Towards Gamification of Advanced Value Stream Analysis and Design: A Game-Based Learning Concept

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Abstract: Advancing the traditional methodology of value stream analysis and design to include aspects such as material flow cost accounting, information logistics and external influential factors, overall application complexity and increasing data volumes are causing a shift in how improvement teams should think and operate. As a result, also the professional training of students and professionals needs to change and requires new solutions. Existing research efforts have not yet resulted in a solution that can convey advanced value stream analysis and design, including its methodological complexity. To address this gap, this paper applies a tailored CRISP gamification framework to develop a game-based learning concept to enable teaching of advanced value stream analysis and design to students and professionals focusing on identification of multi-stage resource-efficient optimization strategies. Activity cycles and progression stairs of the resulting simulation game concept facilitates innovative education while aiming to promote cognitive, motivational, and behavioral learning.

Keywords: Advanced Value Stream Analysis and Design, CRISP Gamification Framework, Game-Based Learning, Simulation Game, Resource-efficient Thinking

1 Introduction

By advancing the methodology of value stream analysis and design, which originates from lean management, to include material flow cost accounting [EK21], the consideration of information logistics [Me20], and external influential factors [ZR15], new opportunities as well as challenges arise. The construct called value stream can be defined as a process chain including value adding and non-value adding activities that are essential for the main flow of a product [RS11]. The methodological advancement withdraws the traditional lead time centricity, thereby major aspects such as material and energy-based waste, digitalization, but also the sales market, labor market, procurement

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market, and other external aspects like policy and trends can be included through advanced key performance indicators, enabling holistic optimizations [GE23]. Emerging diversity across the methodology results in an aggregate growth in application complexity and available data volumes, which changes how improvement teams should think and operate in industrial context. Thus, also training of students and professionals must change, for which new solutions are required.

It is widely recognized that traditional teaching methods such as expository lectures are inefficient in terms of knowledge retention and engagement. While a minority of researchers generally doubt that gamified learning effects can be transferred to non-game contexts through the process of gamification [Bo12, Kl18], direct meta-analyses have proven that gamification in formal education accommodates significant positive effects on cognitive, motivational, and behavioral learning [SH20, HRS20]. In existing research, gamification has already been used to develop concepts to teach various lean management aspects [BMS17, Bá14, GLC13], but have not yet resulted in a solution that can convey advanced value stream analysis and design, including its methodological complexity, in a motivating and vivid fashion. To address this identified gap, this paper utilizes a tailored CRISP gamification framework to the domain knowledge of advance value stream analysis and design. Thereby, a simulation game is conceptualized which gives players the opportunity to deepen their methodological knowledge and encourages to develop multi-stage resource-efficient strategies and reinforce sustainable thinking.

This paper initially introduces the theoretical background of advanced value stream analysis and design, frameworks for enabling game-based learning, and related work. Subsequently, the six-step CRISP gamification framework is introduced and applied to systematically develop game components and the simulation game concept. Detailed derivation and explanation of the CRISP gamification framework will be part of an individual publication currently in preparation. As this paper presents a simulation game concept, within evaluation limitations are analyzed and the prospective evaluation is planned. No deployment is carried out. Lastly, a conclusion and an outlook for further research is presented.

2 Theoretical Background

2.1 Advanced Value Stream Analysis and Design

When applying value stream analysis and design, an improvement team maps the current value stream of a relevant product family and illustrates it using standardized value stream elements (value stream analysis) [RS11]. Then, wastes are identified using the concepts of “muda”, “mura”, and “muri” [Oh13]. By eliminating the identified wastes and applying the value stream design guidelines, the improvement team designs a target value stream that is optimized in terms of lead time (value stream design) [RS11, Er13]. The ubiquitous guideline for all activities is the ideal state known from the toyota production system. Also referred to as the "north star" it consists of 0 defects, 100 % value creation, one-piece flow to customer demand, and safety for people [Ro09].

The methodology of value stream mapping and design is advanced by diversification of input and output characteristics by research [Ba15, BCZ06, CY08]. In this paper, the term advanced value stream analysis and design refers exclusively to the advancements through material flow cost accounting [EK21], information logistics [Me20] and the consideration of external influential factors [ZR15]. Fig. 1 illustrates an example of a current value stream of this advanced form of value stream analysis and clarifies the methodological complexity that is to be conveyed via the concept to be developed.

