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Investigating the Effects of a Virtual Process Environment on the Comprehension of Business Process Models

Master's thesis at Universität Ulm

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Abstract

Within the scope of Business Process Management and Modeling, gamification is used, inter alia, to promote process model comprehension and for motivational and educational purposes. In the context of gamification in Business Process Management, this master thesis aims to investigate the effects of a virtual process environment on the cognitive load a process reader perceives during the comprehension of a process model. The comprehension of process models is essential for the proper modeling of business processes, and vice versa. In addition to the previous research approaches in terms of gamification regarding the management and modeling of business processes, this master thesis takes into account concepts from cognitive research. A study with 72 participants was conducted online. Thereby, measures of interest were the cognitive load of the textual process description, the process model and the process model extended with graphics extracted from the virtual process environment. Therefore, a fractorial desgin was established as only the process model was extended with static pictures. The virtual process environment is realized through a video based on a 3D - warehouse scenario game. As a result, no significant difference in the perceived cognitive load of the process reader was found between the three process variants. In summary, after experiencing a virtual process environment, the cognitive load of the process documentations does not differ significantly. Further analysis has shown that the process reader's confidence in the completeness and adequacy of the shown process documentation is associated with the process document variant. Participants were more confident about the correctness of the process model extended with graphics.

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Contents

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Introduction

1.1 Motivation and Problem Statement

As the adage goes: "*a picture is worth thousands words*". Visualization is therefore an integral part since it can enhance cognitive processes and compensate for cognitive deficits because information is visually portrayed, as is the case with *process models* [1]. Process models are of utmost importance in the management of business processes since they are utilized for documentation and reengineering purposes [2, 3]. Rapid reactions to market conditions are indispensable due to increasing competition in markets, and this presupposes a fundamental management of the business process [4, 5]. Therefore, in the current state of *Business Process Management (BPM)*, enterprises concentrate primarily on the establishment of a process architecture and on major process redesign [6]. In addition to the utilization of process models in the management and modeling of business processes, gameful-designs and virtual environments are an uprising approach in the research and in the practice. Information are displayed either two- or three dimensionally. The concepts are applied in various domains, such as for educational purposes [7, 8], the comprehension of process models [9] and the encouragement and the motivation of domain professionals [10, 11]. This direction of research is indicated as *gamification* [12]. As gamification is gaining attention, it is of interest to examine its impact with respect to diverse theories such as the information processing, the behavioral decision and the cognitive load theory [13]. Research has been done so far primarily to investigate the impact on cognitive processes in terms of gameful-designs [14, 15, 16] or with regard to process models [17, 18, 19]. *But how do a process reader's cognitive processes get affected by a virtual process environment?*

The question addressed has not been analyzed so far and so the investigation of the question should lead to new insights as the basic comprehensibility is not yet given.

1.2 Objective

This master thesis seeks to investigate the impact of a virtual process environment on the process reader's cognitive processes during the comprehension of a process model. With respect to cognitive processes, the investigation focuses on the cognitive load theory (CLT). It is therefore of interest to gain insights as to how a gamification approach can have an effect on the intrinsic, extraneous and germane cognitive load. The virtual process environment is realized through a video based on the game reported in [20]. A study has been conducted for the investigation.

1.3 Structure of the Thesis

This master thesis is structured as follows: Section 2 sets out the fundamentals of human visual perception, gamification and virtual environment. In addition a comparison of the textual process description with the graphical process notation and the cognitive load theory are outlined. The purpose of this chapter is to elucidate the knowledge indispensable for the study of this thesis. Further, Section 3 is concerned with the planning and definition of the study. Therefore, the context and objective of the study is outlined in order to receive insights into the motives for the study. The research questions and the derived hypotheses are presented in Section 3.2 and in Section 3.3. Furthermore, the study setup including the selection of materials and instruments, participants and variables, followed by the study design, is outlined in Section 3 as well. After describing the structure of the study, the risks of validity are discussed in Section 3.6. Section 4 presents the study operation consisting of the preparation and execution of the respective study and the validation of the data collected. The analysis and the interpretation of the findings are described in Section 5. Therefore, in Section 5 the descriptive statistics of the collected data are outlined, the hypotheses are evaluated and subsequently the results of the analysis are discussed and interpreted followed by the limitations and implications of the study. In Section 6 related work is provided to gain insights into research in this area. Finally, the master thesis is completed by the conclusion and discussion of future work.

2

Fundamentals

Human visual perception in conjunction with *virtual environment* may be beneficial with respect to the comprehension of process models. Hence, it is indispensable to introduce the respective fundamentals.
Section 2 is divided into five parts. First, the fundamentals of the human visual perception specifically the information processing of virtual environments and graphics is presented in Section 2.1 respectively in Section 2.2. In Section 2.3 the term gamification is introduced. Subsequently, an outline of the differences between textual process description and process models will be provided in Section 2.4 and finally the cognitive load theory will be presented in Section 2.5 as it is essential for the study.

2.1 Humans Visual Perception

The vision science compromises multiple disciplines and thus is interdisciplinary. It includes perceptual psychology, computational vision, neuroscience and physics [21]. Visual perception is the key factor in how individuals gain insights and experiences through vision [22]. In addition, vision is also among hearing, smelling, touch and taste one of the most strongest senses regarding producing valuable information for the human mind, its cognition and his further intervention [21]. The visual perception process can mainly be divided into three parts: sensory recording, encoding, and interpretation [22].

Sensory Recording: The prerequisite for vision is light. When the light enters the human eye, the retina located at the back of the eye forms the incident light currents into electrical impulses. Light impressions in the environment are projected on the *retina* as an upside-down image [23]. As shown in Figure 2.1, the retina consists of diverse nerve cells such as ganglion cells, intermediate cells (*bipolar*, *amacrine* and *horizontal cells*) and compromises more than 126 million light-sensitive photoreceptors. These receptors can be distinguished into 120 million cones and 6 million rods. These two types are not distributed uniformly across the retina. The cones are responsible for human color perception (green, red, yellow and blue) while the latter is responsible for the brightness (black, white and grey). Thus, the daylight vision of human beings is due to the cones [22, 23]. However, the incident light needs to pass through the ganglion and intermediate cells in order to reach the light-sensitive photoreceptors (see Figure 2.1). The cones and rods are connected to the intermediate cells and when the light reaches the photoreceptors the information is processed through neuronal circuits to the ganglion cells which lead to the encoding phase [23].

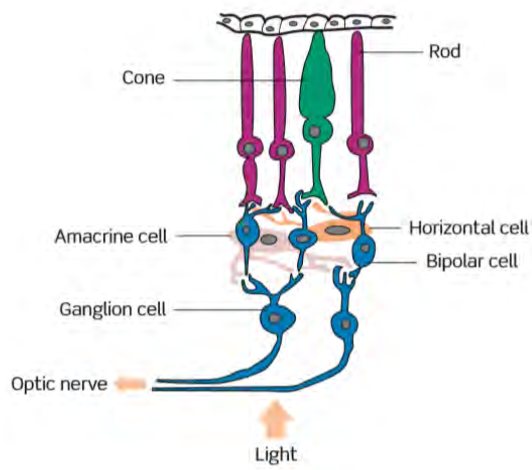


Figure 2.1: View of the Structure of Retina: A Cross-Section [23]

Encoding: The ganglion cells are responsible for transmitting the information through the optic nerve to the *visual cortex* [21, 23]. The visual cortex contains inter alia cells which are, e.g., sensitive to orientation, color and motion. The information is coded by various brain regions depending on the particular stimulus [22].

Interpretation: Once the individual sees an object, it will be projected on the retina two-dimensionally and then processed as perception back to its original form [24]. First of all, the raw materials need to be processed in order to gain perception as an output. For this cognitive processes are essential, e.g., for the spatial and depth perception, the recognition, categorizing and delimitation of objects. Various theories of perception are present in the literature [22]. They can be distinguished into *top-down processing* and *bottom-up processing theories*. The latter is also known as data-driven processing. The theory supposes perception begins with the incident light on the receptors transmitting it to the visual cortex, i.e., cognition starts with the stimuli. Top-down processing relies on the assumptions that in order to achieve the cognitive output previous experience, knowledge, etc. is essential to process the stimuli on the retina [25].

2.2 Virtual Environment

After an introduction to the visual perception process an outline about visual perception in the context of a virtual environment will be provided. The term virtual environment is defined by [26] as a computer-generated environment which is embedded in the physical environment. Inside the virtual environment users are able to communicate, interact or collect information. Furthermore, virtual worlds are a subset of virtual environments. *Virtual worlds* are self-contained and were first only used in a game-based context, describing *Massively Multiplayer Online Role-Playing Games (MMORPGs)* like Elder Scrolls Online [27, 28]. The definition of virtual world can be referred back to [29] initiating a discourse for a common definition. Therefore the author stated, virtual worlds are a "synchronous, persistent network of people, represented as avatars, facilitated by networked computers" [29]. However, it needs to be differentiated from the term *virtual reality*, since virtual reality applies to mechanics (e.g., data gloves) that humans can use in order to interact with the environment over multiple sensory channels. Thus virtual reality can be integrated into virtual worlds [27, 30]. Virtual reality is used, for example, in education, entertainment, medicine or in the military [31].

Individuals first communicated through pictorial languages. It is easier to describe objects (e.g., house, sun, car) using visualization than words. Apart from this, the human vision system is considered to have the most powerful information processing capability.

Graphic information processing is carried out *precociously* thus using graphics will ease the human mind. Visualized information is processed more efficiently than non-visualized information. Furthermore, visualizing information in the form of computer graphics would also allow for human pattern recognition, as it identifies patterns in graphics [32]. It was empirically shown that playing games enhance information processing, i.e., foster cognitive skills [33]. Finally, visualization in the form of computer graphics as a virtual world consists of, enables to represent a vast amount of spatial and non-spatial information requiring only a small area. Human cognition will be eased since those certain bits of information are offloaded to the preconscious perception system. Thus, computer graphics containing useful information can be used as an external memory since the vision system is a *high-bandwidth channel*, i.e., enabling the efficient processing of a vast amount of visual information in parallel [1, 34]. Besides the fact of fast information processing, visualization also supports cognition in the form as a deceptive tool and increased storage, as allowing interaction with graphics enabling experience to the user and visualized information can be stored efficiently in a high amount [1].

2.3 Gamification

The consulting- and auditing company *PriceWaterhouseCoopers (PwC)* developed *Multipoly Next*, an online simulation game. It was used as a virtual interview application process. The participants were placed in the role of a trainee and encountered several scenarios (e.g., workplace scenarios and completing tests scenarios). Throughout the game, the participants were able to gain points. Afterwards, the ranking list was used to choose the winners who will progress to the final round [35]. In this manner, PwC considered gamification aspects while developing its game.

Gamification connotes using game-design elements in *non-game* environments in order to induce motivation and promote contribution, skills, creativity and productivity of a user [12, 36]. Thereby, game mechanics (e.g., badges, leader boards, points, levels) are used to evoke certain effects on a user. The way the mechanics affect the users is known as game dynamics [37]. As an example: To arouse competition among the users, ranking lists can be used. The primary reason for the competition taking place is to achieve social recognition. Further, implementing task or quests is seen as a challenge, promoting cognitive stimulation [38]. Motivation can be distinguished into *intrinsic* and *extrinsic motivation*. Intrinsic motivation emerges within humans inner selves, such as the pursuit of being successful, social interaction and completing fulfilling tasks whereas the latter depends on achieving extrinsic goals surrounding in the environment (e.g., monetary rewards). Extrinsic motivation, however, is not fulfilling on the long term [37, 39]. Game-elements awaken intrinsic motivation and hence deliver intrinsic rewards. These rewards lead to a long-term satisfaction [39]. According to the literature review by [40] the majority of the reviewed empirical studies stated that the participants were positively influenced by gamification, i.e., using gamification provided benefits and positive effects.

2.4 Comparison of Textual Process Description with Process Models

Business Process Management focuses on identifying, reengineering, optimizing and monitoring business processes by using concepts and techniques such as process models and process mining. A business process consists of a set of activities being in chronological and logical order. It produces an output which is in line with the business goals of the company. Further, business processes require resources like staff, raw materials and data as a prerequisite to begin [2, 3].

Business Process Modeling is an integral part of Business Process Management and its life cycle. Identified business processes are documented in terms of process models. Afterwards, the process model may be used as a basis for redesigning the business process in order to achieve a better performance of the business operations [3]. Process models visualize business processes on an abstract level, only the relevant activities and resources are included and thereby reduces the complexity of the real-scenario [2, 3]. Hence, process models are used to document the business processes of an enterprise and are also used to improve the communication in particular among stakeholders [3, 41].

There is a broad research present comparing process models with textual processes. A popular graphical process modeling language is *Business Process Modeling and Notation (BPMN)* [42]. BPMN was developed by *Object Management Group* with the objective to provide a standard that is comprehensible by business users of various domains (i.e., technical and non-technical business users) [41].

Section 2.2 provided insights on how visualization supports cognition (e.g., parallel processing and external memory). Besides virtual worlds, process models are as well graphically represented using rectangles, circles and symbols (e.g., BPMN) [41]. Thus, process models facilitate the cognitive system by offloading the visualized information to the perception system as well (see Section 2.2). A study conducted by [43] compared process models with text-based process descriptions. According to the results, process models promote the comprehensibility in particular for expert users, for non-experts no significant change has been found which implicates that both methods (process models and text) influence the comprehension equally. Thus, knowing the notation was not sufficient to primary understand what was modeled. However, the findings of a study conducted by [44] comparing BPMN with written use cases indicate that using first textual and afterwards showing the graphical notation of the business process maximizes the comprehension regardless of the knowledge (e.g., business analyst, end-user) and the textual aptitude. Having experience in the graphical notation facilitates the understanding in the model whereas textual aptitude leads to a better comprehension of the textual notation. Therefore, the result supports the assertion by [45] that notations need to be learned in order to make a meaningful contribution from it.

In conclusion, there are various criteria that need to be considered when comparing textual notation with graphical notation. From a cognitive perspective, visualization processes information compared to the cognitive system more efficiently [44]. In addition, the textual information processing is linear whereas the elements of a graph notation (e.g., artifacts, activities, control flow) can be spatially distributed which as well leads to an efficient information processing [46]. However, it is also important to consider which process modeling language is being compared to textual descriptions. Therefore, textual descriptions performed better than *Petri nets* with respect to the comprehension [47]. Consequently, process modeling languages can have different effects on comprehension.

An overview of the performance of various modeling languages on cognitive processes delivers for example [17]. Furthermore, there exist various business processes with a multitude of complexity. Which notation should be applied, eventually depends on the facts of the case. Loops may be better presented by graph notation whereas texts are ideal for exceptional cases [44]. Concerning the situation in the practice, [48] for example, evaluated which notation (textual or process model) is current predominantly present regarding software development processes. The results of the evaluation, consisting of multiple interviews, showed that the companies predominantly represent its processes graphically. Textual or tabular representation is mainly used in addition to describing the details of a process. One assumption of the authors for using graphical representation is that it is more time-efficient since reading the whole textual process description will consume time whereas a process model delivers an overall view of the process at a glance. Further, textual descriptions, i.e., work instructions, can be linked to individual activities within the process model enriching it with more details. Therefore, they can be used in addition to validating process models especially for business users such as domain experts, who do not feel familiar with the graphical notation but have extensive knowledge of the visualized process [49, 50]. However, establishing both methods for describing a business process entails the risk of inconsistencies between them [51]. [51] delivers an approach for detecting inconsistencies that occur between both representations, further [49] introduces a technique transforming process models into natural language.

2.5 Cognitive Load Theory

The roots of the *cognitive load theory* can be traced back to the researches of [52] and [53] and serves as a framework for educational research with respect to the cognitive processes and in particular to the human cognitive architecture. It explains the occurring cognitive load of novel information in terms of learning and proposes suggestions about how to alter the cognitive load. According to [54, 55] knowledge can be categorized as biologically primary and biologically secondary knowledge traced back to the evolutionary theory. An individual acquires primary knowledge automatically and without any instructions given (e.g., learning the native language and basic social relations) due to evolution trough a multitude of generations, whereas the secondary knowledge is acquired through the cultural necessity of adaptation, such as reading and writing skills. These skills are essential for interaction with society. Further, the biologically secondary knowledge requires instructions to emerge respective secondary skills. The cognitive load theory, therefore, considers secondary knowledge, as this theory comprises cognitive load in terms of instructions [56].

The *working memory* and the *long-term memory* are components of the human cognitive architecture [56]. Novel information is first absorbed by the working memory before transmitting it to the long-term memory, thereby the working memory serves as a mediator between the external world and the long-term memory [53]. However, the human working memory's inclusion of information is limited by its capacity [57] and its duration [58] whereas the long-term memory is virtually unlimited [53]. In conclusion, if the amount of information conveyed by an instruction exceeds the working memory's capacity for information processing, the unprocessed information will not be transmitted to the long-term memory which negatively means the learning. The theory, therefore, provides advice about how to construct instructions considering the mental effort, i.e., cognitive load. The amount of cognitive load contained in an instruction is also related to the peculiarity of the types of cognitive load. Hence, the cognitive load is built upon three major categories: the *intrinsic* cognitive load, the *extraneous* cognitive load, and the *germane* cognitive load [56].

Intrinsic Cognitive Load (ICL): The intrinsic cognitive load comprises the cognitive load that information (i.e., instruction) contains itself. Thus, it depends heavily on the complexity of the material. It is affected by the interaction of the information fragments, i.e., the element-interactivity. The higher the elements are interconnected the greater is the resulting intrinsic cognitive load and the working load. It is due to the fact that these interconnected fragments of information cannot be progressed separately, but have to be progressed at the same time in order to understand the entire information of the material [53]. The intrinsic cognitive load is said to be invariable, given some expertise, as it refers to the complexity of the information. Further, the extent of the intrinsic cognitive load is attributable to the prior knowledge of the learner as well. Therefore, extensive prior knowledge leads to less intrinsic cognitive load as the knowledge is stored and retained in the long-term memory as a schema enabling to treat it as a single information fragment. Hence, a novice would perceive a higher cognitive load in terms of the complexity than an expert. Furthermore, it needs to be differentiated between the comprehension and the root learning of materials. A material with high complexity may convey low intrinsic cognitive load if the information is memorized solely as its element-interactivity is low, whereas the understanding of a material predominately results in high element-interactivity [56].

Extraneous Cognitive Load (ECL): The extraneous cognitive load is induced by the way the learner is given the information. Therefore, it is affected by the design of the instructions and thus is reduced by altering its representation. The element-interactivity also exerts an impact on the extraneous cognitive load as the instruction may require additional processing of various information simultaneously. This form of cognitive load shall always be minimized as much as possible since it is not relevant to the learning material itself [56]. [59] stated several recommendations in terms of the reduction of the extraneous cognitive load. The respective load may, therefore, be reduced, for example, by physically agglomerating coherent information or by presenting the text and its respective graphics in the same area.

Germane Cognitive Load (GCL): The germane cognitive load comprises the cognitive load which will emerge if the learner deals intensively with the material and thus enables productive learning [56]. Information is stored in the long-term memory as schemata. These schemes are used to handle multiple information as one. The learning process enhances the formation and automation of a schema [53]. Additional resources resulting from the minimizing of the extraneous load will be used to enhance the acquisition of schemata and automation which is subject to the germane load. In conclusion, the extraneous load shall be reduced as far as possible in order to enable high germane load [60]. The germane load provides positive effects as opposed to the intrinsic and extraneous load.

