DEVELOPMENT AND APPLICATION OF SIMULATION GAMES TO INTRODUCE MODEL-BASED SYSTEMS ENGINEERING

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ABSTRACT

Model-based Systems Engineering aims at increasing consistency of information in complex engineering processes that involve different engineering domains. A major challenge when introducing Model-based Systems Engineering is to highlight the interactions of different process activities, like requirement definition, specific methods and available tools as well as roles. These interactions have to be demonstrated to members of the engineering team in order to induce awareness for potential hurdles within the implementation process and to increase acceptance for required changes of processes, methods and tools. Simulation games present a promising approach to generate awareness as well as the needed expertise for successful implementation of Model-based Systems Engineering, in both teaching of students and training of experienced engineers. In this contribution a development process and essential aspects for the game design of simulation games are proposed. The structured process and its specific steps are illustrated by the development of the simulation game *MbSys*.

1 INTRODUCTION

Modern products incorporate crucial technical changes, like dynamic behaviours, intensive networking, connection to the Internet of Things or the use of on demand services [1]. Consequently additional requirements, like cyber security, are placed on the

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product and have to be handled within the engineering process. In most cases a more holistic view on the system and its environment is required to handle the complex requirements and interactions. Therefore the use of different system views are key elements of an engineering process that follow the Model-based Systems Engineering (MBSE) methodology. However, application of MBSE results in new processes, methods and tools (PMT) and the adaption of the existing PMT ecosystem [2]. To generate awareness for required adaptions of the PMT ecosystem, we research the design and application of simulation games.

1.1 Value and Benefits of Gamification Approaches

Gamification within education has become a central opportunity to drive behavioural change among individuals and to enable new methods for training within complex systems [3]. Additionally gamification increases the motivation to study or learn new items [4] within an enjoyable format. With regard to MBSE gamification provides various benefits. First, gamification supports harmonizing terms and wording, e.g. what is meant with the term *model* within MBSE? Second, gamification facilitates the definition and design of engineering processes as well the selection and application of appropriate methods and tools. Furthermore, gamification can be a great support by understanding the interactions between processes, methods and tools within an organisation. The understanding of these interactions are essential for the implementation and permanent application of MBSE within an organization. The following section gives an insight into the basic benefits of MBSE and typical challenges that occur. Target of this paper is, to address these challenges with a simulation game in order to improve engineering design education.

1.2 Benefits and Challenges of MBSE

Systems Engineering (SE) is a holistic interdisciplinary approach for successful development and realization of systems [2, 5]. Thereby, SE involves processes, methods and tools which focusses either single aspects, like architecture definition, or overall challenges, like comprehensive system understanding or interdisciplinary communication [2, 6]. MBSE extends SE by capturing engineering information, like interface control and system description documents, within an overall system model [5] in order to ensure data consistency and traceability along the complete product life cycle. Additional benefits which are reported in literature [5, 7] are: better communication and information sharing, improved system understanding and design, improved collaboration, better management of complexity, increased capacity for reuse, better requirements engineering and management. These selection of expected MBSE benefits highlights the support of MBSE when engineering complex products. However, introduction of MBSE frequently faces different barriers, which can be organizational, processual or educational justified [8]. With this paper and the corresponding simulation game mainly processual and educational barriers will be addressed. Key factor as well as big hurdle, due to widely established discipline and component oriented thinking, for successful SE implementation is holistic systems thinking [2, 6]. A second pivotal element for successful implementation of MBSE is an appropriate PMT framework,

based on the PMTE paradigm pyramid introduced by Martin [9]. Especially, the relations between processes, methods, tools and their environment needs to be understood and respected while definition of new or adaptation of established PMT.

1.3 Research questions and paper structure

This paper propose the use of simulation games for the implementation of MBSE. Therefore, a structured development approach for simulation games is proposed and preliminary experiences from application are presented. The following research questions will be answered within this paper: (1) Which development steps and elements should be considered for a successful design of simulation games? (2) How can the identified development steps and elements be integrated within a structured development process? The presented paper is structured as follows. Within section 2, different gamification approaches are distinguished and based on established literature typical development steps and elements for the design of simulation games are presented. Section 3 describes the proposed development process focussing on the simulation game *MbSys*. The paper closes with a summary and outlook for future work.

2 STATE OF THE ART

The term gamification is used with different understandings in literature. In Fig. 1 a basic distinction of relevant terms for this contribution is illustrated.

