network. This again demands the careful reconsideration of already existing institutional structures in the I-space. Indeed as we have seen in a range of innovation processes, misalignment, due to a range of coping strategies by individual decision makers, caused many problematic patterns later on.

2.3 Results

Between 2011 and 2014 we conducted case studies on three different innovation processes using semi-structured interviews, participant observations and document analysis. Using the PSI framework we analyzed the dynamics in the product, social and institutional space over time (see Van den Hoogen and Meijer forthcoming). We found that in some instances innovation processes indeed tend to converge from a fuzzy front-end towards stability but for some other cases this tendency did not hold. Especially innovation projects that reconfigure the existing system, rather then add-on a new technology, tend to see volatility at later stages of the innovation cycle. From comparing the three cases we distilled two defining parameters of the innovation artifact:

1. The 'systemicity' of the innovation. The extent to which innovation elements are interdependent in providing the overall functionality. The higher the interdependence the greater the need to build momentum early on. More momentum means less volatility
2. The overlap of innovation elements with elements part of the legacy system or other concurrent innovations. The higher the overlap the greater the influence of external pressures on single innovation elements. More pressure means more volatility

Innovations that encompass a multitude of loosely related measures of which many of them are also the focal point of actors in the legacy system or actors involved in concurrent innovation processes see increasing volatility rather then increasing stability. As innovations disperse throughout the organization new actors enter the S-space from different disciplines, focusing on different aspect systems of the innovation. Given that the low systemicity of the innovation allows for little buildup of momentum design changes are abound, impacting again dynamics in the social and institutional space. These dynamics thus do not solely occur at the chaotic earlier stages of innovation (Cheng and Van de Ven 1996), in the fuzzy front-end (Smith and Reinertsen 1998), or in stages where innovations, who have yet to build momemtum, emerge from unstructured niches (Geels 2002). Furthermore, this volatility is especially cumbersome if it is highly concentrated in time. Interfaces make sure that dynamics in one space are encountered with dynamics in other spaces. Given however that usually there is a lag in this realignment of spaces, in highly volatile times rapid movements in one space endanger the balance in other spaces. For innovation and project managers, this results in unpredictability and uncontrollability of the innovation process.

3 IMPLICATIONS FOR GAMING SIMULATION

Volatility can occur at any time due to cumulative and conjunctive progression that drive innovation processes (Gopalakrishnan and Damanpour 1994) and volatility may both increase and decrease during the process. Gaming simulation's contribution to these processes is therefore not solely the provision of additional knowledge, as knowledge sometimes does little to influence the volatility. Rather gaming's impact on volatility is mediated by a plethora of different mechanisms. Most obviously gaming simulation should allow for decreasing volatility. Providing knowledge about the value of an innovation is then only one of the many dimensions that describe this volatility-decreasing effect. In addition, convergence of disciplines, perspectives, languages and the determination of effective institutional arrangements to implement the results from the simulation are effects that gaming simulation should have. In this way, gaming simulation allowed for the convergence on a specific configuration of dimensions in all three spaces, keeping them aligned.

Even if innovation processes indeed solely converge on one outcome this first contribution of gaming simulation would be valuable. It would speed up the process by which organizations go from fuzzy front-ends to implementation. However, highly volatile situations also occur later on, after periods of relative stability. Two innovations may interlock at the final stages of their implementation process, creating dynamics in all three spaces or elements from the innovation might be cherry-picked by the legacy system to solve pressing issues earlier on. This implies for gaming simulation that in some instances it should be able to front-load volatility. Then, gaming simulation should expand spaces and allow for divergent processes. The tool should allow organizations to explore the range of feasible product designs, the range of disciplines involved, both now and in the future, as well as the range of to be expected actors and potential institutional structures to implement the innovation. By doing so the game creates dynamics in the three spaces well before dynamics would otherwise occur. We assume that this results in an even spread of volatility over time, ensuring that the process is manageable for the involved stakeholders.