The total amount of cognitive load that the learner perceives is formed by the intrinsic and the extraneous load. These are considered as independent categories, whereas the germane cognitive load depends on the intrinsic cognitive load. In conclusion, if a material's cognitive load is greater than the working memory's capacity, this will adversely affect the learning process. Thus, the extraneous load should be reduced so that the additional freed resources could be used for deep learning [53].

3 Study Planning and Definition

Empirical research such as studies serves the purpose of investigating the relationship between certain observed quantities. It is of utmost importance to define the parameters to ensure a successful experiment and afterwards to be able to draw valid conclusions. Therefore, it is essential to carry out extensive planning in advance.

Section 3 is organized as follows: Section 3.1 defines the studies context. Section 3.2 describes the goals of the study. Afterwards, in section 3.3 the formalized hypothesis are presented. In Section 3.4 the study setup is explained followed by the explanation of the study design in Section 3.5. In Section 3.6 the consisting risks of the study are evaluated.

3.1 Context Selection

Within Business Process Management gamification is spanning around in various directions. *IBM Innov8* is a gamification platform developed by IBM teaching the fundamentals of Business Process Management in a 3D environment while providing gameful experience to the users [7]. Several studies showed that implementing IBM Innov8 in education were positively received by the students, gaining knowledge faster than traditional methods [61, 62]. Besides the well known IBM Innov8, there exist other simulation games as well, like *imPROVE*. Users are able to experience with imPROVE a 3D-real world scenario, the Manchester triage system. Within the game, they are able to model processes and afterwards simulate their processes while its effects on healthcare and resulting costs are displayed [8]. Another study conducted by [63] considered a gameful-design for their sail boat building game in order to increase motivation and engagement by enabling the chance to fail and to improve throughout the game. The results showed that the motivation and process management competencies increased. Furthermore, [64] proposed a notation extension of the business process modeling language BPMN 2.0 considering gamification elements [64]. [11] presents a BPMS-tool combining *Green BPMN* and gamification. Employees, for example, will be rewarded with badges based on how sustainable their designed processes are. Another practical implementation is *Horus Gamification*. [10] introduced its prototype. The tool considers *Social BPM* and gamification. It implemented game mechanics like badges, leader boards and points which users can gain through modeling based on process quality of their processes. Therefore, gamification is used in Business Process Management in various ways: for educational aspects, extensions of concepts and for practical implementations.

Broad research has been conducted to analyze the understandability of process models considering aspects such as personal factors [65, 66], the degree of the structuredness, the sequentiality, the concurrency and the size of process models [67, 68, 69], different modeling notations [44, 47, 70], modularity [71, 72], and the complexity of a process model [73]. To ensure a high process model quality, which influences the understandability, various guidelines and frameworks have been developed [74, 75, 76, 77]. Furthermore, research on the concept of gamification in Business Process Management focuses primarily on providing gameful-experience, in particular to foster the performance of employees and for educational reasons [7, 8, 9, 10]. Only little research has been conducted to examine the comprehension of a process domain in terms of the use of a virtual process environment, taking into consideration the cognitive complexity a process reader may perceive [13] and therefore whether it facilitates the user to comprehend the respective process model. Thus, a study is being conducted to provide insights into the stated issue.

3.2 Goal Definition

To investigate the impact of a virtual process environment on the comprehension of different business process documentation in terms of the cognitive complexity, the following research question (RQ) is addressed in this thesis:

RQ 1: *Does the application of a virtual environment have an effect on the cognitive load during the comprehension of different process documentations?*

As in Section 2.4 shown, the utilization of a textual process notation or graphical process notations such as BPMN 2.0 contain diverse strengths and weaknesses. Therefore this research question does not solely addresses the impact a virtual process environment may have on the cognitive load of graphical process notations but also comprises the impact on textual descriptions. Thus, it is of high interest to study whether the impact of a virtual process environment differentiates depending on the utilized process documentation. It is not uncommon that enterprises maintain graphical and textual notations to benefit from the strengths of both [49, 50]. Apart from this, another reason to include the impact on textual notation is that human information processing is influenced by the characteristics of an individual, also known as cognitive styles. Therefore there exists inter alia humans that tend to think primary in words and humans who predominately prefer to think in images [78]. Hence, textual descriptions should not be left out.

Furthermore, it is of high interest to analyze whether the cognitive load alters if a process model is extended with graphics extracted from the virtual process environment. To receive insights as to whether the impact of a virtual process environment additionally varies in terms of included graphics, the following research question is addressed as well:

RQ 2: *Does the application of additional graphics have an effect on the cognitive load during the comprehension of a process model?*

The study aims to obtain insights into whether the virtual process environment provides an impact on the cognitive load a process reader perceives and whether a distinction between business process notations exists.

3.3 Hypotheses Formulation

A *hypothesis* can be characterized as a verbal proposition involving the presumptive relationship of two or more variables. The validity has therefore not been proven and hence the researcher attempts to confirm the stated hypotheses, either empirically or experimentally. As a result, a hypothesis may be verified or falsified. In addition, it may also be referred to as a statistical hypothesis and can be delineated from the terms postulate and assumption. There exist two types of hypotheses: null hypothesis and alternative hypothesis [79, 80]:

Null Hypothesis: A null hypothesis serves the purpose of stating that no substantial differences can be identified between the alternatives and in conclusion, the observed difference is due to the fluctuation of the given sample. The null hypothesis is commonly indicated as H_0 [79, 80].

Alternative Hypothesis: A hypothesis that differs from the given null hypothesis is referred to as an alternative hypothesis. These hypotheses are usually denoted as H_1. If the null hypothesis is falsified the alternative hypothesis will be accepted [80, 81].

There exist various statistical tests of significance in terms of analyzing the outcome of a study. The goal of a researcher is to falsify the null hypotheses with a high significance [81]. The research questions addressed in Section 3.2 serve as a fundamental of the following derived hypotheses:

Constructed Hypotheses based on RQ 1:

As outlined in Section 3.1, the cognitive load is classified in three major types and thus it is of interest to study the impact on each type:

Intrinsic Cognitive Load:

Does the application of a virtual environment have an effect on the intrinsic cognitive load during the comprehension of different process documentations?

$H_{0.1}$: There is a significant difference between the different process notations in terms of the intrinsic cognitive load by showing the virtual process environment beforehand.[1]

$$H_{0.1} : \mu_M \neq \mu_T$$

$H_{1.1}$: There is no significant difference between the different process notations in terms of the intrinsic cognitive load by showing the virtual process environment beforehand.

$$H_{1.1} : \mu_M = \mu_T$$

No significant difference is expected in terms of the intrinsic cognitive load, as both process documentation (i.e, graphical and textual process notation) deliver identical information to the process reader.

Extraneous Cognitive Load:

Does the application of a virtual environment have an effect on the extraneous cognitive load during the comprehension of different process documentations?

$H_{0.2}$: There is no significant difference between the different process notations in terms of the extraneous cognitive load by showing the virtual process environment beforehand.

$$H_{0.2} : \mu_M = \mu_T$$

$H_{1.2}$: There is a significant difference between the different process notations in terms of the extraneous cognitive load by showing the virtual process environment beforehand.

$$H_{1.2} : \mu_M \neq \mu_T$$

It is assumed that process models depicting the respective business process contribute to a reduced extraneous cognitive load as this cognitive load reflects the instructions design and thus a process model is presumed to be more representative (e.g., process logic is clearer as it is represented through arcs). Furthermore, the virtual process environment is visualized as well the respective process model and therefore it may facilitate the information processing.

[1] M = Process Model, T = Textual Process Description

Germane Cognitive Load:

Does the application of a virtual environment have an effect on the germane cognitive load during the comprehension of different process documentations??

$H_{0.3}$: There is no significant difference between the different process notations in terms of the germane cognitive load by showing the virtual process environment beforehand.

$$H_{0.3} : \mu_M = \mu_T$$

$H_{1.3}$: There is a significant difference between the different process notations in terms of the germane cognitive load by showing the virtual process environment beforehand.

$$H_{1.3} : \mu_M \neq \mu_T$$

As it is presumed that a graphical process notation is positively more affected by the virtual process environment in terms of the extraneous cognitive load than the textual notation, it implies that the freed resources will be used for deep learning which is subject to the germane load and thus more resources may be available for the process models.

Constructed Hypotheses based on RQ 2:

Both alternatives (process model and process model extended with graphics) will be analyzed with respect to the different cognitive load types as well.

Intrinsic Cognitive Load:

Does the application of additional graphics have an effect on the intrinsic cognitive load during the comprehension of a process model?

$H_{0.4}$: There is a significant difference between the different process models in terms of the intrinsic cognitive load.[2]

$$H_{0.4} : \mu_M \neq \mu_{MG}$$

$H_{1.4}$: There is no significant difference between the different process notations in terms of the intrinsic cognitive load by showing the virtual process environment beforehand.

[2]MG = Process Model extended with Graphics

$$H_{1.4} : \mu_M = \mu_{MG}$$

No significant difference is expected in terms of the intrinsic cognitive load as both process models deliver identical information.

Extraneous Cognitive Load:

Does the application of additional graphics have an effect on the extraneous cognitive load during the comprehension of a process model?

$H_{0.5}$: There is no significant difference between the different process models in terms of the extraneous cognitive load.

$$H_{0.5} : \mu_M = \mu_{MG}$$

$H_{1.5}$: There is a significant difference between the different process notations in terms of the extraneous cognitive load by showing the virtual process environment beforehand.

$$H_{1.5} : \mu_M \neq \mu_{MG}$$

Despite the fact that the virtual process environment that will be displayed as a video may enhance the internal representation [82], information is not retained from a long-term perspective due to its transient nature [83]. Hence, the additional graphics included in the process model could ease the human mind and less mental effort is required. Nonetheless, as more graphics representing the same information is included, it may possibly lead to an overload of information and consequently require to process more information simultaneously as well (i.e., linking video sequence with respective graphics and process elements together).

Germane Cognitive Load:

Does the application of additional graphics have an effect on the germane cognitive load during the comprehension of a process model?

$H_{0.6}$: There is no significant difference between the different process models in terms of the germane cognitive load.

$$H_{0.6} : \mu_M = \mu_{MG}$$

$H_{1.6}$: There is a significant difference between the different process notations in terms of the germane cognitive load by showing the virtual process environment beforehand.

$$H_{1.6} : \mu_M \neq \mu_{MG}$$

On the one hand, in the extended process model, the germane cognitive load could be higher, as it will engage the motivation to comprehend the process model and raise curiosity about how each static picture is linked to the respective process element. On the other hand, the available resources for deep learning are reduced as it is consumed by the additional extraneous cognitive load, due to the additional graphics that may possibly lead to an overload of information.

3.4 Study Setup

After the goals and the objective of the study have been elucidated, it is essential to outline the study setup to guarantee a valid and successful study. The study setup involves the selection of the subjects, the response variables and the utilized instruments and materials.

Selection of Participants

It would be ideal if it were possible to choose a random sample of all business practitioners within the scope of Business Process Management, however this is hardly to achieve. In addition, it is difficult to gather enough domain professionals for the respective study, and hence, for the sake of research, students are invited to participate in the study [84]. It is essential to gather subjects in order to conduct the study and to avoid a cause for failure.

Primarily students, absolving the course Business Process Intelligence at the Ulm University, were invited to participate in the study. The course is predominately designed for master students, therefore it was expected that the students would be fluent in English as the study is held in English. However, as the study was run online, everyone who had access to the study link, had the possibility to participate. No specific restrictions have been made.

Selection of Variables

A study investigates the relationship between two or more variables. There exists two major types of variables that are of interest: the *independent* and *dependent variable* (i.e., response variable) [81]. Further, a variable is "a property or characteristic on which information is obtained" [85] in a study.

Independent Variable:

As shown in Figure 3.1, the independent variable exerts an impact on the dependent variable and its magnitude. These variables may either be controlled or altered in order to study the effect on the dependent variable. Further, the variables that are manipulated over the study are indicated as *factors*. The attributes a factor has are also indicated as levels, thus an independent variable is manipulated by changing its level [81]. Variables that may exert an impact on the response variable without notice from the researcher are referred to as confounding factors. These are linked to the threats to the validity of a study and therefore it is essential to consider the possible confounding factors in terms of the study's performance [84].

Dependent Variable:

The dependent variable is the observed outcome of a study (see Figure 3.1). It is also referred to as the response variable [81]. A study is conducted to analyze the effect that independent variables may have on the observed response variable with respect to its levels [84].

Applied to the study to be conducted, two independent variables are of interest: the *process documentation types* and the *additional usage of static pictures*. The attributes of the first independent variable are: the graphical notation and the textual process description, whereas the second independent variable is differentiated between the existence of static picture in the process documentation. Furthermore, information about the *gender*, *the prior knowledge about Business Process Modeling* and *BPMN 2.0* and

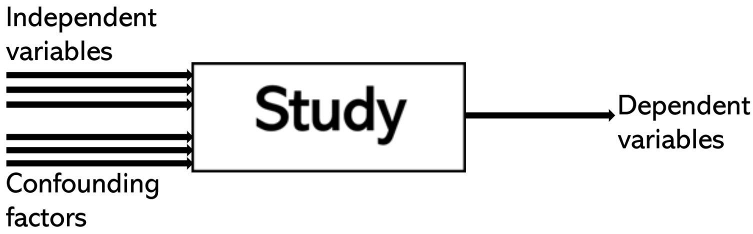


Figure 3.1: Variables in a Study [84] (adapted)

the *gaming experience* is collected and serve as control variables. As the study aims to analyze the usage of a virtual process environment in terms of the cognitive load while comprehending the process documentation, the dependent variables are the cognitive load types: the intrinsic, extraneous and germane cognitive load. To reiterate, Section 2.5 provided a profound outline with respect to the cognitive load.

Selection of Instruments and Materials

Turning now to the utilized instruments and materials, the study was built upon three surveys constructed on the platform SoGoSurvey [86]. This platform has been used as it is practical and has a high ease of use. Each survey consisted of a demographic questionnaire, a questionnaire about the gaming-experience, a video depicting the virtual process environment, a process model (extended with graphics), or a textual process description and a questionnaire in terms of the cognitive load. Considerable attention must be paid when constructing a questionnaire in order to avoid misleading answers, i.e., misleading results [87]. Hence, questionnaires have been used that were utilized in other studies before. The demographic questionnaire is based on the studies of [20] and [43] and was slightly adapted. Personal characteristics in terms of the prior knowledge in particular of Business Process Modeling and BPMN 2.0 were collected. The questionnaire covers in total of 12 questions, which is illustrated in Table 3.1. The values of statements integrating a 7 - Point Likert Scale ranged from *strongly disagree* to *strongly agree*. Further, the gaming questionnaire is based on [20] and has been slightly extended. It summarizes in a total of three questions. One statement included a 7 - Point Likert Scale, which ranged from *strongly disagree* to *completely agree* as well. Table 3.2 provides an outline of the gaming questionnaire.

Question/Statement	Values
Which description matches best your current work status?	Student, Academic, Professional, Other
What is your gender?	Male, Female, Other
Course of studies	User-Defined Text
How many courses related to Business Process Management and/or Modeling have you undertaken in your study so far?	None. One course/discipline. Between two and four courses/discipline. More than four courses/disciplines.
How many process models have you created or edited within the last 12 months?	None. One process model. Between two and four process models. More than four process models.
How many activities did all these models have on average?	I have never worked with business process models before. Between five and fifteen activities. Between fifteen and thirty activities. More than thirty activities.
Do you have working experience related to Business Process Management?	No. Yes, between two and six months. Yes, between six months and a year. Yes, more than a year.
How long ago (months, years) did you start using Business Process Modeling and Notation 2.0 (BPMN 2.0)	I have never used BPMN 2.0 before. Between 1 and 3 months. Between 3 and 6 months. Between 6 and 12 months. More than one year.
Overall I am very familiar with process modeling.	7 - Point Likert Scale
Overall, I am very familiar with the BPMN 2.0 notation.	7 - Point Likert Scale
I feel very confident in understanding BPMN 2.0 process models.	7 - Point Likert Scale
I feel very competent in using BPMN 2.0 for process modeling.	7 - Point Likert Scale

Table 3.1: Demographic Questionnaire

Question/Statement	Values
Are you familiar with video games?	7 - Point Likert Scale
Which platform do you prefer for playing video games?	Computer, Nintendo, PlayStation, Xbox, Other
What is your favorite video game genre?	Action, Action Adventure Adventure, Role-Playing, Simulation, Strategy, Sports, Shooter, Other

Table 3.2: Gaming Experience - Questionnaire

The results in terms of the cognitive load each participant perceived were gathered through a cognitive load questionnaire based on [88]. Table 3.3 illustrates the cognitive load questionnaire which consists of a total of 7 questions. Each question is based on a 7 Likert-Scale ranging from *completely wrong* to *absolutely right*. As the original questionnaire is intended for general use, adaptions to the query of the cognitive load in terms of the process models and to textual descriptions were needed. The Table 3.3 summarizes both variants of the utilized cognitive load questionnaire. Words in brackets apply to the other variant (i.e., participants received the textual description). Participants receiving either the process model or the extended version received the same questionnaire.

CL Type	Statement	Values
ICL	For this process model (textual description), many things needed to be kept in mind simultaneously	7 - Point Likert-Scale
ICL	This process model (textual description) was very complex.	7 - Point Likert-Scale
GCL	For this process model (textual description), I had to highly engage myself.	7 - Point Likert-Scale
GCL	For this process model (textual description), I had to think intensively what things meant.	7-Point Likert-Scale
ECL	During this process model (textual process description), it was exhausting to find the important information	7 - Point Likert-Scala
ECL	The design of this process model (textual description) was very inconvenient for learning.	7 - Point Likert-Scala
ECL	During this process model (textual process description), it was difficult to recognize and link the crucial information	7 - Point-Likert Scala

Table 3.3: Cognitive Load Questionnaire

As in Table 3.3 shown, the cognitive load questionnaire focuses on the measurement of each cognitive load type. Thus, two questions in terms of the intrinsic cognitive load, two questions in terms of the germane cognitive load and three questions in terms of the extraneous cognitive load were constructed.

Turning now to the virtual process environment which is depicted by a video. This video is based on a 3D - game developed by [20] for a study. It was provided by the Information System and Database Department (DBIS). As the study is conducted online, the video is embedded on the respective page on the survey. For the embedding, it was uploaded on Youtube in advance [89]. The copyright holder gave his consent and the uploaded video had restricted access right. Solely viewers with a respective link had access to the video. As the video was embedded on the survey, the subjects in the study also could watch the video. The game describes the typical scenario of warehouse. It begins with a warehouse worker taking a new order (see Figure 3.2) and ends with the loading of the respective goods in the trailer. During the process, the demanding goods must be collected and, inter alia, packed. Further, certain activities may be carried out in a number of ways. For example, the goods may be picked up manually by using the forklift (see Figure 3.3) or automatically by using the automatic picking system instead. The video lasts about 18 minutes and the game was realized in English and therefore the video as well.