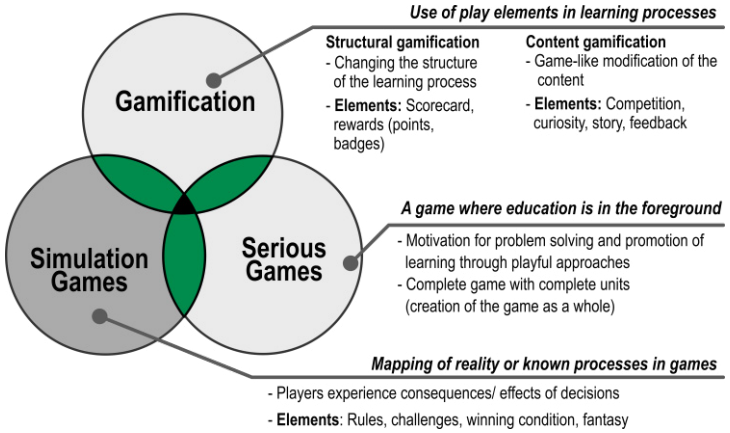

Fig. 1. Differentiation of learning games based on [10, 11, 12, 13]

Thus, different ranges of game-based learning have to be differed, resulting in gamification, simulation games and serious games as basic types. Gamification is the use of game design elements in non-game [10]. As soon as game elements such as fantasy, rules, challenges or winning conditions are added to the simulation, it becomes a simulation game [11]. Here the focus is on the representation of processes and effects known from reality. A third approach are serious game that focus on education rather than entertainment [12]. This paper focus on the development of simulation games and presents therefore a typical development process in the following section.

2.1 Development of Simulation Games

In general the evolution of simulation games can be described as an iterative problem-solving process. Therefore, the identification and the comprehensive understanding of the problem is fundamental. After problem analysis the design evolution, including

technical and project management processes, follows. Thereby the use of development cycles including prototypes, which presents the key functions and a previous visualization of the game, is established. Important for successful game development is the addition of an implementation and evaluation phase, which compares the initial problem and the developed solution. Fig. 2 presents a engineering process, which contains the mentioned development steps, for the introduction of a simulation game.

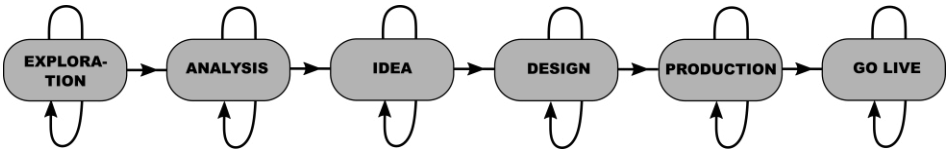

Fig. 2. Development process for simulation games, based on [14]

Especially the exploration phase at the project start, which contains the problem analysis and the definition of contentual and gameplay targets, functions and evaluation criteria, is important. Thereby also first ideas concerning the game content can be considered. Based on different concept sketches within the analysis phase important artefacts, like use cases and context of the game will be described. Methods for requirement definition, like system context analysis or use case scenarios can support these activities. Leveraging on the described concept sketches and artefacts within the idea phase detailed concept papers, including game mechanic, will be elaborated and evaluated. The idea phase closes with the selection of one concept which will be operationalised within the following design phase. Thereby prototypes evolve within an iterative development process. These prototypes will be used for evaluation of the realized game with the initial defined targets and functions. Finally the developed game design needs to be produced and introduced into the defined context. [14]

2.2 Pivotal elements for the development of simulation games

During application of the presented development process (chap. 2.1) we identified that the content of each development phase needs more structure. One possibility for better structuring can be the *Serious Game Design Assessment Framework* [15]. These framework was initially developed to assess games based on essential elements, but can also be a great support for structuring the development phases. Fig. 3 presents the pivotal elements that should be considered while developing a simulation game.

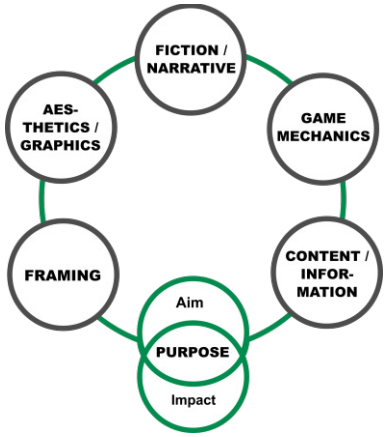

Fig. 3. Essential elements for game design, based on [15]