In table 2 we provide an overview of what expansions and contractions of spaces look like and what gaming simulations allow for these effects. We term the first as exploratory gaming simulations for the generation of hypotheses and the latter explanatory gaming simulations for the testing of hypotheses. A third gaming variant is that where both opening and closing of spaces occurs. We term this variant design game where game players inside a simulation have to creatively seek for solutions (expansion) as well as convergence before the game ends towards one design (contraction)

Table 2: Gaming simulation and the opening and closing of spaces.

	P	S	I	Main activity	Game
Opening (Divergence)	Exploration of structural complexity Introduction of new disciplines Exploration of knowledge gaps	Increase in inclusion Increase in languages Increase in perspectives	Exploration of institutional structure Exploration of potential ties and knowledge access routes	Hypothesis generation	Exploratory Gaming Simulation
Closing (Convergence)	Decreasing complexity Convergence on few disciplines Increase in knowledge	Design of boundaries (decrease inclusion) Convergence on languages and perspective	Determination of institutional structure Formation of ties Design of knowledge access routes	Hypothesis testing	Explanatory Gaming Simulation
Opening and Closing	Divergence and Convergence in P-space	Divergence and Convergence in S-space	Divergence and Convergence in I-space	Design	Design Games

The normative aspect of the PSI-framework helps in better uncovering the true value of gaming simulation in innovation processes. For instance, a gaming simulation might allow a few stakeholders to explore holistically the dynamics of a system. From this they can massively expand the P-space, seeing how infrastructural design, timetables, operator behavior and safety rules all interact. However, if before, during or immediately after the game the S and I-spaces are not expanded as well the rich insights are not capitalized on. The game might show that methods for designing timetables should be altered, but with those responsible for timetables not part of the process, this insight remains just that: an insight.

4 GAMING SIMULATION IN THE DUTCH AND U.K. RAILROAD SECTOR

Since 2009 we have been employing a range of gaming simulations for the railroad sector in the Netherlands and the U.K. In table 3 we provide an overview of the games that have been employed. For a more detailed descriptions of these gaming simulations we refer to Meijer (2012) and Lo et al. (2013).

All simulation experiments involved solely the P-space as the simulant. Innovation actors either explored systems that they would design later on, or tested innovations already designed. There were no gaming simulations to explicitly, in game, explore the S and I-space. Those games would for instance involve the simulation of design processes, rather than operational processes, and through this learn how to improve such collective processes. This does however not mean that the dynamics in S and I spaces played no role before and during the game nor does it mean that these spaces were not affected. As we will show later on, they had a serious impact on the feasibility to open up or close down P-spaces as well as were significantly changed by the experiments in the P-space. Secondly, the table shows that it is not self evident that games designed to do one thing will result in doing exactly this thing. At Bijlmer, NAU, and OV-SAAL we saw that in the end the games caused divergence while the purpose of the whole exercise was convergence.

Table 3: Games and their intended and actual impact.