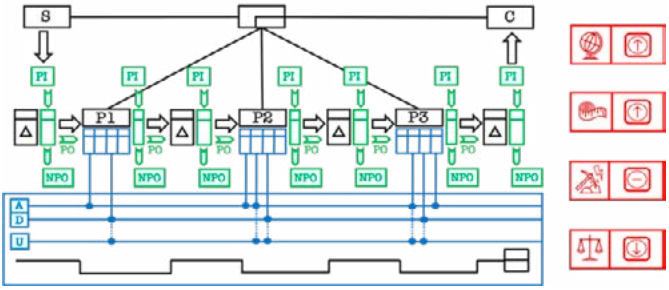

Fig. 1: Concept of a Current Value Stream Utilizing Advanced Value Stream Analysis

The lead time-centered elements of the traditional value stream analysis with suppliers (S), processes (P), inventories, customers (C) and the lead time ladder are shown in black. To resolve the fact of incomplete improvements in favor of the lead time, the consideration of material and energy waste is done via material flow cost accounting according to DIN EN ISO 14051:2011 [De11]. Shown in green, the input and output of a process is differentiated into product input (PI), product output (PO) and non-product output (NPO). The costs of product input, product output and non-product output are broken down into material costs, energy costs, system costs and disposal costs. In addition, key performance indicators such as absolute monetary value added, relative monetary value added, and the degree of value added can be used for presentation [EK21]. By incorporating information logistics, it is possible to track activities and key performance indicators of the information flow via analog (A) and digital storage media (D) and their utilization (U), shown in blue. Evaluation can be performed using the metrics of digitization rate, data availability and data usage. Media discontinuities between the storage media become visible and thus enable the initiation of targeted optimization projects in the context of digitization [Me20]. Focusing primarily on internal factors is not always effective. For example, if major suppliers' geopolitical situations are critical and supply chains are long, a lack of material availability can quickly lead to costly production limitations. Therefore, the external influencing factors shown in red from the sales market, the labor market, the procurement market, and other external factors such as politics, the social field, technology, and general trends should be included to facilitate optimization [ZR15].

2.2 Frameworks for Gamification and Game-Based Learning

Games are voluntary and formally organized activities with goals and rules that can be physical or mental in nature and encourage players to compete, educate, or entertain. Simulated environments are used to experiment with systems in simulation games, a special category of games that can be used for teaching [Wi15]. Gamification is the process of integrating game mechanics and strategies into non-game environments to motivate and encourage players. Point systems, leaderboards, and awards are used to increase interest and participation [BJJ19, SNS15]. Interactive digital or analog games with educational or informational goals are referred to as serious games that promote social interaction, impart knowledge, or train skills [FWW13]. Specially designed games are well suited to impart knowledge and develop skills by combining game elements with educational material [Ah18].

Numerous frameworks and models exist for game development, such as the six steps to gamification [WH20], the mechanics-dynamics-aesthetics (MDA) framework [HLZ04], and the octalysis-gamification framework [Ch19]. In addition, principles unrelated to gamification, such as design thinking, can also be used in game development creativity processes [Hu18]. Different gamification frameworks and models are often combined to create unique solutions for specific tasks. For example, combining gamification principles with software development models can help represent complex processes in a game while encouraging player participation [HS14]. Overall, gamification frameworks can provide a foundation for the development of games and gamified applications.

2.3 Related Work

There have been few efforts in previous research to apply the introduced frameworks and models to develop full-fledged simulation games in the context of advanced value stream mapping and design. Various approaches have been followed to simulate different lean management tools, such as shop floor management [BMS17], the SMED method [Bá14], or the 5S method [GLC13], or to simply model and simulate the value stream mapping process [MVR02, SG09, LV02]. In the field of advanced value stream mapping and design, the deployment of gamification frameworks is scarce. Existing solutions are outdated and do not fully meet the methodological requirements and the core idea of gamification, namely, to generate engagement and motivation while adequately representing the complex methodology of advanced value stream mapping and design. Therefore, demand arises for innovative approaches to game development.

3 Methodology

Objective of this paper is to conceptualize a simulation game which enables to teach advanced value stream analysis and design encouraging to develop multi-stage resource-efficient strategies and reinforce sustainable thinking. In accordance with the lean startup philosophy and the concept of the minimum viable product [LT16], the simulation game of this paper is conceptualization cost-efficient and agile. To realize this objective, this paper adapts the six-step CRISP gamification framework illustrated in Fig. 2. The tailored procedure model is based on the six steps to gamification by Werbach and Hunter [WH20] and the CRISP-DM model by Wirth and Hipp [WH00]. In contrast to other widespread gamification frameworks such as mechanics-dynamics-aesthetics (MDA) [HLZ04] or octalysis [Ch19] this novel model offers a cyclical IT-oriented approach that provides a continuous development flow from conceptual design to the digital realization of a simulation game. Derivation and detailed explanation of this framework will be part of an individual publication currently in preparation.