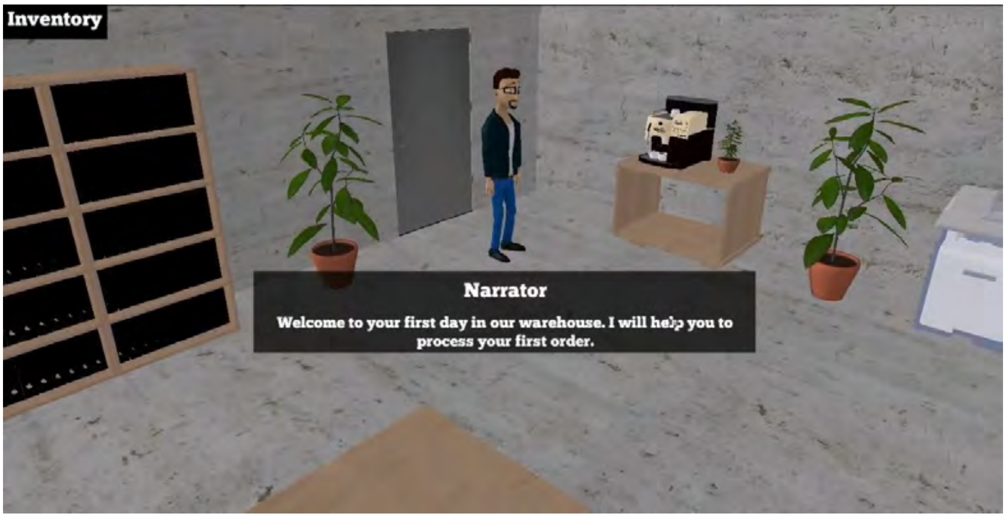


Figure 3.2: Extract from the Video: Starting Sequence

Furthermore, to study the impact of a virtual process environment on process documentation, a process model based on the video was utilized. This process model was provided by the Institute of Information System and Database at the Ulm University as well. As the first research question addresses the effect of process documentation in general, a textual process description based on the process model has been created. To answer the second research question (see Section 3.2) each activity was extended with a static picture extracted from the video. The provided process model included all possible options described in detail. The video describes the possible options of the warehouse worker, however, only the options taken is shown in detail. Therefore, the

Figure 3.3: Extract from the Video: Picking the Goods Using the Forklift

video showed merely a process instance of the resulting process model. In order to not irritate the participants, the process model was recreated in Signavio [90] as the tool supports BPMN 2.0 [41]. BPMN 2.0 was chosen since it is a widespread process modeling language. The activities not shown in the process have been described at an abstract level. Figure 3.4 and Figure 3.5 illustrate the process model of the warehouse scenario. The textual process description and the process model extended with graphics can be viewed in Appendix A.

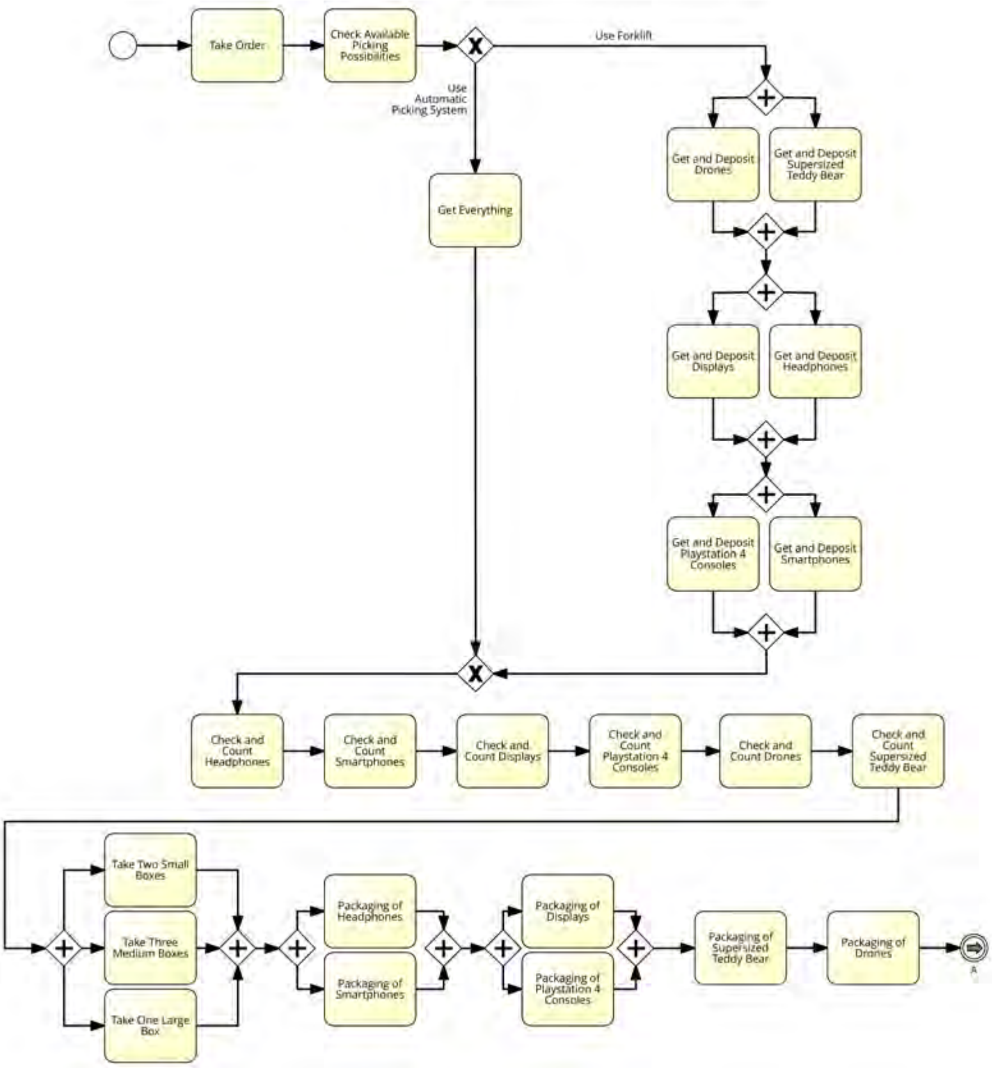


Figure 3.4: Process Model: Warehouse Scenario - Part I

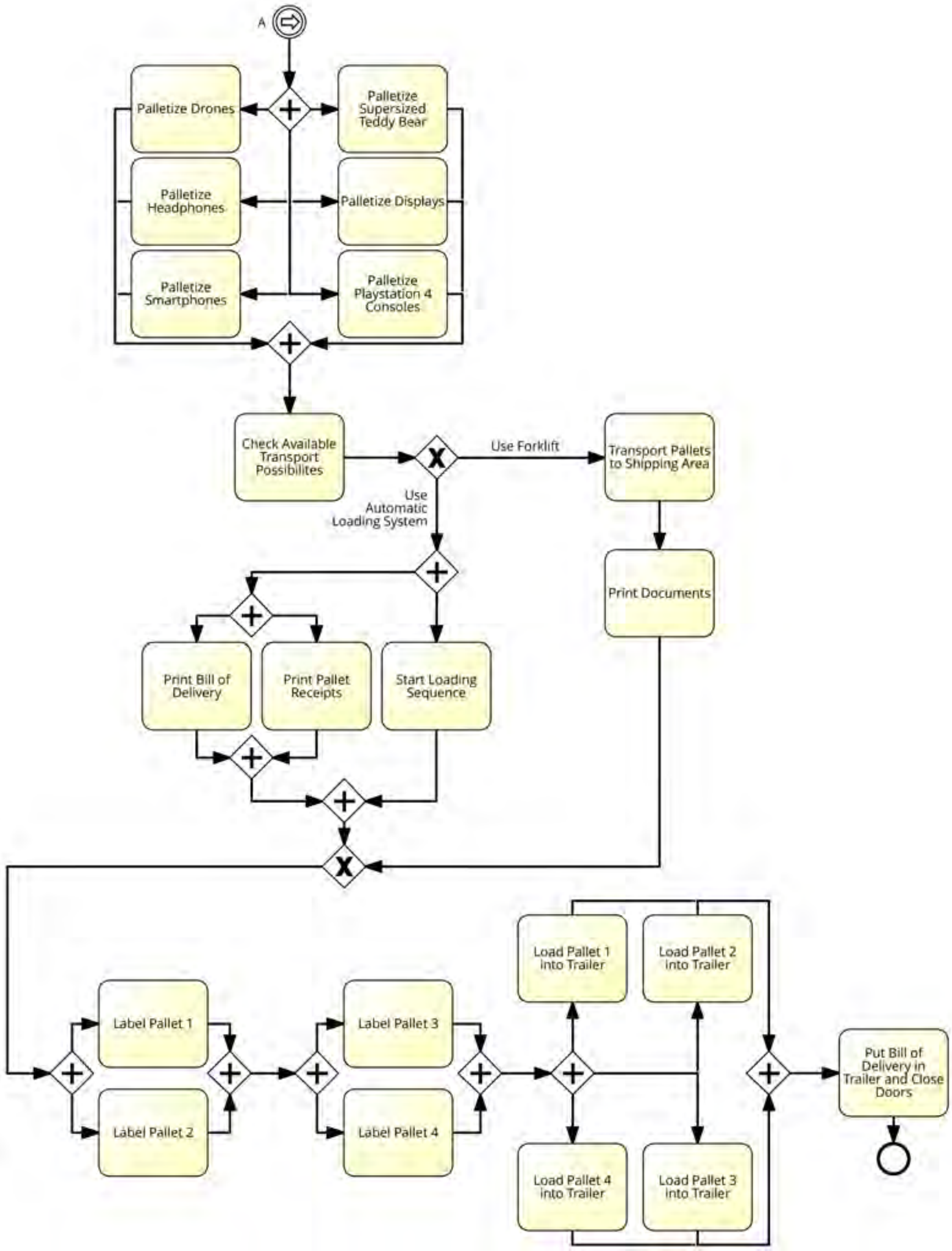


Figure 3.5: Process Model: Warehouse Scenario - Part II

3.5 Study Design

The setup of the study serves as a framework for the study, whereas the study design determines how the respective study is conducted. Therefore considerable attention must be paid when constructing the study design and several design concepts need to be taken into account in order to guarantee valid results, i.e., to inhibit threats to validity. In addition, the statistical methods used to study the results highly depend on the utilized study design [81].

First, used termination in terms of the study design is outlined:

Randomization: Randomization denotes the method by which subjects are randomly assigned to existing groups or treatments [79]. Hence, treatment is referred to as one possible factor variation [80]. Thus, one observed independent variable with a two-level factor will result in two treatments. This design concept is essential to minimize the effect of extraneous variables and undesired biases. Furthermore, with this method, the likelihood of observing uniform groups in terms of the observed and the extraneous variables is higher and serves as a fundamental for the study's validity [79].

Factorial Design: A factorial design is established if two or more variables are observed, i.e. multiple factors, whereas a single-factor design refers to a design in which solely one factor and its levels are studied [85, 91]. When all possible alternatives to the factors are of interest a factorial design is considered. However, as each independent variable may consist of different values the variable may take, it will rapidly lead to an overwhelming number of possible treatments. Thus, two observed factors with a level of three will already lead to the establishment of nine treatments. To overcome this problem a fractional factorial design can be established that studies the characteristics of factors of interest [91].

Interaction Effect: An interaction effect occurs when two or more factors (i.e., independent variables) are analyzed in a study. Thus, it reflects the interaction of the factors. It occurs when the magnitude of one's factor characteristic depends on another factor characteristic that influences the outcome of the response variable [85]. Consequently, while constructing a factorial design attention needs to be paid in terms of the interaction effect.

Between-Subjects: In a between-subject design each subject undergoes solely one treatment whereas the counterpart is the within-subject design. Subjects experience all treatments [92].

As presented in Section 3.4, two independent variables are observed in the study in terms of the impact exerting on the cognitive load (response variable). Therefore, a 2x2 factorial design is established. However, as solely the static picture included in the process model is of interest, only three treatments will be constructed and analyzed. Thus, it's a fractional factorial design. In addition, randomization is considered to ensure equal groups among the treatments. As the study is being conducted online, randomization is applied in the form of a random forwarding the subjects to the respective survey via a website button. Each subject is exposed to one survey (i.e., treatment) and therefore a between-subject design is considered. Figure 3.6 provides a detailed illustration of the procedure. The only aspect that varies between the treatments is the process documentation shown, which is marked blue in Figure 3.6.

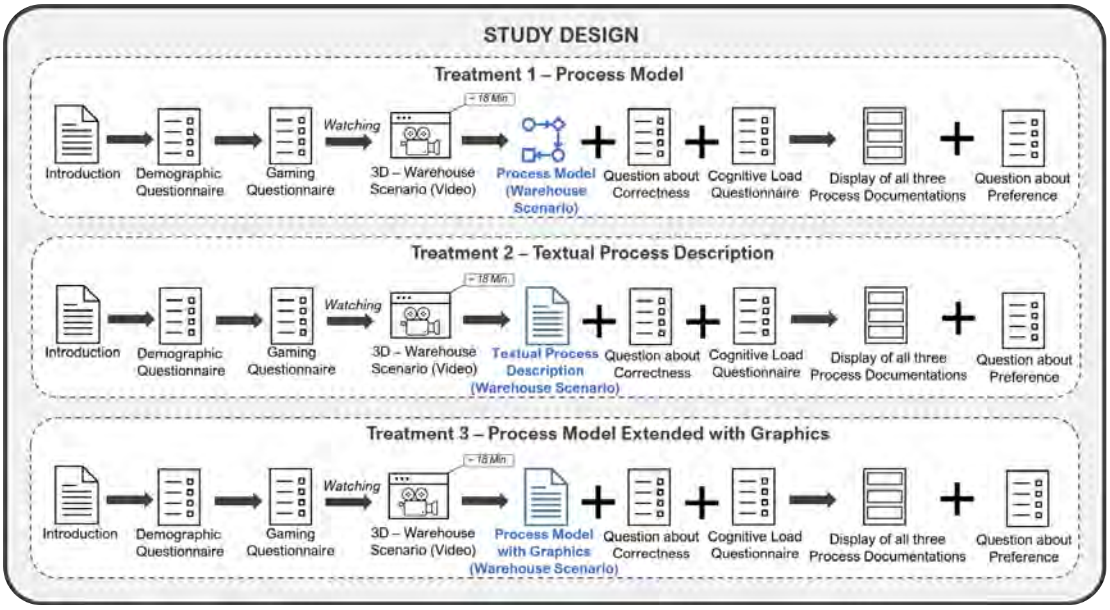


Figure 3.6: Study Design

3.6 Risk Analysis and Migrations

In this section, the threats of the study are evaluated with respect to validity. Validity determines the trustworthiness of the results and drawn conclusions from a study. If a study is not valid, the conclusions and results are probably biased [93]. Therefore, to avoid low validity considerable attention must be paid while planning and designing the study. A study's validity is classified into *external validity*, *internal validity*, *construct validity* and *conclusion validity* [84].

Threats to External Validity: External Validity is given when the results of the study are generalizable in particular with respect to the interested population. In order to ensure the generalization of the results and of the drawn conclusions, it needs to be evaluated whether the sample size is representative and whether the results are representative for the selected target population [84, 94]. As regards the study conducted in this Master's thesis, the subjects are primarily students absolving the course on Business Process Intelligence. It would be ideal to choose business professionals within the scope of Business Process Management, thus this is hardly to achieve. Therefore, students with at least novice knowledge in Business Process Management have been chosen for recruitment as they are easier to gather. Choosing students instead of professionals could be a threat to external validity. However, the findings of [95] indicate that the difference between students and domain professionals in software engineering was not significant and hence students could be used as the sample in the study, rather than domain professionals. In addition, randomization is considered to mitigate biases between groups (i.e., treatments). Another aspect which could be a threat is the utilized process complexity and process domain. The business process model and the deployed video in the study describes a common warehouse process, which is not tied to specific knowledge, but rather intuitive. The process model and the video are thus not complex. The process model contains no loops or sub processes, which might make the process complex. It is linear. However, as the process domain and the process documentation are not complex, it is questionable whether the results can be used to draw conclusions valid on complex process domains. Hence, this study may serve as a fundamental for conducting multiple studies with respect to different process complexity and whether the virtual process environment exerts different impacts depending on the complexity. In addition, the process models were designed in BPMN 2.0. This graphical process notation is a widespread and accepted process model language and notation. Another aspect, which is attributable to external validity is the sample size. 74 students were recruited for the study, which can serve as a representative sample size.

Threats to Internal Validity: Internal Validity is related to the impact of confounding factors affecting the response variables unknown to the researcher conducting the study. Hence, confounding factors present potential threats to the hypothesized cause-effect relationship [84, 94]. As the study is conducted online, the subjects may participate in the study in any environment they wish and thus a history threat may occur. A history threat is concerned with events that occur during the participation which may affect the study outcome [94]. Since it is hard to control the environment in which the participant is during the study, events such as disturbance by other people may occur. A subject, for example, may be disturbed while watching the 3D-Warehouse scenario and thereby may overlook process-relevant information. Consequently, advice to watch the video in an undisturbed area was given in advance to prevent the described history threat. It was assured that the subjects could also pause the video at any point and the video could be fast and forwarded. Furthermore, the characteristics of the subject may vary and could be considered as a threat as students from different courses of studies are able to absolve the Business Process Intelligence course and thus have prior knowledge in particular of industrial experience and BPMN 2.0. Therefore, to mitigate this threat several questionnaires such as the demographic questionnaire and gaming experience questionnaire are applied to obtain personal characteristics. In Section 4.3 the obtained data is validated. In addition, subjects were assigned randomly to the treatments in order to obtain uniformly distributed groups. Another aspect, which could be considered as a threat are the utilized instruments. Poorly designed instruments may negatively impact the response variable [81]. As various questionnaires have been used as measurements, considerable attention must be paid to the questions, as poorly formulated questions can lead to misleading answers [87]. Therefore, questionnaires were utilized which were applied in other studies before. The video showed every possible activity, i.e, option, that could be taken, however only the chosen option in the video was shown in detail.

Furthermore, the video was shown in an appropriate speed. The process model (also extended with graphics) and the textual process description were based on the video. Thus, not selected options were described on an abstract level to avoid irritation among the subject. Furthermore, other factors could influence the cognitive load perceived by the process readers. The structure and design of the process model might affect the extraneous cognitive load as it is related to the design of the instructions (see Section 3.1). The process model is based on the video used in the study of [20] and was provided by the Institute for Information Systems and Databases and therefore has been reviewed in advance. The textual description was generated as neutral and structured as possible to minimize the influence of the formulation and of the structure on the subject. However, external validity must be given in order to establish internal validity, and vice versa [96].

Threats to Construct Validity: Construct Validity is related to the degree to which the operations reflect the theory behind the study [94]. One threat to the study may be caused by the participants. As they are aware that they are participating in a study, their behavior could be affected and therefore they would not act as they would normally. Since the study is conducted online, each participant could choose the time and environment to participate in the study and thereby feel more comfortable as the experimental environment is not present. In addition, participation is anonymised, which increases the likelihood of truthful answers, as there are no possibilities for traceability. Furthermore, a major threat to the construct validity is also posed by the researcher. The researcher may influence the subjects indirectly or explicitly by leading them to a particular response using the formulation of questionnaires. Considerable attention was therefore paid when choosing the right questionnaires for the measurements. It was assured that the measurement applied for the cognitive load types, which serves as the response variables, is defined in an abstract level and thus the subjects could not suspect the response variable being examined.