Game	Goal	Model	Intention	Impact
BIJL-MER	Testing predesigned traffic control procedures for dealing with future high traffic volumes around Amsterdam	Paper-based model of infrastructure, highly detailed computerized interfaces, realistic timetables, traffic controllers	Closing P-space	Opening P-space
ETMET	Testing predesigned traffic control procedure for dealing with disruptions on the Dutch central corridor and metro-like timetables.	Paper-based model of infrastructure, low tech interfaces, realistic timetables, traffic controllers from different organizational entities	Closing P-space	Closing P-space
NAU	Testing predesigned traffic control task separation to unbundle areas of control around central hub of the Dutch network	Paper-based model of infrastructure, low tech interfaces, realistic timetables, traffic controllers from different organizational entities	Closing P-space	Closing / Opening P-space
WINTER	Replay of traffic control processes when network gridlocked due to snow	No technical model, communication between operators disciplined by real timeline of events, traffic controllers as players	Opening P-space	Opening P-space
LEEDS (UK)	Testing predesigned traffic control roles and procedures needed for consolidating traffic control from 800 local control centers to 13 regional centers.	Paper-based model of infrastructure, low tech interfaces, realistic timetables, traffic controllers from different organizational entities	Closing P-space	Closing P-space
TMS (UK)	Finding requirements for the design of a traffic management system.	High tech prototypes of traffic management system, realistic timetables, traffic controllers	Opening P-space	Opening P-space
IPAT	Finding additional requirements for the design of a railroad tunnel	High tech prototype of tunnel hardware and software, representatives and operators from operational echelons as players	Opening P-space	Opening P-space
OV-SAAL	Testing four predesigned infrastructure expansions on their robustness against medium-sized disruptions.	Paper-based model of infrastructure, low tech interfaces, realistic timetables, traffic controllers from different organizational entities	Closing P-space	Opening P-space

4.1 Opening the P-space

IPAT, WINTER, and TMS were games that were designed to open up the P-space. Of these three WINTER was the only game solely meant for diagnosis purposes. This game was designed to allow operational personnel of the Dutch railroad sector, such as train and traffic controllers, to replay a day where the whole network collapsed due to wintery weather. Before the simulation was conducted, the designers of procedures for handling disruptions knew that the low robustness and resilience of the network was not caused by individual behavior nor solely by technical failures. Rather they wanted to explore where in the cooperative structures between different operators the reasons lie for the system's inability to cope with train and track failure down due to icing. For representatives of higher echelons this presented a chance to study processes holistically that are otherwise separated in space and time.

The other two games were designed to specify requirements for technical artifacts in conjunction with operator roles and procedures. IPAT intended to deliver a set of issues revolving around the mismatch between the software and hardware of a tunnel and the procedures designed to operate it. TMS was a test to study what changes had to be made to the design of an intelligent traffic management system to allow it to support future operational roles and procedures in the British railroad sector.

For all three of them holds that before the employment of the game no hypotheses were present. Because of this the game model had to be large enough to allow for exploration. This entailed both a large number of processes from the referent system becoming part of the game model and the running of many scenarios. By doing so, we decreased the chance of overlooking certain interesting aspects of the real life system. Furthermore we found that the ability of a game to allow for exploration relies heavily on the dialogue between operators (of the P-space) playing the game and designers (from the S-space) observing the game. Real-time play and immersion seem undesirable. Both parameters of game design inhibit game players to be in a reflexive mode, a mode that is crucial for creating the needed dialogue. In addition, the IPAT ensured this dialogue by having representatives from the S-space with sufficient operational knowledge play the game thereby effectively ensuring a dialogue between the P and S-space inside one person. This feature helped greatly in translating the outcomes to concrete actions afterwards.

Of crucial importance for effectively designing exploratory games is that the many insights that result from it are acted upon after the game. Therefore, next to expanding the P-space, the S and I-space need to expand as well. For the IPAT game, the S-space was already expanded due to the instigation of a special commissioning team with representatives of the tunnel project and the current organization. This allowed for the design of the game to incorporate all relevant processes, as well as for the design of interesting scenarios. This open design process made sure that the exploration during gameplay would touch upon all factors deemed relevant by all stakeholders. Additionally, the institutional structure was already in place, making it for most of the requirements easy to determine who was responsible for what. The build up of trust well before the employment of the game also caused game participants and observers to design new institutional arrangements in the debriefing. This was especially valuable for those requirements for which the specific coordination mechanisms were yet unclear. The TMS game was similar in that the way requirements were acted upon was strictly organized through market mechanisms. The simulation results could simply be put in the upcoming tender, as requirements, for which three suppliers of the TMS were still in the race.