The *purpose* contains the *aims* of the game and the *impact* on the players, which the game should evoke. These elements are essential and should be reflected in all other elements. The element *content / information* represents all information and data offered and used in the game. The interaction between the players and the game is part of the *game mechanics*. To describe these interactions definition and visualization of actions can be helpful. Typically the *game mechanic* contains basic rules, space for decision making, in-game targets, challenges and events. Therefore often a simulation model is used in the background to define all existing relations. *Fiction / narrative* are needed to give the game mechanics a fictional content. Especially for simulation games the fiction and narrative should illustrate the real-world situations. The *aesthetics* and *graphics* refers to the audio and visual illustration of the game and present the game to the player. All listed elements should consider the target group of the game. Therefore the *framing* of the game has influence on all other elements and should answer at least the following questions: What is a suitable game type? Which prior knowledge attendees require? Are the learning targets easy or difficult to acquire? Which kind of game events can motivate players and affects the game dynamic? [15]

The presented elements should be considered within the development process of a simulation game in order to generate a purposeful game design. In section 3 these elements will be integrated into the presented development phases, see section 2.1.

3 DEVELOPMENT OF SIMULATION GAME MBSYS

Key element of this contribution is the description of the development process for simulation games *MbSys*. For a better structuring we integrated the pivotal elements of a simulation game into the presented development process, see Fig. 4. The production and go-live phases are out of scope within this contribution.

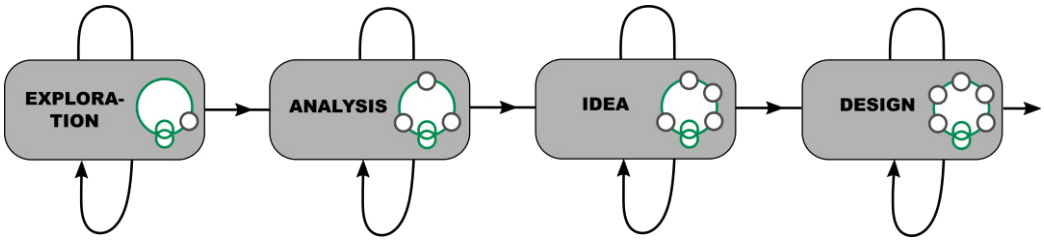

Fig. 4. Integration of essential elements into simulation game development process

While integrating the essential game elements into the development phases we identified that each phase considers different or additional elements. The exploration phase meanly focusses the *purpose* and the fundamental *content* of the game. During the analysis phase additionally the *framing* and *fiction* will be considered by a more detailed use case description. Afterwards an appropriate *game mechanic* needs to be selected, which is the core of the idea phase. Finally, during the design phase all elements based on the previously phases will be operationalised and the *graphical* visualization will be developed. Following the application of the introduced development process will be presented for the simulation game *MbSys.*

Exploration phase

Within the exploration phase we defined the aim of the game and the impact that the game should have on the player. *MbSys* has the aim to make MBSE including essential development processes and artefacts perceptible for the attendees. By knowing important artefacts, engineering decisions and influencing factors within MBSE, the attendees should adjust their functioning to a more model-oriented working behaviour. Additionally, we defined first aspects of the game content. We will use a typical product development process, which includes gates and artefacts, as an established game fundamental. These known fundamental should enable an easy game access, which is one of the game targets. The outcome of the exploration phase was an abstract product development process as the game vision, see Fig. 5.

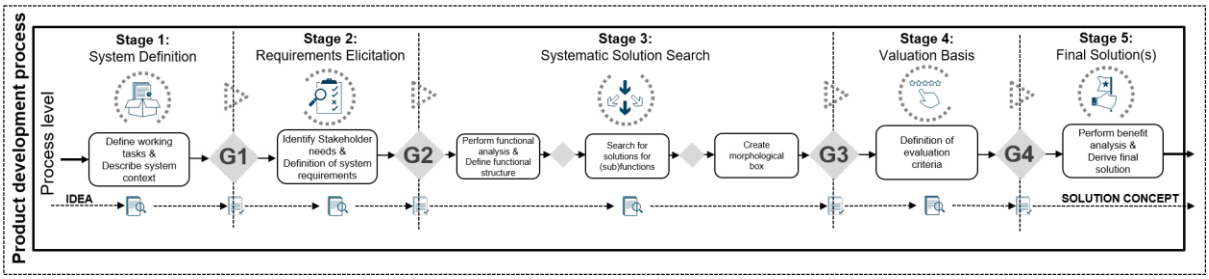

Fig. 5. Product development process as game fundamental

This development process includes different development stages and gates. Within each stage exemplary development activities are included, which are required to provide the needed artefacts at the individual gate.

Analysis phase

Part of the analysis phase is the consideration of the defined game use case (Fig. 5) in more detail and an in-depth understanding of the game attendees in this context. Thereby the initial game content was extended by an appropriate selection of development methods and tools, which are needed for successful MBSE, see Fig. 6.