Threats to Conclusion Validity: Conclusion validity is related to the credibility of the conclusion drawn on the relationship between the observed treatment and the outcome [84]. There exist two types of errors which can be made by a researcher when reaching to a conclusion. Type-I error is concerned with the acceptance of the null hypothesis even though it is false. Choosing high statistical significance (i.e., alpha level) will decrease the type-I error. The counterpart is a type-II error related to the issue of the falsification of a null hypothesis which is true [94]. Therefore, an alpha level of α = .050 was chosen to minimize the threat of hypothesis validity. Furthermore, the experiment design determines which statistical test may be used and vice versa, hence a parametric *one-way analysis of variance (ANNOVA)* test was utilized which is suitable for the established experiment design.

4

Study Operation

In this section, the study operation is elucidated by presenting the preparation and the execution of the study. Before a study may be conducted, considerable preparation must be made in order to ensure a smooth and successful study execution. Further, the collected data is validated in Section 4.3.

4.1 Study Preparation

Before the study's execution, the website (i.e., button) was modified for randomization purposes with respect to the respective survey links representing the three treatments established in the study. Thus, the website function as an intermediate step. Furthermore, a study pilot was carried out in advance in order to test aspects such as data collection, randomization, video functionality and to debug the survey in general. Thus, questionnaires and the study procedure were adapted based on the issues raised during the pilot study. The process models and the textual process description were several times reviewed in order to ensure the quality of the process documentation.

4.2 Study Execution

The study was being executed during the period from 06. June 2020 and 30. June 2020. Students absolving the course Business Process Intelligence were predominantly recruited to participate in the study. For this, the link to the study was published in the respective moodle course [97]. To encourage the participation, the students earned bonus points relevant for the course.

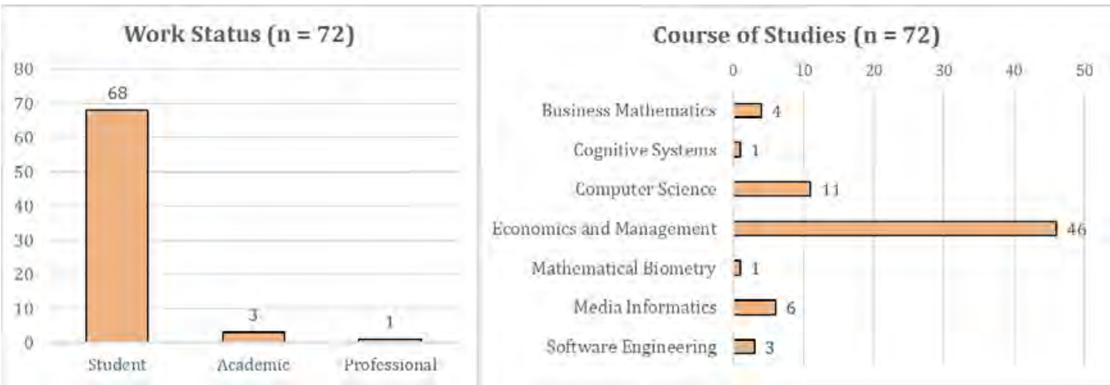
The treatment structure is fairly similar for all treatments. First, personal characteristics are obtained by the utilized demographic and gaming experience questionnaire. Afterwards, the subjects are forwarded to the video of the warehouse scenario. In all three treatments the video is identical. After viewing the video, depending on the treatment, either the initial process model (see Figure 3.4 and Figure 3.5), the textual description (see Figure A.1 and Figure A.2) or the process model extended with graphics (see Figure A.3 and Figure A.4) will be shown to the subjects.

In this section, the cognitive load questionnaire must be answered with respect to the displayed process documentation. In addition, they are asked about the process documentation's correctness. In order to investigate aspects such as the self-assurance, the option "*Unsure*" is included. The only aspect that varies between the treatments is the process documentation shown. After completing the section, the subjects are exposed to all the process documentation observed in this study and have to chose the process documentation that is in their opinion best suited. Subsequently, subjects are asked to generate their individual code as they will receive bonus points for their participation. The study ends with the acknowledgement for the participation in the study. The whole study can be viewed in Appendix B.

4.3 Data Validation and Data Set Reduction

Before the collected data can be analyzed, it needs to be validated. The objective is to check whether the data collected is reasonable and whether errors need to be excluded. An error, for example, relates to subjects who have not seriously completed the survey [81]. A total of 74 persons have participated in the study. However, the data of two subjects had to be excluded from further analysis on the premise that they had not fully completed the survey. Therefore, two outliers have been identified and, thus, data from 72 subjects will be validated in the following.

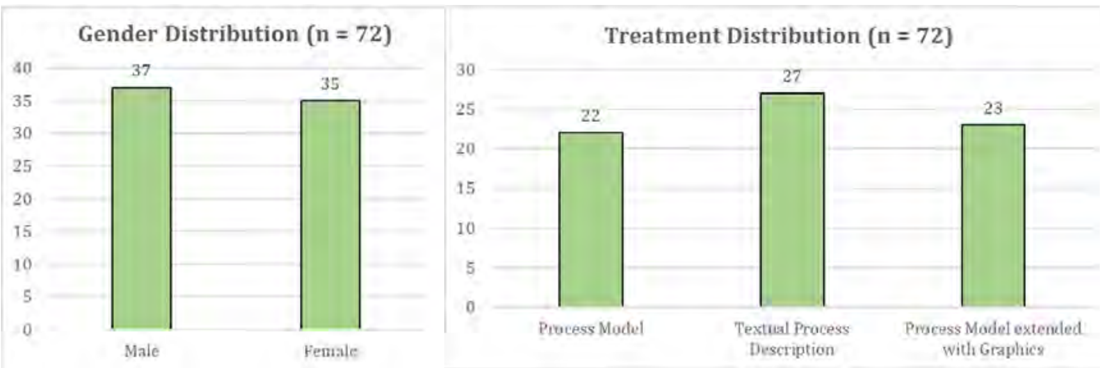
Participants in this study consisted primarily of students (68) of diverse courses of studies (see Table 4.2). The majority of the subjects complete studies in Economics and Management (in total of 46 subjects) as reported in Table 4.2. The respective data is additionally illustrated in Figure 4.1a and Figure 4.1b.



(a) (b)

Figure 4.1: Work Status and Course of Studies

Among the subjects, 37 indicted to be male and 35 to be female (see Table 4.2). The allocation of the gender is, therefore, fairly balanced. In addition, as shown in Table 4.2, the distribution of treatments is as follows: A total of 22 subjects participated in the process model treatments, 27 subjects received a textual process description and 23 participants evaluated the process model extended with graphics. The distribution of gender and treatment are additionally shown in Figure 4.2a and Figure 4.2b.



(a) (b)

Figure 4.2: Gender Distribution and Treatment Distribution

The majority of the subjects recorded having absolved one course/discipline (36 subjects) or between two and four courses/disciplines (27 subjects) related to Business Process Management and/or Modeling. Concerning the modeling experience, around 19 percent of the subjects have never created a process model, and around 83 percent of subjects have stated that they do not have any industrial experience in the field of Business Process Modeling. The majority of the process models created by the subjects had, on average, between five and fifteen activities which contributes to the assumption that the knowledge of process modeling is limited to simplifying business processes. Furthermore, only 13 subjects have never started to use BPMN 2.0 for modeling purposes. With respect to the familiarity with process modeling and the familiarity with BPMN 2.0 Notation, both median (md) values are 5.000, measured on a 7-Point Likert-Scala. In addition, the perceived competence in using BPMN 2.0 for process modeling and the perceived confidence in the understanding of BPMN 2.0 process models provides a median score of 5 as well (see Table 4.1).

	Median
Familiarity with Process Modeling	5.000
Familiarity with BPMN 2.0 Notation	5.000
Perceived Competence in using BPMN 2.0 for process modeling	5.000
Perceived Confidence in understanding of BPMN 2.0 process models	5.000

Table 4.1: Median of Familiarity, Perceived Confidence and Perceived Competence

Turning now to the gaming experience, half of the subjects are slightly to very familiar with video games as the median score is 5.000. According to Table 4.2, 32 participants prefer to play video games on a computer whereas 15 participants indicated to prefer Playstation and, inter alia, 10 subjects are playing on Nintendo.

In terms of the favorite video genre in particular on computers, subjects prefer to play strategy or role adventure game. However, in general there is no genre that stands out. Every genre was chosen, at least once.

Independent Variable	Values	N
Work Status	Student	1
	Academic	2
	Professional	3
Course of Studies	Business Mathematics	1
	Cognitive Systems	1
	Computer Science	2
	Economics and Management	3
	Mathematical Biometry	4
	Media Informatics	5
	Software Engineering	6
Gender	Male	1
	Female	2
Platform for Video Games	Computer	1
	Nintendo	3
	PlayStation	4
	Tablet	5
	Xbox	6
	Other	7

Table 4.2: Results of Frequency Distribution of Data Depending on Different Variables

5

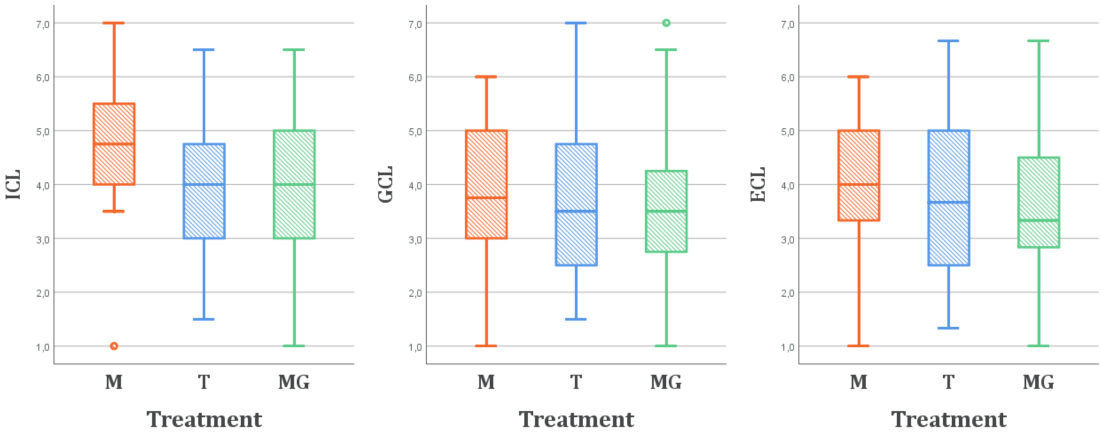
Study Analysis and Interpretation

The output of the study is analyzed and interpreted in this section. First, a raw data analysis is presented and descriptive statistics are reported. Subsequently, the derived hypotheses from the research goal in Section 3.3 are tested for significance. After the analysis of the collected data, a summary is presented followed by the final discussion of the gathered output from the analysis. Finally, in Section 5.4 and in Section 5.4 the limitations and implications of the study are outlined. Data analysis was performed by using *SPSS*.

5.1 Analysis of Raw Data and Descriptive Statistics

Descriptive statistics are concerned with the analysis of the data by plotting and visualizing it in order to obtain an overview thereof. Furthermore, an objective is, inter alia, to detect invalid data points (i.e., outliers) [84]. It is essential for further analysis, in particular for the analysis and interpretation of the data hypotheses, as it is attributable to an understanding of the nature of the data collected.

Descriptive statistics for 72 data points are reported as 72 subjects are considered in this study (see Section 4.3). A boxplot is utilized to analyze the relationship between the treatments and the cognitive load types (i.e., intrinsic, germane, and extraneous). A boxplot represents the dispersion of the data. The rectangle (i.e., the box plot) indicates where 50 percent of the data is located which is also known as the interquartile range. The lower box border represents the first quartile (i.e., 25 percent) and the upper boundary indicates the third quartile (i.e., 75 percent). The whiskers from and to



(a) (b) (c)

Figure 5.1: Boxplot of ICL, GCL and ECL Depending on Treatments

the rectangle display the maximum and minimum score in the data. The outliers are presented as data points outside the whiskers and are considered atypical observations. The value of the median is indicated by the line inside the boxplot.

Turning now to the collected data in the study, based on Figure 5.1a [1] it is noteworthy that the median score for the treatment process model in terms of the intrinsic cognitive load (md = 4.750) differs from the median score of the other treatments (md = 4.000 for both treatments). Furthermore, an outlier is identified for the intrinsic cognitive load. However, the respective observation has not been an outlier for the germane cognitive load and for the extraneous cognitive load. Considering the median score in terms of the germane cognitive load, the result just marginally differs (see Figure 5.1b). Another noticeable aspect is that in general, when reading a process model extended with graphics, the subjects experienced the lowest extraneous cognitive load (md = 3.333) (see Figure 5.1c). On the contrary, the subject who received solely the process model perceived the highest extraneous cognitive load (md = 4.000) and therefore the extraneous cognitive load was 20 percent higher. The mean and the standard deviation for the respective cognitive load types are reported in Table 5.1 for further analysis.

In addition, the subjects also had to answer whether the process model (or the textual process description) corresponds adequately and completely to the process shown in

[1] M = Process Model, T = Textual Process Description, MG = Process Model extended with Graphics

	Treatment	N	Mean	SD
ICL	Process Model	22	4.614	1.214
	Textual Description	27	4.037	1.278
	Process Model with Graphics	23	4.000	1.422
	Total	**72**	**4.201**	**1.318**
GCL	Process Model	22	3.864	1.264
	Textual Description	27	3.539	1.448
	Process Model with Graphics	23	3.457	1.544
	Total	**72**	**3.632**	**1.417**
ECL	Process Model	22	3.909	1.322
	Textual Description	27	3.840	1.559
	Process Model with Graphics	23	3.609	1.369
	Total	**72**	**3.787**	**1.416**

Table 5.1: Descriptives for ICL, GCL and ECL

the video (see Section 3.4). Figure 5.2 illustrates the allocation of the answers provided by the subjects. Nearly half of the participants were confident that the displayed process documentation corresponds adequately and completely with the warehouse scenario seen in the video. Once each treatment is considered individually, it is evident that the subjects were more confident about the process model extended with graphics, whereas the textual process description was classified mostly as inadequate and incomplete.

Treatment	N	Yes	No	Unsure
Process Model	22	9	3	10
Textual Description	27	7	9	11
Process Model with Graphics	23	16	2	5
Total	**72**	**32**	**14**	**26**

Table 5.2: Allocation of Answers in terms of Correspondence

Table 5.3 represents the summary of responses to the preference of a specific process documentation differentiated between the treatments. According to Table 5.3, the majority chose the process model as their favorite. A small minority indicated their preference for the textual process description.

As interaction effects are of interest, a median split was conducted to divide the sample size into groups based on the gaming experience and on the business process modeling experience as well. The median is, therefore, considered as a reference point for dividing the data set into two classes. In view of the gaming experience, the median score

Treatment	N	Process Model	Textual Process Description	Process Model with Graphics
Process Model	22	11	3	8
Textual Description	27	19	1	7
Process Model with Graphics	23	14	1	8
Total	**72**	**44**	**5**	**23**

Table 5.3: Summary of Results for Preference

of the familiarity with video games was chosen to divide the groups into *low gaming experience* and *high gaming experience* (md = 5.000). With respect to the business modeling experience, the split was based on the median of the created and/or edited process models over the last 12 months (md = 2.000) and was also split into *high* and *low* groups. The values were measured on an ordinal scale ranging between 0 and 4. Table 5.4 represents the distribution of the identified high and low groups.

Gaming Experience	N	Values
low gaming experience	43	$\leq$ 2.000
high gaming experience	29	$>$ 2.000
Business Process Modeling Experience		
low modeling experience	39	$\leq$ 5.000
high modeling experience	33	$>$ 5.000

Table 5.4: Distribution of the Groups

Furthermore, Table 5.5 reports the descriptives for the score of the intrinsic, germane, and extraneous cognitive load differentiated between the high and low groups considering the gaming experience. Interestingly, there is a difference between the groups in terms of the intrinsic cognitive load. The group with low gaming experience therefore experienced

	Group	N	Mean	SD
ICL	low gaming experience	39	4.385	1.227
	high gaming experience	33	3.985	1.406
GCL	low gaming experience	39	3.692	1.360
	high gaming experience	33	3.561	1.499
ECL	low gaming experience	39	3.949	1.390
	high gaming experience	33	3.596	1.442

Table 5.5: Descriptives for High and Low Gaming Experience

a higher intrinsic cognitive load (mean of 4.385) overall compared to the group with high gaming experience (mean of 3.985). In addition, the high gaming experience group experienced in general a lower extraneous cognitive load relative to subjects with low gaming expertise. Turning now to the modeling expertise, the descriptives are presented in Table 5.6. Generally speaking, the mean score of each cognitive load type is lower for participants with high modeling expertise.

	Group	N	Mean	SD
ICL	low modeling experience	43	4.395	1.370
	high modeling experience	29	3.914	1.203
GCL	low modeling experience	43	3.756	1.548
	high modeling experience	29	3.448	1.198
ECL	low modeling experience	43	3.915	1.427
	high modeling experience	29	3.598	1.401

Table 5.6: Descriptives for High and Low Modeling Experience

Differences in the data have been identified, however they need to be tested for significance.

5.2 Hypotheses Testing

Hypotheses Testing is concerned with determining the significance of null hypotheses. Constructed hypotheses in Section 3.3 will therefore be tested. As mentioned before (see Section 3.6), a significance criterion (i.e., alpha level) of α = .050 is selected. There are various statistical tests for hypotheses. Hence, a parametric *one-way ANNOVA* test is applied. The one-way ANNOVA test compares the mean of at least two samples [81] and is therefore suitable for the experimental design in the study as three groups are studied.

First, used termination in terms of the hypotheses testing is outlined. Observed differences are considered to be significant if the *p-value* is within the defined significant criterion. As the significance level is set to .050, the p-value should therefore be lower than the level. The p-value is also defined as *p*. In addition, a test's *power analysis* is related to the probability of rejecting the null hypothesis and thus finding statistical significance results when one actually exits. Power-Analysis was performed by using *G*Power* [98]. The effect size reflects the magnitude of an effect exerted by independent variables on the response variable. Thus, it describes the effect of a phenomenon. Effect sizes are important since, for example, a finding may be significant, but its effect is so minimal that it is considered trivial [99]. Various effect sizes are used for different statistical tests. Effect sizes d and f are hence considered for the respective analysis. According to [99], the effect size d of .800 and the effect size f of .400 are classified as large and therefore the effect of .800 and .400 is used for further analysis, such as estimating the necessary sample size for significance given the desired effect and power.

Intrinsic Cognitive Load:

In terms of the intrinsic cognitive load, the analysis did not show any significant differences (F(1.580) = 2, p = .213) among the process documentations. Thus, the null hypothesis $H_{0.1}$ and $H_{0.4}$ are accepted.

Extraneous Cognitive Load:

None of these differences in terms of the extraneous cognitive load were statistically significant (F(.277) = 2, p = .759). As the p-value is greater than the significance level, the alternative hypotheses $H_{1.2}$ and $H_{1.5}$ are rejected, and therefore $H_{0.2}$ and $H_{0.5}$ are accepted.

Germane Cognitive Load:

There were no significant differences (F(.474) = 2, p = .625) between the treatments with regard to the germane cognitive load. The null hypotheses $H_{0.3}$ and $H_{0.6}$ are not refuted.

As no significance was identified, no posthoc test for multiple comparisons considering Bonferroni was applied. Table 5.7 summarizes the results of hypotheses testing.