4.2 Closing the P-space

When a simulation outcome rejects or accepts an hypothesis, in this case about the effect of an innovation, the P-space contracts. Knowledge availability increases and the innovation can now be implemented by dividing the innovation in modular work packages. This decrease the complexity and makes it less multidisciplinary. The ability of gaming simulation to ensure this effect relies on the perceived validity and reliability of the outcomes of the game by all involved stakeholders.

To provide with more certainty that an innovation has a certain effect on for instance punctuality, robustness or resilience, the gaming simulation needs to be designed according to strict experimental design principles. Stakeholders with which we designed and executed successful games, such as ETMET, NAU and LEEDS, all deemed these valid because of a range of similar features of these simulations. Firstly, they often involved a pretest-posttest experimental design, creating higher internal validity. Secondly, a clear conceptual model on the links between innovation and a predetermined dependent variable was present. Therefore we were able to operationalize the parameters we are interested in as well as structure the debriefing and analysis of the game in such a way that hypotheses could be accepted or rejected. Thirdly, we modeled processes from the referent system in high detail. Stakeholders often acknowledge the sensitivity of overall system behavior to small changes and only processes with high detail can replicate this behavior. Realistic movements of trains according to real life time tables, precise procedures for communicating between operators are a few design parameters by which we ensured external validity. This high detail creates the need for many different processes to be modeled in the game because system boundaries expand and ecological validity of the game needs to be maintained. Furthermore we often use real-time play to allow for this high granularity in processes to become valuable. Fourthly, immersion of game players is of vital importance. Whereas for exploratory gaming simulations we need a dialogue between operators and designers, in these explanatory gaming simulations we need operators to act precisely as they would in real life. Real-time play, or at least time pressure, and high detailed processes seem to contribute to immersion. On the other hand we have found that the relation between level of detail of representation seems hyperbolic. With our very low-tech representations (infrastructures printed on whiteboards, sponges as trains) we have seem to create higher levels of immersion than games using more high tech and detailed interfaces (BIJLMER).

Gaming simulation as pure experiments have many shortcomings. Often we can only run a few simulations in one a day, threatening the reliability of our results. Usual ways of overcoming these such as repeated runs, sensitivity analysis and elaborate factorial designs (Balci 1998; Sargent 2005) are therefore infeasible. In previous work we provided a framework the debriefing of such explanatory gaming simulations to alleviate some of these validity threats (Van den Hoogen et al. 2014). Here the debriefing should allow for the assessment of the reliability and sensitivity of the outcomes.

To effectively contract the P-space the relevant S-space should at least observe the gaming simulation and participate in the debriefing. This way, stakeholders can observe why an innovation brought about changes in the dependent variable. This increases the confidence the S-space has in rightfully contracting the P-space. Next to that, we found that the S and I-space deserve little attention. This is because the game design process already incorporates the relevant S space and often the innovation to be tested is already on the way to implementation. For instance in both NAU and ETMET the game model incorporated many different operational processes creating the need to incorporate designers of these processes to be involved in the game design process as well. Next to that, the contraction of the P-space leads to the effect that rarely actors outside of the current S-space need to act upon the results. In other words, if a game is about traffic control the results will not impact the design of safety signaling.

The only exception of his is OV-SAAL. This was because the game was about testing four variants on one dependent variable, whereas the final choice for the variants incorporated many other variables. In these instances a much broader S-space must be incorporated in the design process of the game. However, given that these designers usually stem from completely different disciplines and the specific P-space for the game only revolves around one aspect system, this is hard to ensure

4.3 Mixed Results

BIJLMER, NAU and OV-SAAL were games that had a different impact on volatility then originally intended. The causes for this we propose are faulty design choices, the context in which the game was employed as well as a natural tendency of collaborative simulation efforts towards exploration rather than explanation. In a sense, this is not inherently a bad thing. Additional insights can prove to be highly valuable. For instance, the NAU game showed the directly involved innovation managers that the traffic control procedure they had designed worked well. On the other hand, the game also led to insights about additional measures that had to be taken for the innovation to fully work. The fact that this game had many interrelated processes in the game model led beforehand to the involvement of many actors in the design process. Therefore the S-space was already expanded before the actual employment of the game and many observers from different organizational entities were present during the run. This created more possibilities to act upon the expanded P-space. However, the I-space was still uncertain. The actual coordination mechanisms as well as the directions in which the innovation was going became a hot topic of debate, during the debriefing and long after the game was finished.