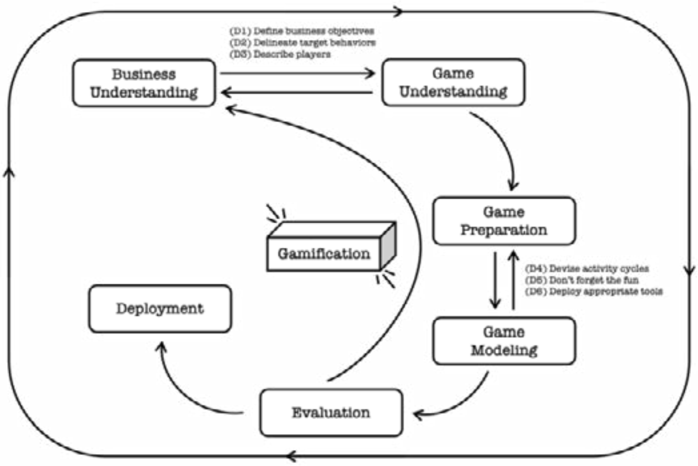

Fig. 2: CRISP Gamification Framework

In business understanding, in which the immediate business goal of the system to be gamified are defined. In the subsequent game understanding, the target behavior within the game is specified in bi-directional alignment with the business understanding as well as the player target group is characterized. During game preparation, the abstract framework of the game is conceptualized by creating game components, activity cycles, and progression stairs. This preparation is subsequently realized in game modeling via creativity processes with appropriate tools. Lastly, the developed game is logically tested and compared with the defined business objectives in the context of evaluation. If the game meets the business objectives, it can be deployed, if not, the game development is continued iteratively. As this paper presents a concept, within evaluation limitations are analyzed and the prospective evaluation is planned. No deployment is carried out.

4 Implementation and Results

4.1 Business and Game Understanding

In order to understand the business context as part of the business understanding, the explanations of the theoretical background provided in section two should be considered as the basis of the simulation concept. Broadly speaking, the objectives of the gamified system correlate with the teaching objectives in university teaching of advanced value stream analysis and design. This includes, for example, the acquisition of methodological knowledge, but also practical application to practical examples. Thus, the overarching objective of the game is to enable a vivid and motivating transfer of methodological knowledge while explicitly promoting the development of multi-level resource-efficient strategies and sustainable thinking.

The player's target behavior within the simulation game, associated with game understanding, involves applying traditional and advanced value stream design guidelines to design and model optimized target value streams toward the "north star" – including understanding impacts across a variety of scenarios and using resources strategically. It is critical that the target group of players, consisting of lean management-savvy students and professionals, not simply understand the method, but also comprehend the real-world complexities. Overall, being able to implement the concept over the long term while achieving above-average improvements – in line with the five levels of mastery [KS10].

4.2 Game Preparation and Modeling

Prior to overall modeling of the game concept the four essential game components – game board, game toolbox, activity cards, and payout wheel are conceptualized within a first creativity process. Fig. 3 illustrates the first two components game board and game toolbox which represent the main body of the game environment.

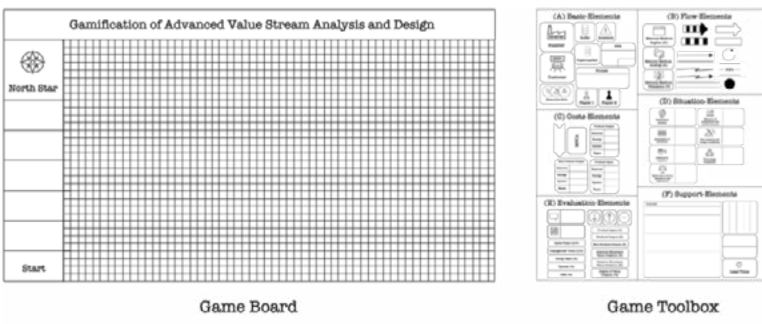

Fig. 3: Game Board and Game Toolbox as Game Components

Thereby, the game toolbox as part of the game environment, can be understood as a collection of traditional and advanced value stream elements. The value stream elements of the game toolbox can be segmented into the six element groups: basic-elements (A), flow-elements (B), cost-elements (C), support-elements (D), situation-elements (E), and evaluation-elements (F). Within the simulation game, the individual elements are available multiple quantities and can be used to create an initial individual value stream on the game board as well as to modify it applying activity cards. Utilization of the game toolbox is carried out on the game board, which is also part of the game environment. The game board consists of a patterned field on which the value stream elements can be placed in a structured manner to construct a value stream. During the simulation game, this value stream is considered as a system that must be analyzed and designed. The progression stairs are located on the left side of the game board, where all players start the game at the starting point and try to get as close as possible to the “north star”.