Response Variable	**Differences**	**P-Value**	**Significance**
intrinsic cognitive load	between groups	.213	No
extraneous cognitive load	between groups	.759	No
germane cognitive load	between groups	.625	No

Table 5.7: Results of Test of Significance (One-way ANNOVA)

In addition, it was also of interest to study whether the expertise in terms of gaming and modeling experience has an impact on the perceived cognitive load regardless of the process documentation. The *parametric two-sample t-test* is applied to analyze the difference between independent variables, which compares the population mean of two unrelated groups for significant differences [91]. The test is also known as the independent t-test.

Gaming Expertise:

According to the descriptive statistics provided before, the means for each cognitive load type was lower for the high gaming experience group relative to the low gaming experience groups. As the study was an exploratory one, a *two-tailed t-test* was applied. However, the analysis did not show any significant differences for the intrinsic (t(1.288) = 70, p = .202)), extraneous (t(1.054) = 70, p = .295) and germane (t(.391) = 70, p = .697) cognitive load. Further, equal variance was assumed as the *Levene's test for equality of variance* was not significant for all three response variables (i.e., intrinsic (p = .776); extraneous (p = .320); germane (p = .867). Therefore, no statistical differences have been detected and thus the variations are attributable to random occurrence.

Business Process Modeling Experience:

Considering the descriptive statistics with respect to the modeling expertise, the two groups differ in all three types of cognitive load. The high modeling experience group experienced less cognitive load as opposed to the low modeling experience group, as well. However, none of these differences in terms of the cognitive load types were statistically significant (i.e., intrinsic (t(1.535) = 70, p = .129); extraneous (t(.931) = 70, p = .355); germane (t(.902) = 70, p = .370). According to *Levene 's test*, the study showed that equivalent variance could be assumed for intrinsic (p = .718), extraneous (p = .931) and germane cognitive load (p = .901). Table 5.8 reports the results of the test for significance, applying the two-sample t-test for both area of expertise.

	Response Variable	P-Value	Significance
Gaming Expertise	ICL	.202	No
	ECL	.295	No
	GCL	.697	No
Modeling Expertise	ICL	.129	No
	ECL	.931	No
	GCL	.901	No

Table 5.8: Results of Test for Significance (Two-Sample T-Test)

Self-Confidence and Preference for Process Documentation:

As noted before, a tendency about the self-confidence of subjects about the completeness and adequateness of the process documentation were found (see Table 5.2). Therefore, the textual process description was most rated as false whereas the process model extended with graphics were procentually most rated as to correspond the process warehouse scenario. It is of interest whether an association between the process documentation and the self-confidence may be concluded. To test the findings for significance, a nonparametric *likelihood-ratio chi-quare test of independence* is applied. A chi-square test analyzes the association between two categorical variables and is based on data displayed as frequencies, thus it is suitable for the respective data set (see Table 5.2) [100]. This test is conducted in terms of the findings of preference as well.

According to the analysis, it can be concluded that an association between the self-confidence about the process documentation and the treatment exists (χ^2(4) = 11.834, p = .019). *Cramer's V* effect size is considered as categorical variables with more than two characteristics are considered in this analysis. As shown in Table 5.9, the Cramer's V effect size is .287 (p = .019) which can be converted into the *w index* of [99] resulting in w = .406. The magnitude of the respective w is classified as a moderate effect (.300 $\leq$ w $<$ .500) [99, 100]. Comparing the standardized residuals, reported in Table 5.10, one can suggest that the confidence about the completeness and adequateness of the process model extended with graphics shows the strongest difference. Therefore, more subjects were confident about that process model than expected. In addition, subjects were more confident about the incompleteness and inadequacy of the textual process description, thus it was not false.

Association	P-Value	Cramer's V		w
		effect size	p-value	
Self-Confidence - Treatment	.019	.287	.019	.406
Preference - Treatment	.524	.153	.498	.216

Table 5.9: Results of Test for Significance (Likelihood-Ratio Chi-Square Test)

		Yes	No	Unsure
Treatment	Process Model	-.200	-.600	.700
	Textual Process Description	-1.400	1.600	.400
	Process Model extended with Graphics	1.800	-1.200	-1.100

Table 5.10: Standardized Residuals of Self-Confidence and Treatment)

Turning now to the findings with regard to the preference, no statistical significance (χ^2(4) = 3.203, p = .498) could be identified. Therefore, no association between the preference for a process documentation and treatment exists.

Interaction effects:

Furthermore, it is of interest whether there is an interaction effect between the expertise (i.e., modeling and gaming experience) and the treatments. As explained in Section 3.5, if more than two independent variables are observed and one independent variable influence on the response variable is dependent on another independent variable attribute, an interaction effect may occur. It is therefore studied whether the impact of certain process documentation (i.e., treatment) depended, for example, on the level of expertise that a subject has and vice versa. A *multiple linear regression model* is applied to analyze potential interaction effects. The regression model results are reported in Table 5.11[2].

Model 1 and model 2 refer to the intrinsic cognitive load as the response variable, model 3 and 4 are concerned with the extraneous cognitive load and model 5 and 6 analyze the germane cognitive load. Thereby, measures of interest are the interaction terms *Gaming Experience*Treatment* and *BPM Experience*Treatment*. According to Table

[2]The predictors are coded as follow: Treatment (0 = Process Model, 1 = Textual Process Description, 2 = Process Model extended with Graphics); Gaming Experience (0 = low gaming experience, 1 = high gaming experience); BPM Experience (0 = low modeling experience, 1 = high modeling experience)

	Coefficients (p-value)					
	ICL		ECL		GCL	
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment	-.249 (.327)	-.319 (.176)	-.144 (.604)	-.073 (.778)	-.227 (.416)	-.186 (.470)
Gaming Experience	-.246 (.626)		-.307 (.570)		-.199 (.721)	
*Gaming Experience * Treatment*	-.201 (.616)		-.064 (.874)		.038 (.931)	
BPM Experience		-.523 (.323)		-.058 (.920)		-.248 (.669)
*BPM Experience * Treatment*		.034 (.936)		-.261 (.574)		-.064 (.890)

Table 5.11: Interaction Effects between Expertise and Treatments

5.11 no significant interaction effect for the intrinsic (p = .616), extraneous (p = .874) and germane cognitive load (p = .931) between the gaming expertise and treatment is identified. In addition, in terms of the interaction effect, the analysis did not show any significant effect between the business process modeling experience and treatments with respect to the intrinsic (p = .936), extraneous (p = .573) and germane cognitive load (p = .890). Taken as a whole, the analyzes did not detect any significant interaction effect and thus no dependency between the expertise and treatments exists in this experiment.

Power Analysis and Estimated Sample Size:

No significant differences were identified in the prior analysis. However, it is likely that there is a phenomenon that could not be detected due to insufficient sample size and/or low power. The power of the test depends on various factors, such as the size of the sample, the variance in the size of the sample, the level of significance chosen and the effect size [101].

Of interest are in particular the differences between the treatments with regard to the intrinsic and extraneous cognitive load and the impact of the level of business process modeling expertise on the cognitive loads as the subjects with a high level of expertise experienced in general a lower cognitive load relative to the low expertise group. The differences for each cognitive load type in terms of the process documentation utilized were analyzed with the one-way ANNOVA test. In order to analyze whether no significant results could be yield owing to low power, a retrospective power analysis is conducted. To estimate the power of the respective test, the effect size f is required and calculated. The effect sizes, the power and the necessary sample sizes are reported in Table 5.12. According to Table 5.12 the power analysis for the one-way ANNOVA test in terms of the intrinsic cognitive load reported a power of 33.655 percent with an effect size f of .214 which is classified as a small effect according to [99]. Further, the power-analysis of the one-way ANNOVA test with regard to the extraneous load showed a power of 9.409 percent. The respective effect size f is .090, which is considered as trivial. Generally speaking, it was unlikely that the tests would be able to detect significant results on the basis of such low power. The essential size of the sample is hence estimated by a power of .800 and the desired effect of .400. The minimum sample size required consists of 66 subjects. Thus, the population in this study consisted of 72 subjects and exceeded the essential threshold, however the effect size of the test is low.

Furthermore, the effect of a phenomenon tested with a two-sample t-test is indicated by the effect size d [99]. Hence, the statistical analysis of the impact of modeling experience on the different cognitive loads resulted in an effect size d of .373 with a power of 33.441 percent for the intrinsic, an effect size d of .224 with a power of 15.123 percent for the extraneous and an effect size d of .222 with a power of 14.967 percent for the germane cognitive load. Taken as a whole, the likelihood of rejecting the hypothesis is low and all the reported effect sizes d are considered to be small effects. The minimum sample size given an effect size d of .800 and a power of .800 is 52. Thus, the sample size in this study exceeded the necessary size, but the effect size is low which contributes to the low power. The results of the power-analysis and of the estimation of the sample sizes are reported in Table 5.12 as well.

	Test	**Effect Size**	**Power**	**Estimated Sample Size**
ICL - Treatment	One-way-ANNOVA	.214	.337	66
ECL - Treatment	One-way-ANNOVA	.090	.094	66
ICL - Modeling Expertise	Two-Sample T-Test	.373	.334	52
ECL - Modeling Expertise	Two-Sample T-Test	.224	.151	52
GCL - Modeling Expertise	Two-Sample T-Test	.222	.150	52

Table 5.12: Results of Power-Analysis and Estimation of Sample Sizes

5.3 Summary and Discussion

In summary, the findings of the study show that the type of process documentation does not affect the cognitive load after experiencing a virtual process environment. The aim of the study was to provide insight into the research questions raised in Section 3.2. As a result, with respect to *RQ 1*, no significant differences between the process notations could be identified in the analysis and, in addition to *RQ 2*, the analysis did not indicate any significant differences between the impact of process model and process models extended with graphics on the intrinsic, extraneous and germane cognitive load.

As assumed, no differences were identified between the process documentation with respect to the intrinsic cognitive load, as all three process documentation deliver identical information. Contrary to expectations, the study did not find any substantial differences between the process documentation in terms of the extraneous load. As the extraneous load is concerned with the design of the instruction (i.e., information), a difference was expected to be found between the documentation of the process as all three variations display different information presentation. The findings, however, lead to the conclusion that a process model, a textual process description and a process model extended with graphics generally exert the same external cognitive load after watching the related virtual process environment. Thus, none of the process documentation increased or decreased the cognitive load and therefore facilitated the information processing. Consequently, this also leads to another conclusion that the additional graphics in the process model will not have an detrimental impact on the cognitive load. One possible reason for a negative aspect might be that the additional static pictures increase the interactivity of the element, since the information on the graphics also needs to be considered and linked to the video shown before. Nonetheless, one could have expected a positive effect: when key information is again presented with graphics, it might have facilitated the memory. Interestingly, no significant differences were found with respect to the germane cognitive load, and thus the slight differences are attributed to random occurrence. One assumption for the static image to raise the germane cognitive load may be that subjects could be inspired to understand how the graphics and process elements are connected together, thus that is not the case.

Generally speaking, based on the findings two assumption may be suggested:

- The video results in that the cognitive load exerted by the different process documentation is not significant different from one another.
- The video has no effect on the cognitive load exerted by the different process documentation and the cognitive load alone does not vary sustainably.

It is therefore of interest how the results would have been when there was no virtual process environment considered.

Considering the expertise in business process modeling, it is surprising that there are no notable differences in the impact on intrinsic cognitive load, as the expertise can influence the intrinsic cognitive load as stated in [56]. Consequently, the high modeling group with extensive prior knowledge would have stored the respective knowledge as schemas enabling the respective knowledge to be treated as one information. The group with high expertise would therefore have experienced less intrinsic cognitive load in terms of the complexity of the process documentation. In addition, the analysis detected no significant differences between the level of gaming expertise on cognitive load. This leads to the assumption that, regardless of the gaming expertise, the virtual process environment and subsequently the process documentation are perceived the same way. However, given that the findings are based on a demographic questionnaires including only three question about the gaming expertise, the results should be treated with a considerable caution.

With regard to the stated preference for a process documentation, no association can be concluded between the treatments and the participant's preference for one as no substantial differences have been analyzed. Thus, the frequencies distribution, displayed in Table 5.3, is attributed to random occurrence. Interestingly, a significant association has been detected in terms of self-confidence and treatments. The process model extended with graphics was thus mostly graded as a complete and adequate correspondence of the warehouse process in the video. Following the findings, one can conclude the following assumptions: Self-confidence was increased, because

- each process activity was enriched with a static picture and this lead to the assumption the displayed process must be correct.

- wrong activities had to be enriched with false static picture, which was possibly not expected by the participants.

In addition, the textual process description was more rated as false among all process documentation. This result can be explained by the different degree of abstraction that the participants have and the process formulation could have been interpreted differently.

Through qualitative research, the current results could have been expanded by asking the respondents why they chose the respective answer. Aspects regarding further scientific research are discussed in Section 7.

Further, interaction effects have been studied as well. It was therefore of interest if the degree of expertise and the treatment are interdependent and whether the interaction had an effect on the outcome. However, the study showed no significant interaction effect, leading to the conclusion that the magnitude of the intrinsic, extraneous and germane cognitive load imposed by the treatment is not dependent on the expertise and vice versa.

Overall, the investigations so far have been applied to a small sample size and thus the apparent lack of correlation can be attributed to the low sample size and to the low power of the tests as well. Furthermore, the environment in which the study was conducted could not be completely controlled and this could affect the validity of the results. Hence, further studies need to be conducted and this study can serve as a fundamental.

5.4 Limitations

It is plausible that a number of limitations might have influenced the results obtained. First, the study was conducted online. The environment could therefore not be completely controlled and the participants could have encountered disruption during the study, which could have influenced the cognitive load. Another potential source of error is that with regard to the preference query, the three types of process documentation were always shown in the same sequence. Unfortunately, it was not possible to further investigate the significant relationship of the subject's self-confidence and the treatments due to the fact that the study was focused solely on the investigation of the process reader's cognitive load. Furthermore, the virtual process environment was limited to a video based on a game. Therefore the gameful-experience could not be fully considered as the game was not played by participants. Since participants just watched the video and could not play the game, the length of the study may have affected the participants' interest and motivation more.

5.5 Implications

Since the results suggest that no substantial difference exists between the process documentation in terms of cognitive load after experiencing the virtual process environment, it can be inferred that a virtual process environment may thus be created in practice where both the textual process notation and the graphical process notation are used in particular. In addition, after seeing the video, process readers were more confident of the correctness and adequacy of the process model. Thus, a virtual process environment can be considered in particular with process models. It can be used when testing the accuracy of a process model, because after experiencing the virtual process environment the process readers are more confident to process models. However, contrary to [56], the study results showed as stated before that no significant difference was observed in the business process modeling experience in terms of the cognitive load. Process readers with different modeling expertise experience the same cognitive load after watching the video. As process readers are from various fields of practice, such as process analysts and domain experts, modeling expertise differs and therefore a virtual process environment can be considered before reading the respective process model [3].

6 Related Work

Research has tended to concentrate on gamification with respect to Business Process Modeling and Management rather than in conjunction with cognitive load theory. Therefore, research related to the three domains and intermediated research is listed in this section, which is also mainly referred to in this master thesis.

Gamification is used in Business Process Management in various ways: for educational aspects, extension of concepts and for practical implementations. For example, IBM Innov8 was developed with the aim of teaching BPMN 2.0 using a 3D virtual environment. In the game, the player has been hired to evaluate and optimate existing processes. Those processes represents real-life scenarios [7]. Studies have shown that students acquired knowledge of BPMN 2.0 faster than traditional methods [61, 62]. Thus, the incorporation of gamification into the management of business processes has the potential to have positive results. However, gamification is a widespread domain. Besides the utilization of a virtual environment, gamification consists of the use of game-mechanics as well. [44] for example, proposed a BPMS-Tool known as Horus Gamification. It considers game-mechanics such as ranking, leader boards and points which employees may collect on the basis of the quality of their process models. Furthermore, [64] suggested the expansion of BPMN 2.0, including gamificiation elements such as levels, leader boards, points, etc. In terms of process model comprehension, *Tales of a Knightly Process* has been developed to study whether the game promotes the comprehension of process models. The findings indicated an increase of process comprehension attributable to the use of the game. In addition, it has been shown that the complexity of the process model has an effect on comprehension [9]. The virtual process environment utilized in this research is based on the game reported in [20]. [20] presents a gamification approach to analyze the impact of social distance on the granularity, qualitiy and strucutre of BPMN 2.0 process models. Gamification has already been used and researched in the sense of Business Process Management for various reasons, but the effect on cognitive load by gamification has scarcely been considered.

Taken a step back, a 3D virtual process environment depicted as a video can be seen as an intercept between an animation and gamification. [32] points out why it is reasonably to use simulation (i.e., animation) which are displayed in a 2D or 3D environment. Accordingly, the author notes that the reason for animation is that the processing of graphical information takes place preconciously comparable with breathing. In terms of 3D process visualization, [102] presents the interactive tool 3D Flight Navigator that analyzes and displays business process models in a 3D virtual environment while providing an heads-up display. Furthermore, gamification is cloesely linked to virtual reality, which takes a new perspective on the use of virtual environments. The authors of [103] introduced a VR-BPMN concept and developed a prototype based on immersive business process diagrams experience. In addition, a remote collaborative process modeler was implemented by [104] considering augumented technology in a collaborative virtual environment. In terms of the cognitive processes with regard to Business Process Modeling and Management, research has mainly concentrated on the cognitive load a process noation exerts itself. [72] for example conducted an eye-tracking study to examine the cognitive load of business process models using different modularization approaches for BPMN 2.0 diagrams. [17] formally analysis various graphical process notations (i.e., Petri Nets, BPMN 2.0, Event-driven Process Chains (EPC)). BPMN 2.0 exerts the least cognitive load, based on the authors' study. Another study with respect to cognitive load is conducted by [105], which analyzes the effect of *swimlanes* in BPMN process models.

With regard to research on textual and graphical process notations, the use of textual process descriptions and process models in practice in software engineering has been analyzed by [33]. Therefore, textual process description is used in addtion to describe the details of a process and should thus be considered in analysis as graphical and textual process notation has both strength and weaknesses. [43] studied whether textual process notation or graphical process notation is better for process comprehension.

According to their findings, no substantial differences could be detected for novice process readers whereas the graphical notation facilitate the process understanding for experienced process readers.

In contrast to the stated above, the master thesis analyzes the impact of gamification on the cognitive load while understanding the process documentation. [22] and [23] delivers an thorough overview of human visual perception which is essential for the visual information processing. To gain a deeper insight into the cognitive load theory [53], [56] and [52] are recommended.

7

Conclusion and Future Work

This master thesis has investigated the impact of a virtual process environment on the cognitive load that the process reader perceives during the comprehension of a process model. An online study with 72 participants was conducted to receive insights into the research questions. Of interest was the impact on the cognitive load of a textual process description, a process model and a process model extended with graphics which is based on the virtual process environment. The treatments were assigned to the participants at random. Since three variants of process documentation were analyzed, three treatments, each representing a process documentation, were defined. First, a video was watched by the subjects. The video is based on a game in a virtual 3D environment so it is referred to as a virtual process environment. A process documentation of the 3D warehouse scenario was subsequently demonstrated for the subjects followed by a questionnaire assessing the cognitive load of the respective process documentation. In addition, subjects were asked about the adequacy and completeness of the respective process documentation in order to study the subjects' self-confidence regarding the process. Finally, the preference for a certain process documentation was obtained by displaying all three documents to the subjects and asking which one they prefer.