The BIJLMER game saw a similar dynamic. However, here the P-space was expanded to such an extent that infrastructure design and station layouts became part of the solution space. This unexpected expansion of the P-space was not met with a coherent expansion of the S-space as nobody expected these kind of aspect systems to become part of the P-space. This led to many insights not being capitalized through the concerted actions of many actors. This in contrast to games that were intentionally designed to expand the P-space where the involvement of the S-space in the design and execution of the game (IPAT) or the careful design of the I-space beforehand (TMS) led to a coherent change in multiple spaces.

4.4 Uncanny Valley

The BIJLMER game was one of the first games we designed for the railroad sector. The game served to test a traffic control concept that was deemed necessary if in the future traffic volumes were to drastically increase. In the game model we tried to achieve high detail in processes and interfaces, because we intended to make the results internally and externally valid. However it seemed that players had problems with the accuracy of the interfaces. This created low levels of immersion and posed threats to the validity of the simulation results. Comparing to later simulations we have designed, it appeared that an uncanny valley effect can arise when designers strive for too much similarity between the model and the referent system. Slight difference between the game and reality then significantly impact the way game players experience it. In other similar games, lower tech representations often worked much better.

4.5 Context Dependence

The OV-SAAL game provides a perfect example where the context in which the game was conducted led the impact of the game to be completely different from what was originally intended. In a highly volatile and political context, we were asked by the traffic and logistics department to design a simulation of the Amsterdam Airport – Lelystad corridor. This corridor was to be upgraded and the department had four variants they wished to analyze on their robustness. Robustness is the extent to which the infrastructure gives the traffic controllers enough possibilities to cope with small and medium-sized disruptions. We designed the game as an explanatory gaming simulation, hoping that the outcomes would be a convergence on one of the four variants.

However the highly volatile environment in which we designed and executed the game led to a few interesting results. Dynamics in the P-space before and during our design process resulted in many changes in the variants, even during the game. Additionally the gaming simulation provided an window-of-opportunity to test the variants in conjunction with other changes such as newly designed timetables and a capacity-increasing safety system. These dynamics led to an explosion of our factorial design. Our initial desire to simulate in high detail, and probably in real-time, became impossible because we needed 20 runs. Operators are rarely available for longer than a day and the results needed to be delivered quickly. Because the game now became more abstract and game players were less immersed the analysis of the many variants became highly qualitative. It also expanded the P-space because of a rich dialogue between facilitators who observed the simulation and operators who played the simulation. However when trying, in the debriefing, to converge on one of the variants that according to game players was most optimal, we found that the designers who were only present during the debriefing found this variant no longer relevant. So in highly volatile contexts gaming simulation sees two threats: firstly, volatility impacts the ability to design simulations in such a way that they converge on one solution. Secondly, the delay between the question (as input of the game) and answer (as output) means that these do not align anymore when P-spaces are highly dynamic.

4.6 Eigendynamics

Gaming simulations bare in them an internal tendency to create divergent and exploratory processes. The fact that we bring together operators (part of the P-space) and designers (from the S-space) creates certain expectations. For innovation managers this is one of the few times they actually communicate with operators. And for operators it is one of the few moments they are incorporated in the design process. Especially since they themselves are part of the to be designed product, they see these gaming simulations as an opportunity to influence the design process. These expectations from both sides creates an internal force that pushes towards dialogue between these separated worlds. However to ensure convergence we need the simulation run to be externally valid. This demands from game players to act as they would do in real life. A constant dialogue between operators and designers is certainly not part of this real life.