Outside the game environment, the activity cards, and a payout wheel, illustrated in Fig. 4, are conceptualized as triggers for activity cycle composed of actions, feedback, and motivation. The game features different activity cards that reflect the traditional and advanced value stream design guidelines in a gamified context.

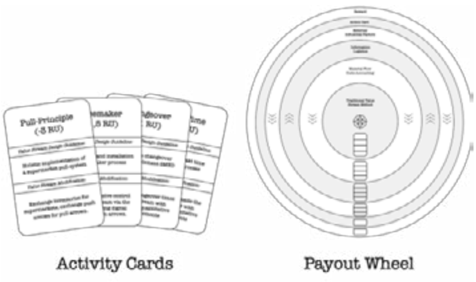

Fig. 4: Activity Cards and Payout Wheel as Game Components

Each activity card embodies one gamified value stream design guideline. The cards contain a brief description of each guideline, information on the resource costs of deploying the card in-game, and information on how to modify the current value stream with value stream elements when the card is successfully activated. For example, the activity card “pull-principle” embodies the value stream design guideline holistic implementation of a supermarket pull system, generates a cost of three resource units (RU) for the player when it is activated, and when successfully implemented, unregulated inventories are exchanged for regulated supermarkets and material flow push arrows are exchanged for pull arrows. While the activity cards define which actions have which effect on the game environment at which resource condition, neither feedback nor motivation arises. To enable these features, a payout wheel is used generate a reward based on the feature combination of the value stream in combination with the activity card as feedback for the player.

After conceptualizing the necessary components for the simulation game, in a second creativity process the game components are harmonized resulting in the five-step simulation concept, illustrated in Fig. 5. The simulation game concept aims to teach advanced value stream analysis and design in a gamified context and to reinforce resource-efficient thinking. The progression stairs of the game board display players progress through a total of five game turns within which players start at the starting point and compete to reach the target point “north star”. The five-step activity cycle (step 0 to step 5) runs turn-based and allows players to choose from random sets of actions in each round, resulting in positive or negative feedback from the payout generator. After five turns, the player who manages resources most efficiently and gets closest to the “north star” wins.

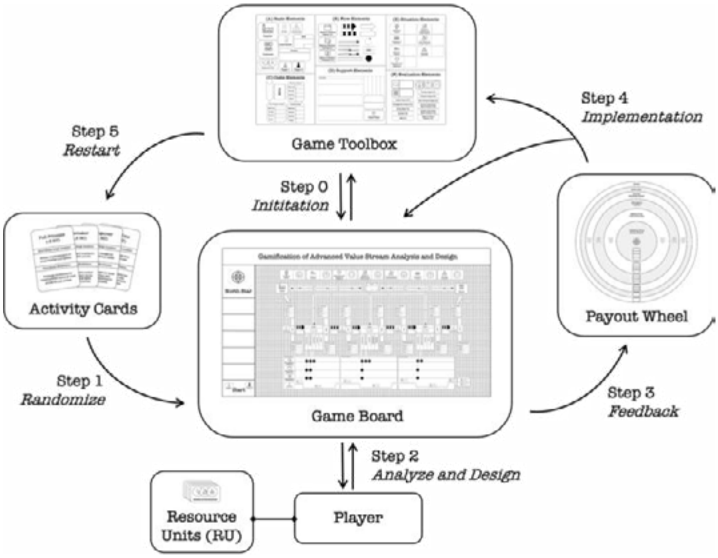

Fig. 5: Five-Step Simulation Game Concept Including Four Game Components

The conceptualized simulation game is to be played with three players, while one of the three players embodies the instructional game leader. Within game initiation, an educational value stream is constructed by the game leader by using the value stream elements from the game toolbox. The players game figures are placed on the starting point. At the beginning of the game, each player receives resource units that can be used to modify the value stream during the five game turns (step 0). After the different activity cards are randomized via shuffling by the game leader, five cards are randomly distributed to each of the player. Due this randomization of the activity cards, players are unaware of fellow players cards (step 1).