In conclusion, the findings indicate that there are no significant differences between the process documentation in terms of cognitive load after the video has been shown. As little research has been done in this area, these findings are left to interpretations and assumptions and further investigations are thus needed. Considering the findings, the question arises as to whether the virtual process environment does not lead in any differences between the process documentation or whether the respective virtual environment does not provide an impact on the process documentation. The present research examined the cognitive load only after having experienced the virtual process environment. Consequently, based on this study, the question posed cannot be answered. Nevertheless, further findings in this study suggest an correlation between the self-confidence about the adequacy and completeness of the process documentation and the process documentation displayed. Process readers were more confident about the correctness and adequacy of the process model extended with graphics whereas the textual process description was mostly regarded as incorrect. Further work needs to be done to establish transparency in terms of the association of a process documentation and the process reader's self-confidence. No notable results were found in light of the relationship between the process reader's preference and process documentation (i.e., treatments). In addition to the research so far, the effect of modeling and gaming experience on cognitive load styles has also been investigated. The respective findings did not result in any noteworthy outcome.

With respect to potential future work, this research has given rise to many questions in need of further examination. In terms of the cognitive load, it is of interest as stated before how the cognitive load is effected solely by the virtual process environment. Furthermore, since the participants have only watched the virtual process environment, this work may serve as a fundamental for studying the impact on cognitive load after the game has been played. In addition, the study was based solely on one process that is intuitive and can be seen as rather simple, and thus further studies are needed to examine the effect of a virtual process environment with regard to complexity of the process.

Bibliography

[1] Tory, M., Moller, T.: Human Factors In Visualization Research. IEEE Transactions on Visualization and Computer Graphics **10** (2004) 72–84

[2] Weske, M.: Business Process Management: Concepts, Languages, Architectures, 2nd ed. Springer, Berlin, Germany (2019)

[3] Dumas, M., La Rosa, M., Mendling, J., Reijers, H.A.: Fundamentals of Business Process Management. 2nd ed. Springer, Berlin, Germany (2018)

[4] Dadam, P., Reichert, M., Rinderle-Ma, S.: Prozessmanagementsysteme. Informatik-Spektrum **34** (2011) 364–376

[5] Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., Shankar, R.: Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies. 3rd ed. McGraw-Hill (2008)

[6] Harmon, P., Garcia, J.: The State of Business Process Management 2020. Technical report, BPTrends (2020)

[7] Lali, A.: Play the Innov8 game to learn business process management. (Website) Online available at `https://www.ibm.com/developerworks/library/ws-bpm-innov8/ws-bpm-innov8-pdf.pdf`, last accessed on: 23. April 2020.

[8] Ribeiro, C., Fernandes, J., Lourenço, A., Borbinha, J., Pereira, J.: Using Serious Games to teach Business Process Modeling and Simulation. In: Proceedings of the 96th International Conference on Modeling, Simulation and Visualization Methods (MSV), Las Vegas, USA (2012) 133–139

[9] Winter, M., Pryss, R., Probst, T., Reichert, M.: Learning to Read by Learning to Write: Evaluation of a Serious Game to Foster Business Process Model Comprehension. JMIR Serious Games **8** (2020) e15374

[10] Pflanzl, N., Vetter, A., Hussong, K., Oberweis, A., Schönthaler, F., Vossen, G.: Horus Gamification: Ein Prototyp zum Einsatz von Gamification im Rahmen des

Social BPM . In: Proceedings of the 46th Annual Conference of the German Informatics Society (INFORMATIK), Chemnitz, Germany (2017) 433–438

[11] Mancebo, J., Garcia, F., Pedreira, O., Moraga, M.A.: BPMS-Game: Tool for Business Process Gamification. In: Proceedings of the 16th International Conference on Business Management (BPM) Forum, Barcelona, Spain (2017) 127–140

[12] Deterding, S., Dixon, D., Khaled, R., Nacke, L.: From Game Design Elements to Gamefulness: Defining "Gamification". In: Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments (Mindtrek), Tampere, Finland (2011) 9–15

[13] Putz, L.M., Treiblmaier, H.: Creating a Theory-Based Research Agenda for Gamification. In: Proceedings of the 21th Americas Conference of Information Systems (AMCIS), Puerto Rico, USA (2015) 3219–3231

[14] Mullins, J.K., Sabherwal, R.: Gamification: A cognitive-emotional view. Journal of Business Research **106** (2020) 304–314

[15] Lumsden, J., Edwards, E.A., Lawrence, N.S., Coyle, D., Munafò, M.R.: Gamification of Cognitive Assessment and Cognitive Training: A Systematic Review of Applications and Efficacy. JMIR Serious Games **4** (2016) e11

[16] Turan, Z., Avinc, Z., Kara, K., Goktas, Y.: Gamification and Education: Achievements, Cognitive Loads, and Views of Students. International Journal of Emerging Technologies in Learning (iJET) **11** (2016) 64–69

[17] Studerus, C.: Kognition im Business Process Management - Konzeption eines optimalen Prozessmodells unter Berücksichtigung kognitiver Fähigkeiten. Master's thesis, Ulm University, Germany (2018)

[18] Tallon, M., Winter, M., Pryss, R., Rakoczy, K., Reichert, M., Greenlee, M.W., Frick, U.: Comprehension of business process models: Insight into cognitive strategies via eye tracking. Expert Systems with Applications **136** (2019) 145–158

[19] Zugal, S., Pinggera, J., Weber, B.: Assessing Process Models with Cognitive Psychology. In: Proceedings of the 4th International Workshop on Enterprise

Modelling and Information Systems Architectures (EMISA), Hamburg, Germany (2011) 177–182

[20] Zimoch, M.: Influence of Psychological Distance on Process Modeling: A Gamification Approach. Master's thesis, Ulm University, Germany (2015)

[21] Thompson, W., Fleming, R., Creem-Regehr, S., Stefanucci, J.K.: Visual Perception from a Computer Graphics Perspective. A K Peters/CRC Press (2011)

[22] Müsseler, J.: Visuelle Informationsverarbeitung. In: Allgemeine Psychologie. 3rd ed. Springer, Berlin, Germany (2017) 13–50

[23] Snowden, R., Thompson, P., Tom, T.: Basic Vision: An Introduction to Visual Perception. Rev. ed. Oxford University Press (2012)

[24] Jobst, M.: Benutzerschnittstellen in der multimedialen 3D Kartografie–eine Gegenüberstellung. In: Proceedings of the 9th international symposion on ICT and planning and impacts of ICT on physical space (CORP), Vienna, Austria (2004) 579–584

[25] Démuth, A.: Perception Theories. Towarzystwo Słowaków w Polsce (2013)

[26] Harrison, G.W., Haruvy, E., Rutström, E.E.: Remarks on Virtual World and Virtual Reality Experiments. Southern Economic Journal **78** (2011) 87–94

[27] Bartle, R.A.: Designing Virtual Worlds. New Riders (2004)

[28] ZeniMax Online Studios: Elder Scrolls Online. (Website) Online available at `https://www.elderscrollsonline.com/en-gb/home`; last accessed on: 20. April 2020.

[29] Bell, M.W.: Toward a Definition of "Virtual Worlds". Journal For Virtual Worlds Research **1** (2008) 2–5

[30] Brey, P.: Virtual Reality and Computer Simulation. In: The Handbook of Information and Computer Ethics. 2nd ed. John Wiley & Sons (2008) 361–384

[31] Burdea, G.C., Coiffet, P.: Virtual Reality Technology. 2nd ed. John Wiley & Sons (2003)

[32] Rohrer, M.W.: Seeing is Believing: The Importance of Visualization in Manufacturing. In: Proceedings of the 2000 Winter Simulation Conference (WSC), Orlando, USA (2000) 1211–1216

[33] Powers, K.L., Brooks, P.J., Aldrich, N.J., Palladino, M.A., Alfieri, L.: Effects of video-game play on information processing: A meta-analytic investigation. Psychonomic Bulletin & Review **20** (2013) 1055–1079

[34] Munzner, T.: Visualization. In: Fundamentals of Computer Graphics. 4th ed. A K Peters (2016) 665–669

[35] PriceWaterhouseCoopers: Multipoly Next. (Website) Online available at `http://multipoly.hu/en/how-to-play/how-to-play.html`; last accessed on: 22. April 2020.

[36] Hamari, J.: Gamification. In: The Blackwell Encyclopedia of Sociology. John Wiley & Sons (2019)

[37] Zichermann, G., Cunningham, C.: Gamification by Design: Implementing Game Mechanics in Web and Mobile Apps. O'Reilly Media (2011)

[38] Blohm, I., Leimeister, J.M.: Gamification: Design of IT-based Enhancing Services for Motivational Support and Behavioral Change. Business & Information Systems Engineering **5** (2013) 275–278

[39] McGonigal, J.: Reality is Broken: Why Games Make Us Better and How They Can Change the World. Penguin Press (2011)

[40] Hamari, J., Koivisto, J., Sarsa, H.: Does Gamification Work? — A Literature Review of Empirical Studies on Gamification. In: Proceedings of the 47th Hawaii International Conference on System Sciences (HICSS), Waikoloa, USA (2014) 3025–3034

[41] Object Management Group: Business Process Model and Notation (BPMN). (Website) Online available at `https://www.omg.org/spec/BPMN/2.0`; last accessed on: 26. April 2020.

[42] Ko, R.K., Lee, S.S., Lee, E.W.: Business process management (BPM) standards: a survey. Business Process Management Journal **15** (2009) 744–791

[43] Rodrigues, R.D.A., Barros, M.D.O., Revoredo, K., Azevedo, L.G., Leopold, H.: An Experiment on Process Model Understandability Using Textual Work Instructions and BPMN Models. In: Proceedings of the 29th Brazilian Symposium on Software Engineering (SBES), Belo Horizonte, Brazil (2015) 41–50

[44] Ottensooser, A., Fekete, A., Reijers, H.A., Mendling, J., Menictas, C.: Making Sense of Business Process Descriptions: An Experimental Comparison of Graphical and Textual Notations. Journal of Systems and Software **85** (2012) 596–606

[45] Siau, K.: Informational and Computational Equivalence in Comparing Information Modeling Methods. Journal of Database Management (JDM) **15** (2004) 73–86

[46] Larkin, J.H., Simon, H.A.: Why a Diagram is (Sometimes) Worth Ten Thousand Words. Cognitive Science **11** (1987) 65–100

[47] Moher, T.G., Mak, D., Blumenthal, B., Levanthal, L.: Comparing the comprehensibility of textual and graphical programs. In: Proceedings of the 5th Workshop of Empirical Studies of Programmers, Palo Alto, USA (1993) 137–161

[48] Diebold, P., Scherr, S.A.: Software process models vs descriptions: What do practitioners use and need? Journal of Software: Evolution and Process **29** (2017) e1879

[49] Leopold, H., Mendling, J., Polyvyanyy, A.: Supporting Process Model Validation through Natural Language Generation. IEEE Transactions on Software Engineering **40** (2014) 818–840

[50] Baier, T., Mendling, J.: Bridging Abstraction Layers in Process Mining by Automated Matching of Events and Activities. In: Proceedings of the 11th International Conference on Business Process Management (BPM), Beijing, China (2013) 17–32

[51] van der Aa, H., Leopold, H., Reijers, H.A.: Detecting Inconsistencies between Process Models and Textual Descriptions. In: Proceedings of the 13th International

Conference on Business Process Management (BPM), Innsbruck, Austria (2015) 90–105

[52] Sweller, J., Chandler, P.: Evidence for Cognitive Load Theory. Cognition and Instruction **8** (1991) 351–362

[53] Sweller, J.: Cognitive Load Theory: Recent Theoretical Advances. In: Cognitive load theory, Cambridge University Press (2010) 29–47

[54] Geary, D.: Educating the Evolved Mind: Conceptual Foundations for an Evolutionary Educational Psychology. In: Psychological Perspectives on Contempory Educational Issues, Information Age Publishing (2007) 1–99

[55] Geary, D.: An evolutionarily informed education science. Educational Psychologist **43** (2008) 179–195

[56] Sweller, J.: Cognitive Load Theory. Psychology of Learning and Motivation **55** (2011) 37–76

[57] Miller, G.A.: The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychological Review **63** (1956) 81–97

[58] Peterson, L., Peterson, M.J.: Short-term retention of individual verbal items. Journal of Experimental Psychology **58** (1959) 193–198

[59] Chandler, P., Sweller, J.: Cognitive Load Theory and the Format of Instruction. Cognition and Instruction **8** (1991) 293–332

[60] Bannert, M.: Managing cognitive load—recent trends in cognitive load theory. Learning and Instruction **12** (2002) 139–146

[61] Boughzahla, I., Tantan, O., Lang, D.: Feedback on the Integration of a Serious Game in the Business Process Management Learning. In: Proceedings of the 21st Americas Conference on Information Systems (AMCIS), Fajardo, Puerto Rico (2015) 3025–3034

[62] Pavaloiu, I.B., Neagu, A.M., Dragoi, G., Rosu, S.M.: IBM INNOV8 business simulation games for e-learning and education. In: Proceedings of the 12th

International Scientific Conference eLearning and Software for Education (eLSE), Bucharest, Romania (2016) 534–540

[63] Ploder, C., Bernsteiner, R., Schlögl, S.: Improving Business Process Management Competencies by Applying Gamification Aspects in Teaching Bachelor Students. In: Proceedings of the 7th International Workshop on Learning Technology for Education Challenges (LTEC), Žilina, Slovakia (2018) 15–23

[64] Morschheuser, B., Hrach, C., Alt, R., Lefanczyk, C.: Gamifizierung mit BPMN. HMD Praxis der Wirtschaftsinformatik **52** (2015) 840–850

[65] Mendling, J., Strembeck, M.: Influence Factors of Understanding Business Process Models. In: Proceedings of the 11th International Conference on Business Information Systems (BIS), Innsbruck, Austria (2008) 142–153

[66] Reijers, H.A., Mendling, J.: A Study into the Factors that Influence the Understandability of Business Process Models. IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans **41** (2010) 449–462

[67] Mendling, J.: Detection and Prediction of Errors in EPC Business Process Models. PhD thesis, Vienna University of Economics and Business Administration (WU Wien), Austria (2007)

[68] Mendling, J.: Metrics for Process Models: Empirical Foundations of Verification, Error Prediction, and Guidelines for Correctness. Springer (2008)

[69] Mendling, J., Reijers, H.A., Cardoso, J.: What Makes Process Models Understandable? In: Proceedings of the 5th International Conference on Business Process Management (BPM), Brisbane, Australia (2007) 48–63

[70] Sarshar, K., Loos, P.: Comparing the Control-Flow of EPC and Petri Net from the End-User Perspective. In: Proceedings of the 3rd International Conference on Business Process Management (BPM), Nancy, France (2005) 434–439

[71] Reijers, H., Mendling, J.: Modularity in Process Models: Review and Effects. In: Proceedings of the 6th International Conference on Business Process Management (BPM), Milan, Italy (2008) 20–35

[72] Baß: Investigating the Effects of Modularization in Business Process Models on the Cognitive Complexity of Humans. Master's thesis, Ulm University, Germany (2019)

[73] Cardoso, J., Mendling, J., Neumann, G.: A Discourse on Complexity of Process Models. In: Proceedings of the 4th International Workshop on the Business Process Mangagement (BPM), Vienna, Austria (2006) 117–128

[74] Mendling, J., Reijers, H.A., van der Aalst, W.M.: Seven process modeling guidelines (7PMG). Information and Software Technology **52** (2010) 127–136

[75] Becker, J., Rosemann, M., Uthmann, C.: Guidelines of Business Process Modeling. In: Business Process Management, Springer, Berlin, Germany (2000) 127–136

[76] Lindland, O.I., Sindre, G., Solvberg, A.: Understanding Quality in Conceptual Modeling. IEEE Software **11** (1994) 42–49

[77] Krogstie, J., Sindre, G., Jørgensen, H.: Process models representing knowledge for action: a revised quality framework. European Journal of Information Systems **15** (2006) 91–102

[78] Riding, R., Cheema, I.: Cognitive Styles—an overview and integration. Educational Psychology **11** (1991) 193–215

[79] Singh, Y.K.: Fundamental of Research Methodology and Statistics. New Age International (2006)

[80] Juristo, N., Moreno, A.M.: Basics of Software Engineering Experimentation. Springer (2013)

[81] Wohlin, C., Runeson, P., Höst, M., Ohlsson, M.C., Regnell, B., Wesslén, A.: Experimentation in Software Engineering. Springer (2012)

[82] Tversky, B., Morrison, J.B., Betrancourt, M.: Animation: can it facilitate? International Journal of Human-Computer Studies **57** (2002) 247–262

[83] Ayres, P., Paas, F.: Making Instructional Animations More Effective: A Cognitive Load Approach. Applied Cognitive Psychology **21** (2007) 695–700

[84] Wohlin, C., Hörst, M., Henningsson, K.: Empirical Research Methods in Software Engineering. In: Empirical Methods and Studies in Software Engineering, Springer, Berlin, Germany (2003) 7–23

[85] Mason, R.L., Gunst, R.F., Hess, J.L.: Statistical Design and Analysis of Experiments: With Applications to Engineering and Science. 2nd ed. John Wiley & Sons (2003)

[86] SogoSurvey: Online Survey Tool. (Website) Online available at `https://www.sogosurvey.com`, last accessed on: 01. June 2020.

[87] Brace, I.: Questionnaire Design: How to plan, structure and write survey material for effective market research. 4th ed. Kogan Page (2018)

[88] Klepsch, M., Schmitz, F., Seufert, T.: Development and Validation of Two Instruments Measuring Intrinsic, Extraneous, and Germane Cognitive Load. Frontiers in Psychology **8** (2017) 8:1997

[89] YouTube: Broadcast Yourself. (Website) Online available at `https://www.youtube.com`; last accessed on: 04 June 2020.

[90] Signavio: BPM Academic Initative. (Website) Online available at `https://academic.signavio.com/p/login`; last accessed on: 04 June 2020.

[91] Montgomery, D.C.: Design and Analysis of Experiments. 9th ed. John Wiley & Sons (2017)

[92] Charness, G., Gneezy, U., Kuhn, M.A.: Experimental methods: Between-subject and within-subject design. Journal of Economic Behavior & Organization **81** (2012) 1–8

[93] Runeson, P., Höst, M.: Guidelines for conducting and reporting case study research in software engineering. Empricial Software Engineering **14** (2009) 131–164

[94] Trochim, W.: Research Methods: The Essential Knowledge Base. 2nd ed. Cengage Learning (2015)

[95] Höst, M., Regnell, B., Wohlin, C.: Using Students as Subjects—A Comparative Study of Students and Professionals in Lead-Time Impact Assessment. Empirical Software Engineering **5** (2000) 201–214

[96] Slack, M.K., Draugalis Jr, J.R.: Establishing the internal and external validity of experimental studies. American Journal of Health-System Pharmacy **58** (2001) 2173–2181

[97] Moodle: Moodle Lernplattform Universität Ulm. (Website) Online available at `https://moodle.uni-ulm.de/login/index.php`, last accessed on: 29 June 2020.