Other validity threatening aspects of gaming simulation play a role in its inherent problems of ensuring convergence. Gaming simulations are played by humans and they not always behave as experimentalists would like them to behave. They get distracted and sometimes do not follow exactly the rule-set designed beforehand. This is problematic as it hampers reliably coming to one valid conclusion.

5 DESIGN PARAMETERS

From the many games we have designed for two different purposes we distill a few design parameters that made them effective. For the game designers these parameters enable a careful manipulation of the effect of a gaming simulation. In table 4 we provide an overview of these parameters.

Table 4: Designing exploratory and explanatory gaming simulations.

Parameter	Exploratory Games	Explanatory Games
Experimental design	Single test (per scenario)	Pretest Posttest
Amount of processes	As much as needed to find interesting phenomena	As much as needed to ensure ecological validity
Process detail	Low	High
Measurement	Flexible methods and sources	Predesigned measurement instruments
Immersion	Low	High
Game players	Players with operational knowledge	Real operators
Real-time	No	If needed
Scenarios	Many	Few
Flexibility	Yes, allows for searching and finding of interesting phenomena	No, endangers internal validity
Dependent variable	No, might emerge from game	Predetermined, fully operationalized
Debriefing	Unstructured, focused on insight	Structured, focused on validity

In two instances the game design process itself needs careful consideration by the game designer. When designing explanatory gaming simulations in highly volatile times the design process can alleviate many of the problems found for these games. An open and flexible process allows the game design to move with the volatility in the P-space. Last minute innovation changes can quickly be incorporated in the game. This ensures that the effect of the lag between game design and outcomes is reduced.

For exploratory gaming simulations, the design process is much more important. The simulation should explore a vast problem and solution space and beforehand its boundaries are unknown. The incorporation of many innovation actors increases the chance that the game touches upon a wide array of interesting phenomena. For instance at the IPAT game everybody was able to contribute to the design of scenarios, making sure that after the gaming simulation all relevant phenomena were uncovered. Additionally, the game design process is the moment that changes in the S and I-spaces can be realized. These are needed to allow the insights from the game to have any impact outside of the game. An open process results in a joint fact-finding session, where different actors can discuss the model and the assumptions. These features of an open design process make sure that results are shared by all actors.

6 DISCUSSION AND CONCLUSION

This paper identifies multiple roles of gaming simulation in innovation processes. Over the course of an innovation, games have shown to have a strong interaction with process volatility, and therefore provide more functions than the traditional simulation function of generating knowledge. This is in line with Duke and Geurts' (2004) work on policy interventions with gaming, but now also shown for innovations.

The manipulation of volatility can be ensured by designing gaming simulations in such a way that they allow for opening and closing of product spaces. This paper has provided a set of design parameters by which game designers can create either of the two effects. Game model detail, immersion levels of players, amount of scenarios and experimental designs are some of parameters designers can manipulate.

Furthermore this paper pointed to pitfalls gaming simulation designers can encounter when designing games for innovation processes. Because gaming simulation needs the involvement of many disciplines and encompasses the bringing together of operators and designers they have a tendency to open up the P-space. This has three implications for game design. Firstly, for game designers wishing to design an explanatory game this means that more energy is needed to encounter this tendency. Secondly, to capitalize on expanded P-spaces, game designers should take into account the specific constellation of the S and I-space. Otherwise the many insights that games deliver are not translated into coordinated actions. Thirdly, the context in which gaming simulation is employed impacts to what extent a game designer can direct a game towards closing spaces. Especially in already volatile situations, where dynamics in P, S and I spaces are profound, it is a cumbersome task to design explanatory gaming simulations. Volatility begs for explanatory gaming simulation, due to its ability to close spaces, but volatility itself forces games to become ever more exploratory. Strategies to cope with this are definitely a theme for future research.

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