Players are challenged to analyze and design the value stream. Thereby, the players examine their available cards and activate whichever activity card they think is most suitable in current value stream configuration. The cards are placed face-up by at the same time. A player can only activate one game card per turn. After activation, each player must pay the cost of activating the card from their resource account and hand it over to the game leader. The resource units are thus considered consumed, i.e., they are not refunded regardless of the outcome (step 2). To generate feedback significant feature combinations of the present value stream and the individual activated activity cards are utilized via the payout wheel. The process is confirmed by the game leader. The player who achieves the highest reward via his activity card wins the current game turn and receives permission to move one step closer to the "north star" (step 3). The value stream design guideline of the turn winning player is implemented into the existing value stream using the modification information on the activity card and the value stream elements from the game toolbox (step 4). Lastly, all remaining activity cards are collected, and next game turn starts again, although the now present value stream already contains modifications, and each player has consumed resource units (step 5).

4.3 Evaluation

As pre-evaluation of the simulation game concept the presented game components been partially realized as paper prototypes, as illustrated in Fig. 6. To initially identify limitations, the paper prototype was superficially tested for functionality and logic with five different members of the Institute for Production and Service Systems with interdisciplinary backgrounds.

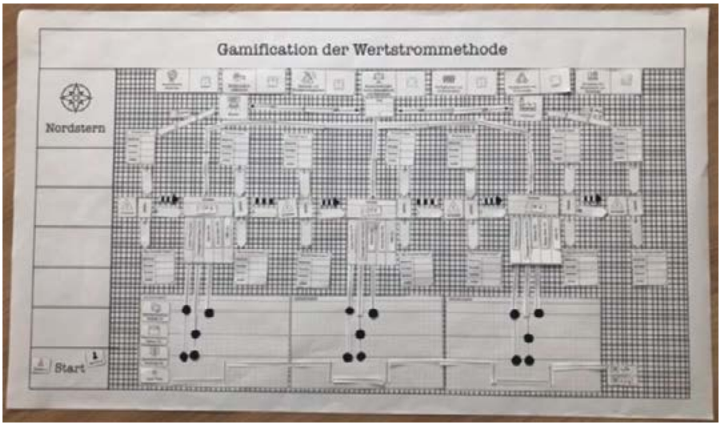

Fig. 6: Paper-Prototype for Practical Evaluation of Game Board and Game Elements

The most relevant limitation of the prototype is the value stream dimensioning restriction by the game board, which is realized on a size of DIN A0. At present, value streams with a maximum of three processes can be displayed legibly. Although three processes are sufficient to play the game and learn the concepts of advanced value stream analysis and design, it limits overall representable complexity. To overcome this limitation, it should be considered in the future to move the game to a larger surface such as a blackboard. Additionally, the game currently requires a game leader who has prior knowledge about value streams and can perform the initial setup. This limitation can be solved by a short informative playbook. A final limitation to be mentioned is the design of the game for three players. Even though the prototype is designed for three players, it would be possible to duplicate the activity cards, which would allow larger groups of students to enjoy the game together, e.g., within a lecture.

Considering known limitations and after realization of the simulation game as a computer-based game, an empirical investigation of the usability components effectiveness, efficiency, and satisfaction according to ISO 9241-11 is planned as part of the future evaluation of the simulation game concept [He03]. For this purpose, a three-stage evaluation procedure is planned in which the simulation game is to be tested within the scope of the lecture “Digital Lean Manufacturing” in 5th semester of the program “Engineering and Management” at the Jade University of Applied Sciences. Within evaluation procedure, relevant value criteria and expected performance standards for application of the simulation game in teaching are initially formulated. Subsequently, the simulation game will be used to teach advanced value stream mapping and design in scope of the planned lecture. As part of an analysis of effectiveness, efficiency, and satisfaction, students are surveyed, e.g., via qualitative interviews [Ka14]. Finally, the results of the survey are merged and a unified judgment can be created.

5 Conclusion and Outlook

Objective of this paper was to conceptualize a simulation game using a gamification approach, which enables advanced value stream analysis and design to be taught via game-based learning to students and professionals in a vivid and motivating fashion. To achieve this objective a customized six-step CRISP gamification framework was applied to the domain knowledge. The resulting concept for a simulation game includes as game components a game board, a game toolbox, activity cards and a payout wheel. Application of these game components via progression stairs and an activity cycle generates the five-step simulation game which may be able to consolidate methodological knowledge and encourage players to develop multi-stage resource-efficient strategies and sustainable thinking.

Within pre-evaluation the simulation game concept was partially realized as a paper prototype and tested for functionality and logic with five interdisciplinary members of the Institute for Production and Service Systems to identify initial limitations. In continuation of this paper, the simulation game concept will be transferred in the digital world and enriched via artificial intelligence. To perform evaluation of effectiveness, efficiency, and satisfaction the game is to be empirically investigated in scope of the lecture “Digital Lean Manufacturing” the Jade University of Applied Sciences.

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