[98] Faul, F., Erdfelder, E., Buchner, A., Lang, A.G.: Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. Behavior Research Methods **41** (2009) 1149–1160

[99] Cohen, J.: Statistical Power Analysis for the Behavioral Sciences. Routledge (1988)

[100] Sheskin, D.J.: Handbook of Parametric and Nonparametric Statistical Procedures. 5th ed. CRC Press (2011)

[101] Thomas, L., Juanes, F.: The importance of statistical power analysis: an example from Animal Behaviour. Animal Behaviour **52** (1996) 856–859

[102] Effinger, P.: A 3D-Navigator for Business Process Models. In: Proceedings of the 12th International Workshop on Business Process Management (BPM), Tallinn, Estonia (2013) 737–743

[103] Oberhauser, R., Pogolski, C., Matic, A.: VR-BPMN: Visualizing BPMN Models in Virtual Reality. In: Proceedings of the 8th International Symposium on Business Process Modeling and Software Design (BMSD), Vienna, Austria (2018) 83–97

[104] Poppe, E., Brown, R.A., Recker, J.C., Johnson, D.M.: A prototype augmented reality collaborative process modelling tool. In: Proceedings of the Demo Track of the 9th International Conference on Business Process Management (BPM), Clermont-Ferrand, France (2011) 1–5

[105] Bera, P.: Does Cognitive Overload Matter in Understanding BPMN Models? Journal of Computer Information Systems **52** (2012) 59–69

A

Process Documentation

This appendix is comprised of the two additional process documentation used in this study. Each treatment consisted of a different way of documenting the process: subjects received either a process model, a textual process description or a process model extended with graphics. The latter two are presented in this appendix.

Warehouse Process - Textual Description

The process begins by taking an order. Afterwards, the warehouse worker checks the picking possibilities that are available. He may choose between two options:

- The **automatic picking system** or
- the **forklift**.

If the automated picking method is selected, the system starts to get everything.
If the employee has decided to use the forklift instead, he will start to pick up the items subsequently. First, he will pick up the drones and the teddy bear and deposits them respectively. Afterwards, he may pick up the displays and the headphones, deposit it respectively and continue to get the PlayStation 4 consoles and the smartphones and deposit it respectively as well.

After he got all the goods (independent of the selected pick up possibility), he will check and count the headphones, the smartphones, the displays, the PlayStation 4 consoles, the drones, and the supersized teddy bear successively.

Afterwards, he needs to package the goods in separate boxes. For the packaging, two small boxes, three medium boxes, and last but not least one large box is needed. Subsequently, he starts to package the headphones and the smartphones into the respective boxes. Then, he continues to package the displays and the PlayStation 4 consoles. After he has finished packaging the four goods, he will first packages the supersized teddy bear and then the drones.

Afterwards, all the goods need to be palletized. The drones, the supersize teddy bear, the displays, the headphones, the smartphones and the PlayStation 4 consoles can be palletized in any order. The next step is to check the available transport possibilities.

He may choose between two options:

- Use the **automatic loading system** to transport the pallets to the shipping area or
- use the **forklift** to transport the pallets to the shipping area.

If he has chosen to use the automatic loading system, he can start the loading sequence which will transport the pallets in the respective area. In the meantime, he can print the required delivery documents: the bill of delivery and the pallet receipts.

Figure A.1: Textual Process Description: Warehouse Scenario - Part I

If he has chosen to use the forklift instead, he needs transport all the pallets with the forklift and print the required documents afterwards.

After all the pallets are transported and the required delivery documents are printed, the warehouse worker needs to label the pallets. First, Pallet 1 and Pallet 2 are labeled followed by Pallet 3 and Pallet 4.

The last step is to load each pallet into the trailer and then place the delivery bill inside the trailer. The loading of the pallets is not bound to a specific order. The process is finished by closing the doors of the trailer.

Figure A.2: Textual Process Description: Warehouse Scenario - Part II

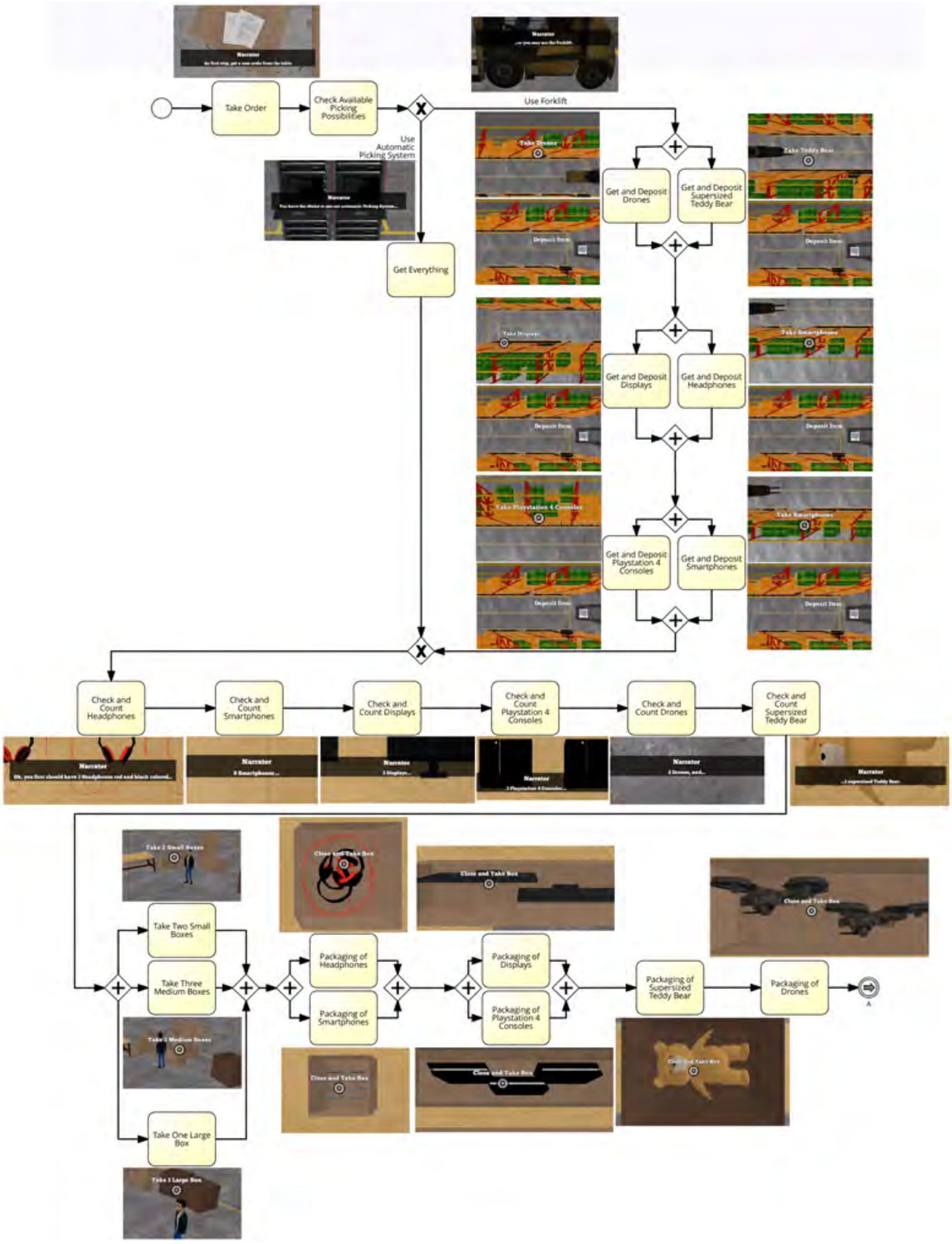


Figure A.3: Process Model extended with Graphics: Warehouse Scenario - Part I

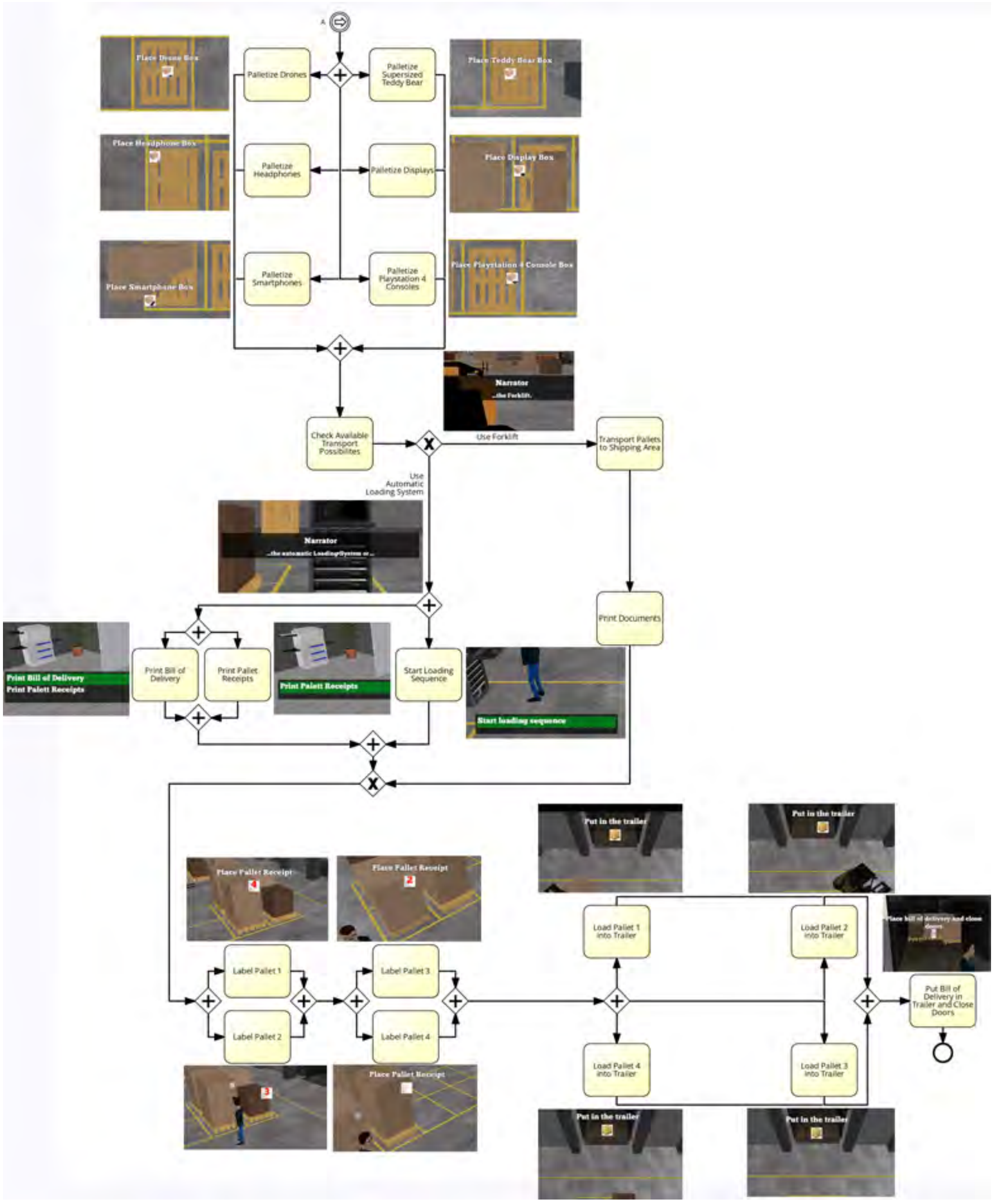


Figure A.4: Process Model extended with Graphics: Warehouse Scenario - Part II

B

Study

In this appendix, the materials of the study are presented. As each treatment consisted of a different process documentation, each variant is provided.

Section 1: Introduction

Study - Comprehension of Process Models Using Virtual Environment

Welcome to the study: Comprehension of Process Models Using Virtual Environment.

The study is being conducted under the leadership of Carina Spitzer (Master's student, Ulm University) and Michael Winter (PhD student at the Institute for Databases and Information Systems (DBIS) and pursues purely scientific goals.

Procedure of the Study

The study consists of four sections. The first section comprises a demographic questionnaire. Subsequently, you will be asked multiple questions about your gaming experience. After you have filled out the two questionnaires you will proceed to the third section. In this section you will be asked to watch a video. Please watch it carefully. In the last section, you will receive multiple questions about the comprehensibility of the process documentation. Take your time to answer these questions, there is no time limit.
The study will take around 25 - 30 min.

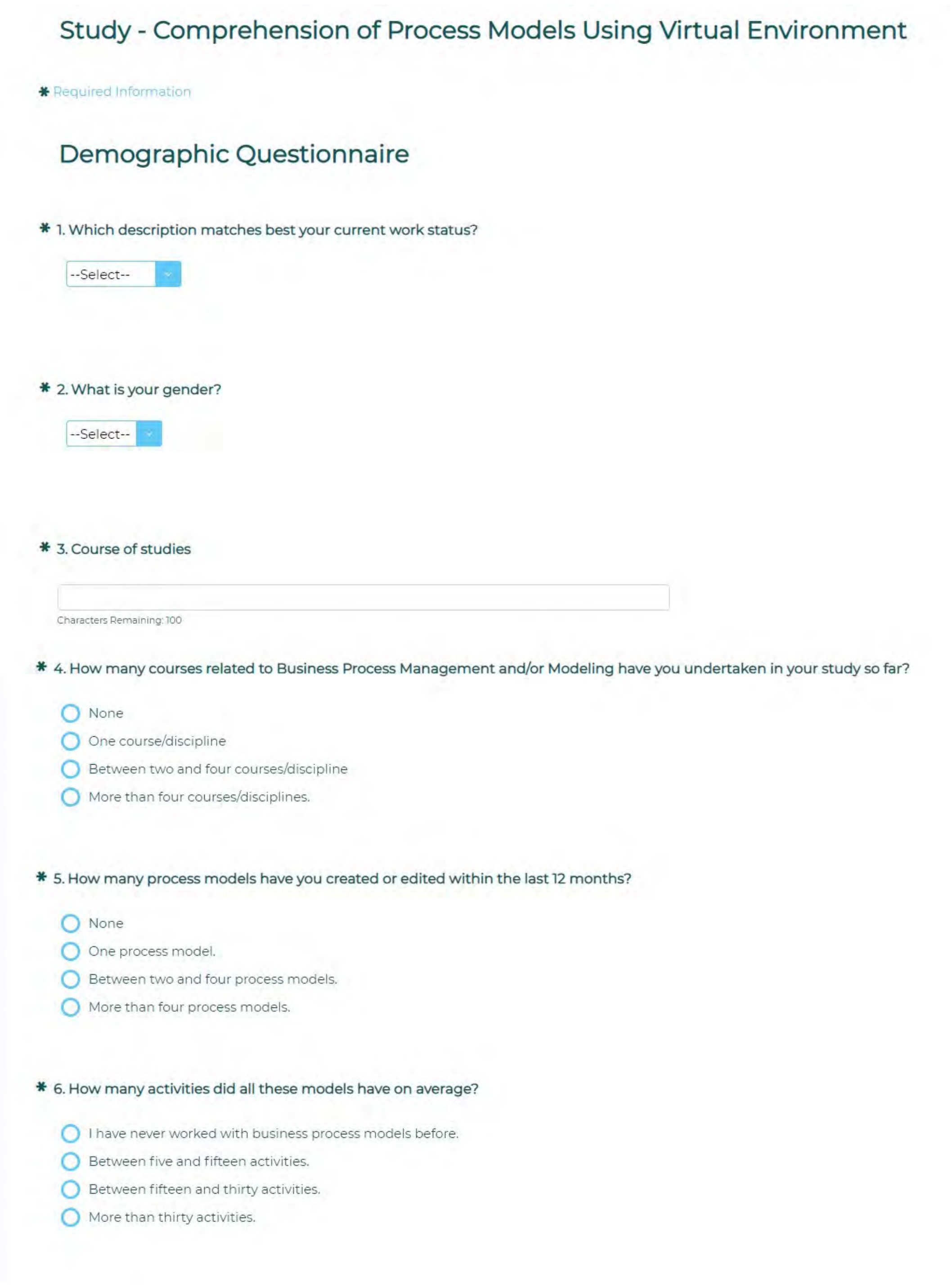
Voluntary Participation

The study is voluntary. You participate in this study on your own will and you have the right to revoke your consent at any time without giving reasons. All data collected up to that point for study purposes will then be deleted. This possible cancellation has no effect on your person.

If you have finished reading, proceed with "Next".

Figure B.1: Introduction of the Study

Section 2: Demographic Questionnaire



Study - Comprehension of Process Models Using Virtual Environment

* Required Information

Demographic Questionnaire

* 1. Which description matches best your current work status?

--Select--

* 2. What is your gender?

--Select--

* 3. Course of studies

Characters Remaining: 100

* 4. How many courses related to Business Process Management and/or Modeling have you undertaken in your study so far?

- None
- One course/discipline
- Between two and four courses/discipline
- More than four courses/disciplines.

* 5. How many process models have you created or edited within the last 12 months?

- None
- One process model.
- Between two and four process models.
- More than four process models.

* 6. How many activities did all these models have on average?

- I have never worked with business process models before.
- Between five and fifteen activities.
- Between fifteen and thirty activities.
- More than thirty activities.

Figure B.2: Demographic Questionnaire - Part I

* 7. Do you have working experience related to Business Process Management?

- No
- Yes, between two and six months.
- Yes, between six months and a year.
- Yes, more than a year.

* 8. How long ago (months, years) did you start using Business Process Modeling and Notation 2.0 (BPMN 2.0)?

- I have never used BPMN 2.0 before.
- Between 1 and 3 months.
- Between 3 and 6 months.
- Between 6 and 12 months.
- More than one year.

* 9. Overall I am very familiar with process modeling.

Strongly Disagree | Neutral | Strongly Agree

1 2 3 4 5 6 7 Clear

* 10. Overall, I am very familiar with the BPMN 2.0 notation.

Strongly Disagree | Neutral | Strongly Agree

1 2 3 4 5 6 7 Clear

* 11. I feel very confident in understanding BPMN 2.0 process models.

Strongly Disagree | Neutral | Strongly Agree

1 2 3 4 5 6 7 Clear

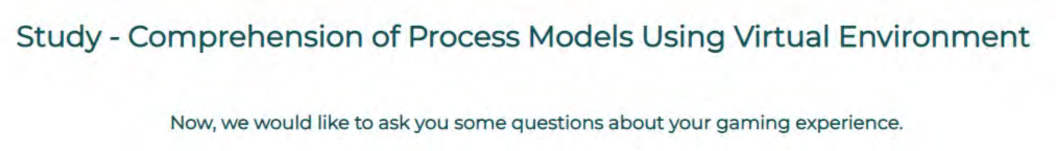
* 12. I feel very competent in using BPMN 2.0 for process modeling.