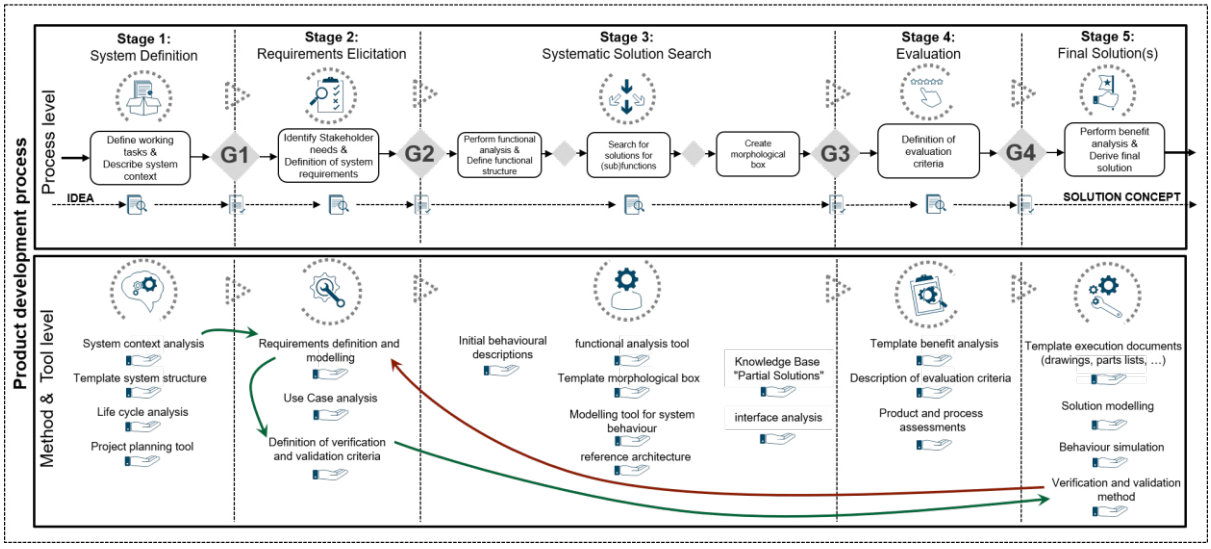

Fig. 6. Product development process including processes, methods and tools

One of the key question in these phase was the game opportunities of the players. Within a simulation game the players require some freedom to act within the defined content. In the case of *MbSys* we determined that the process level in the development process is fixed as a frame for the game and the players should select appropriate methods and tools to provide the needed artefacts at the individual gate. Thereby needs to be considered that typically not one method leads to the needed artefact. The players should understand the relations between different kind of methods and tools. A second aspect that increases the opportunities of the players is the integration of a quality classification for the applied development methods. That means a player has to decide in which quality (poor, medium, best) a method should be applied. While framing the game we identified the need that the game should have a flexible structure, e.g. the amount of gates, the required artefacts or the selected methods and tools should be adjustable. This is causes by individual stakeholder requirements.

Idea phase

Core of the idea phase was the evaluation of different game mechanics concerning the described use case. For *MbSys* we selected a role play oriented game mechanic, because the use case presents a sequence of events (stages, gates) that happened successively and the players can be seen as development team members. This can be compared with a guiding storyline including operating characters. In addition we wanted to simulate events (e.g. test case failed, post freeze requirement changes) that could occur within a development process. Therefore the described mechanic is also suitable. The occurrence of events can happen randomly, e.g. by rolling a dice.

Design phase

During the design phase the game concept and mechanic will be operationalised. The iterative development of prototypes supports evaluating the content and experience-oriented game targets, which were defined during the exploration phase. In case of *MbSys* we identified that additional resources (available development time) for each player increases that game dynamic intensively. Accordingly, each player has a defined amount of development time and has to decide which development methods should be applied and which quality level should be considered. Typically a higher quality level requires more development time. In parallel the aesthetics and graphical appearance of the game was defined and evaluated. *MbSys* uses classical elements for game appearance, e.g. printed game plan, 3D-characters, playing cards and dices. For game introduction and special events announcement the narrator will be support by audio-visual elements.

Presently *MbSys* is in the production phase and it is planned to apply *MbSys* for Model-based Systems Engineering education in the second half of this year.

4 SUMMARY AND FUTURE WORK

MBSE can have various benefits for the development of complex products but different barriers can inhibit a successful implementation. Gamification approaches can support

by overcoming these barriers. Therefore this paper presents an appropriate development process, including different phases and essential elements, for simulation games. Furthermore, this paper gives an insight into the development of the simulation game *MbSys*, which follows the evolved development process. The target of future work is the application *MbSys* to support MBSE implementation and the identification of conclusions for the educational success.

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