Strongly Disagree | Neutral | Strongly Agree

1 2 3 4 5 6 7 Clear

Figure B.3: Demographic Questionnaire - Part II

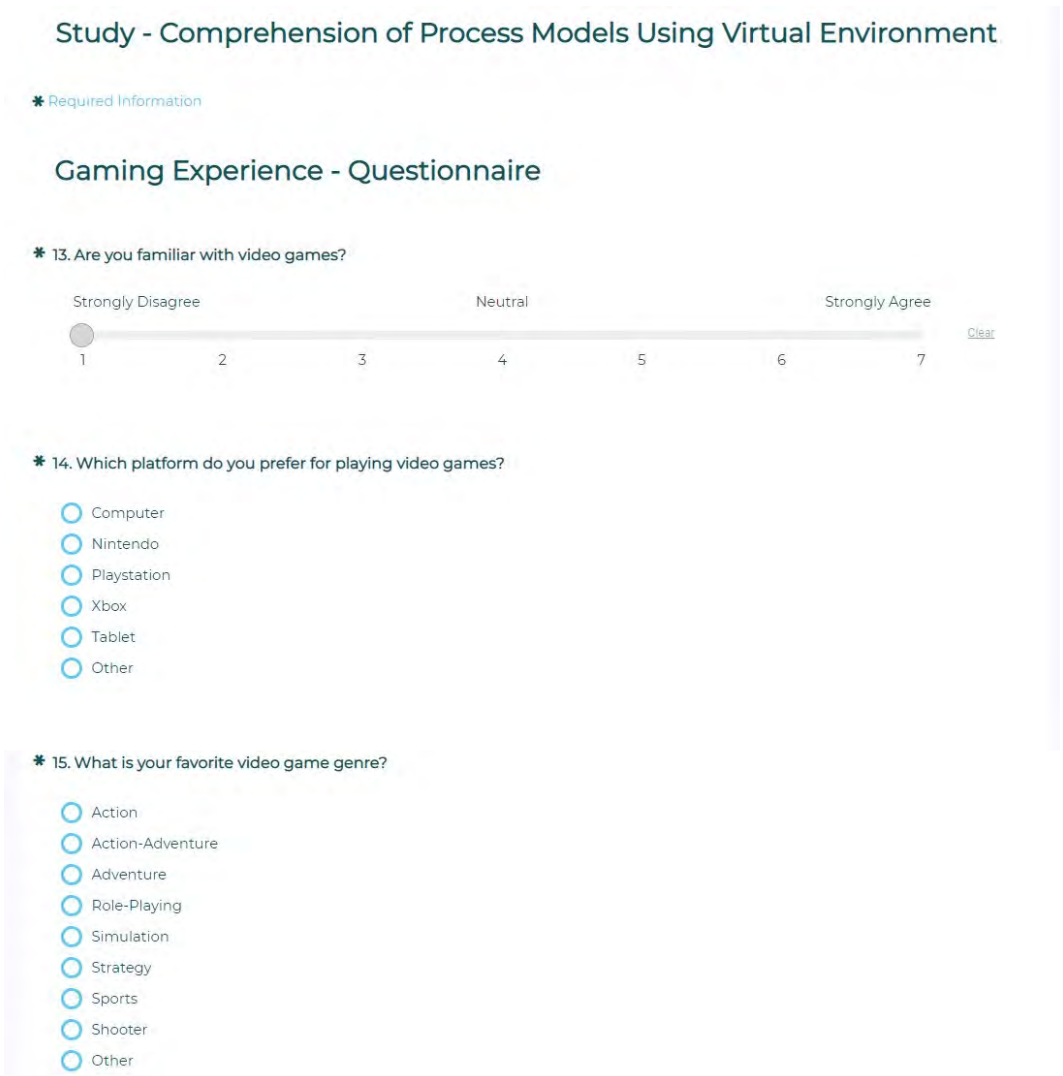
Section 3: Gaming Experience Questionnaire



Study - Comprehension of Process Models Using Virtual Environment

Now, we would like to ask you some questions about your gaming experience.

Figure B.4: Note on the Next Step - I



Study - Comprehension of Process Models Using Virtual Environment

* Required Information

Gaming Experience - Questionnaire

* 13. Are you familiar with video games?

Strongly Disagree | Neutral | Strongly Agree

1 2 3 4 5 6 7 Clear

* 14. Which platform do you prefer for playing video games?

- Computer
- Nintendo
- Playstation
- Xbox
- Tablet
- Other

* 15. What is your favorite video game genre?

- Action
- Action-Adventure
- Adventure
- Role-Playing
- Simulation
- Strategy
- Sports
- Shooter
- Other

Figure B.5: Gaming Experience Questionnaire

Section 4: Virtual Process Environment

Study - Comprehension of Process Models Using Virtual Environment

In the next section, you are going to watch a video. Please ensure that you are in an undisturbed environment where you are able to watch the video in its full length without interruption.

No loudspeakers or headphones are needed as the video is soundless.

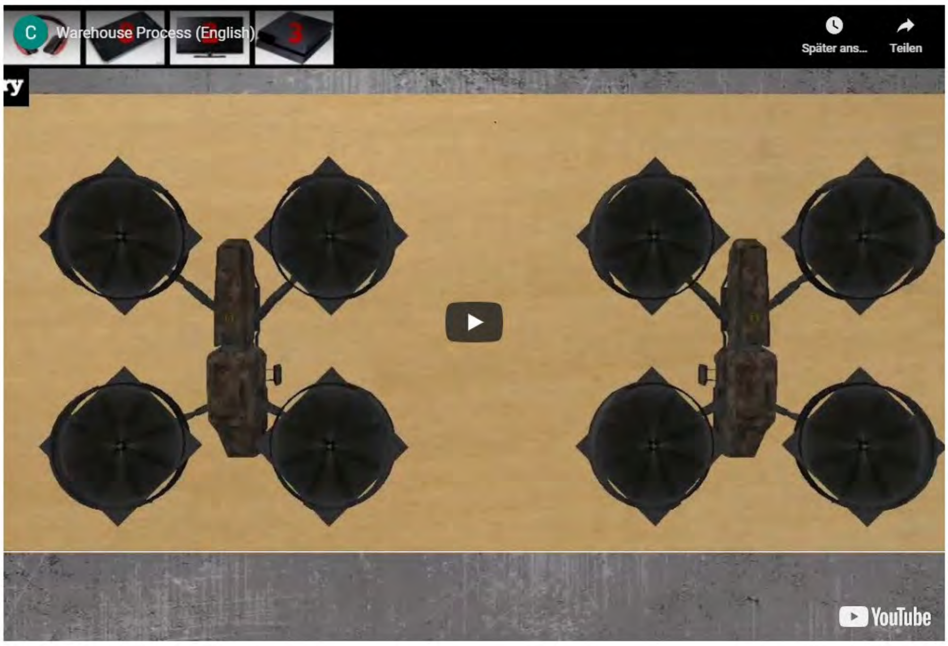
Figure B.6: Note on the Next Step - II

Study - Comprehension of Process Models Using Virtual Environment

3D Wahrehouse Scenario - Length: ~ 18 Min.

Instructions:

- Start the video by clicking on the video.
- Pause the video by clicking on the video.
- Get fullscreen by double clicking on the video.
- Exit fullscreen by double clicking on the video.



If you have finished watching the video, please proceed with "Next".

Figure B.7: Virtual Process Environment

Section 4: Variants of the Process Documentation of the 3D-Warehouse Scenario

<u>Treatment: Process Model</u>

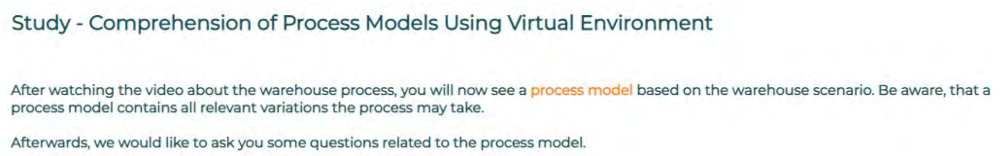


Figure B.8: Note on the Next Step (Process Model) - III

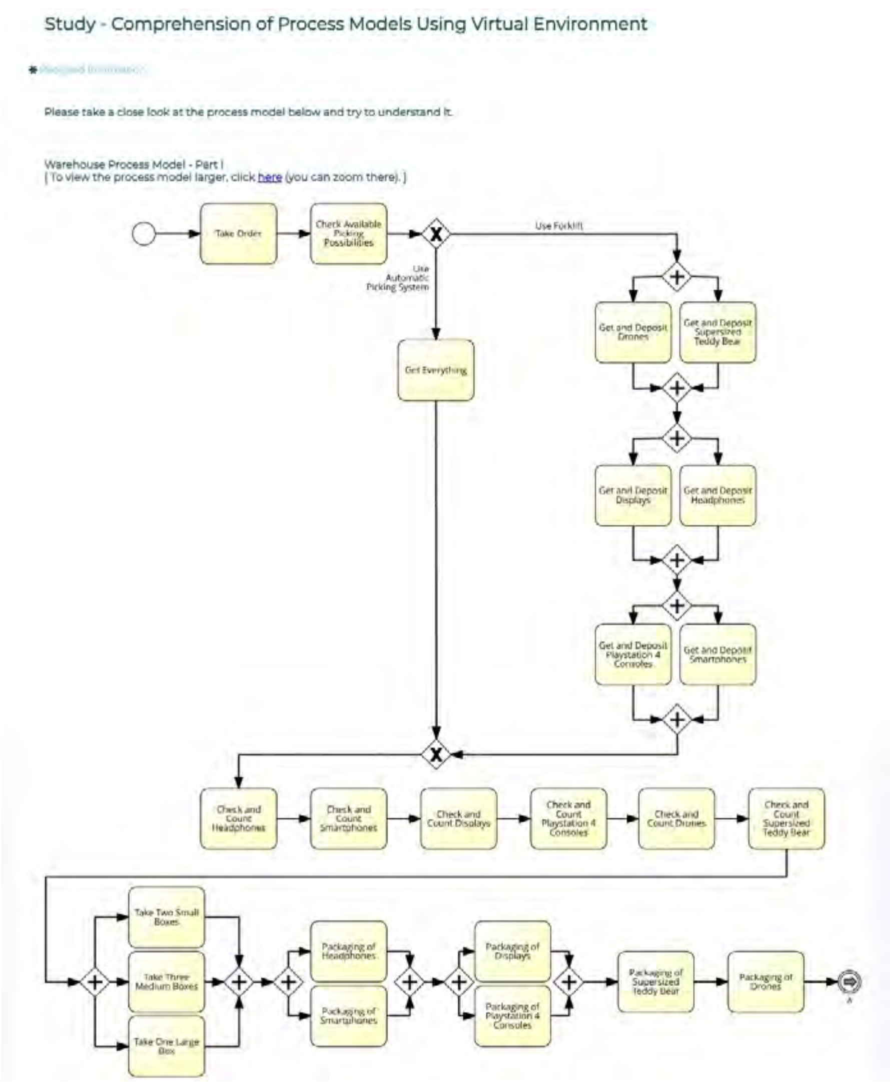


Figure B.9: Treatment: Process Model - Part I

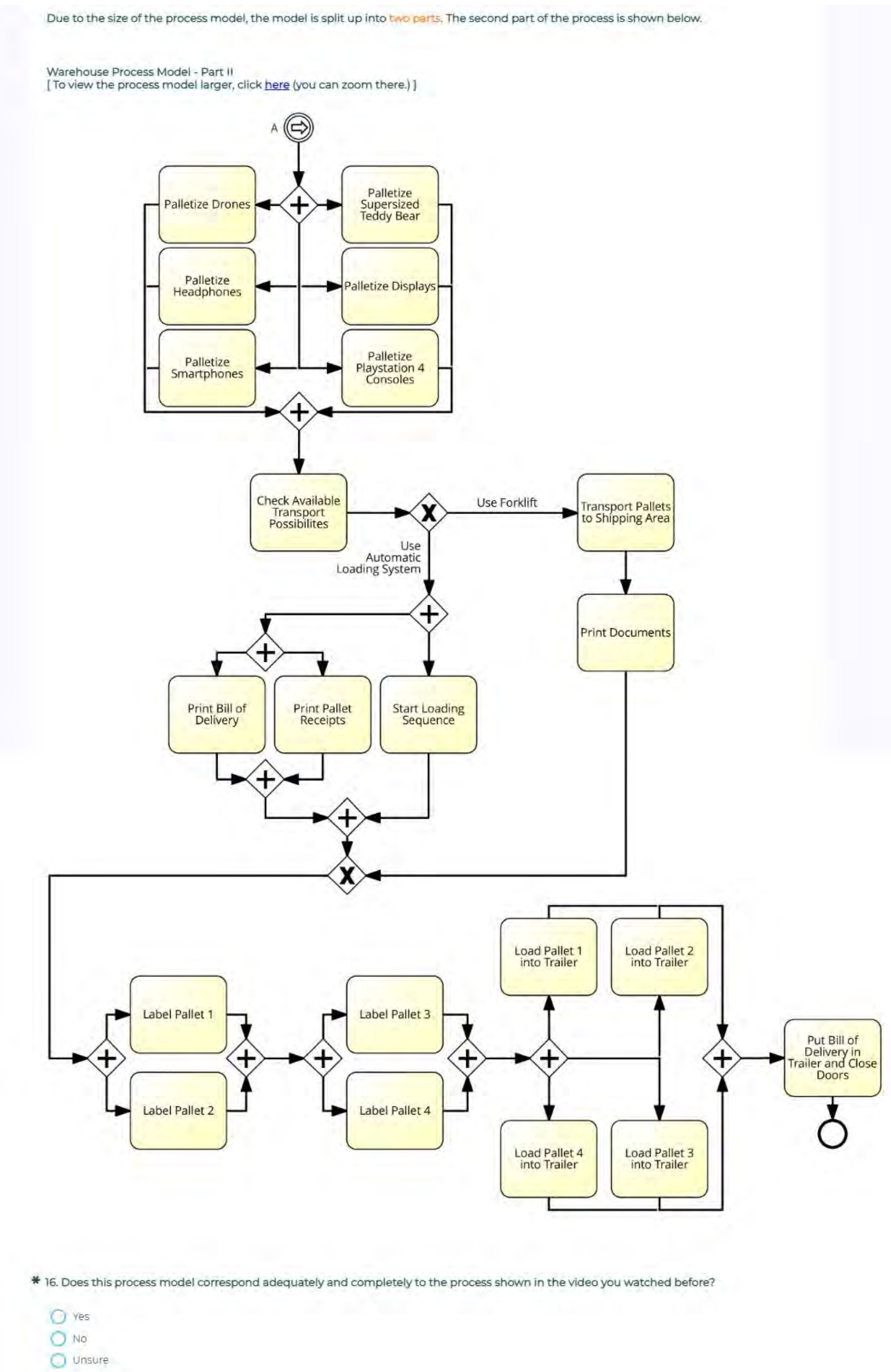
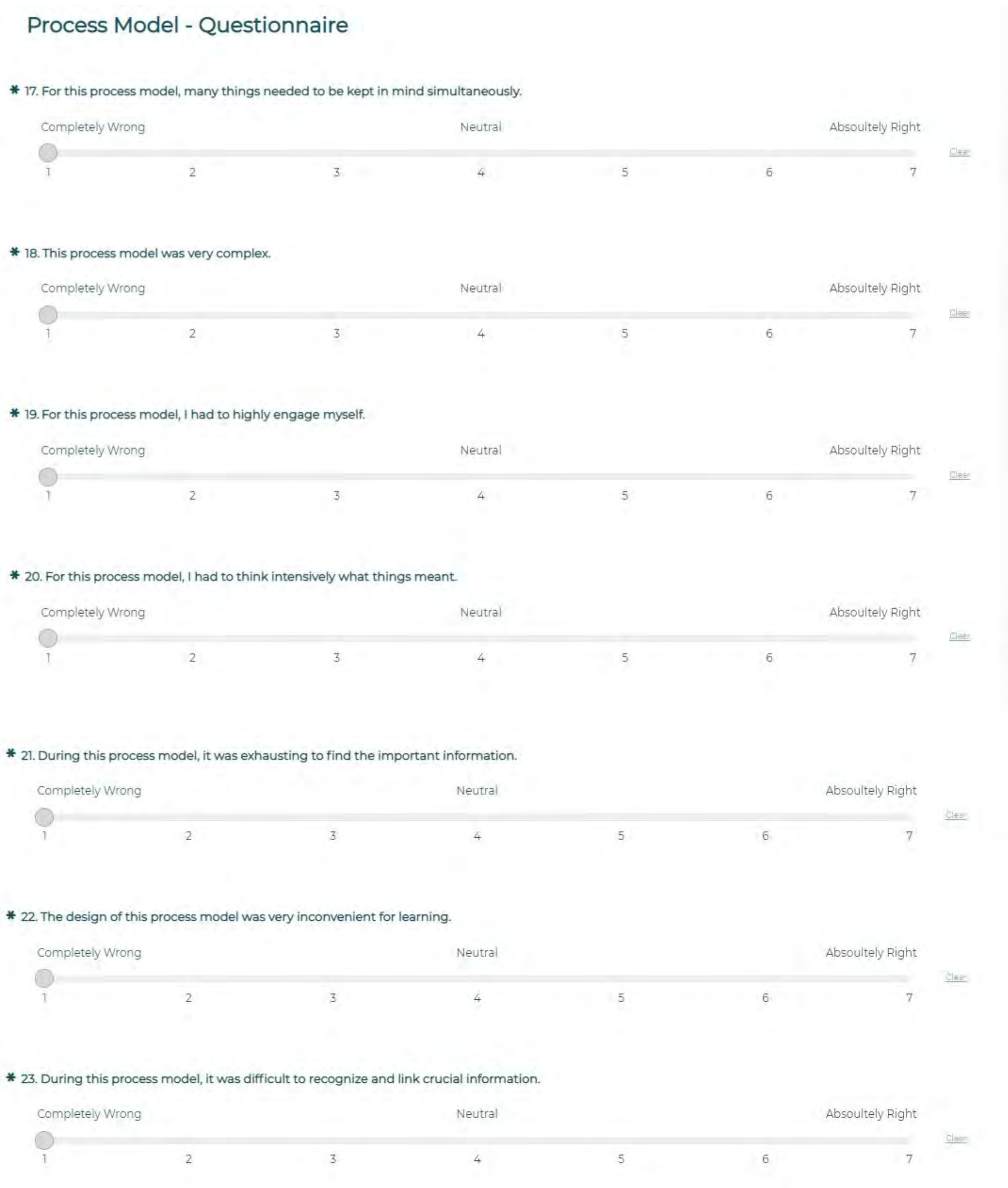


Figure B.10: Treatment: Process Model - Part II



Process Model - Questionnaire

* 17. For this process model, many things needed to be kept in mind simultaneously.

Completely Wrong | Neutral | Absoultely Right

1 2 3 4 5 6 7 Clear

* 18. This process model was very complex.

Completely Wrong | Neutral | Absoultely Right

1 2 3 4 5 6 7 Clear

* 19. For this process model, I had to highly engage myself.

Completely Wrong | Neutral | Absoultely Right

1 2 3 4 5 6 7 Clear

* 20. For this process model, I had to think intensively what things meant.

Completely Wrong | Neutral | Absoultely Right

1 2 3 4 5 6 7 Clear

* 21. During this process model, it was exhausting to find the important information.

Completely Wrong | Neutral | Absoultely Right

1 2 3 4 5 6 7 Clear

* 22. The design of this process model was very inconvenient for learning.

Completely Wrong | Neutral | Absoultely Right

1 2 3 4 5 6 7 Clear

* 23. During this process model, it was difficult to recognize and link crucial information.

Completely Wrong | Neutral | Absoultely Right

1 2 3 4 5 6 7 Clear

Figure B.11: Treatment: Process Model - Part III (Cognitive Load Questionnaire)

Treatment: Textual Process Description

Study - Comprehension of Process Models Using Virtual Environment

After watching the video about the warehouse process, you will now see a textual process description based on the warehouse scenario. Be aware, that a textual descriptions contains all relevant variations the process may take.

Afterwards, we would like to ask you some questions related to the textual process description.

Figure B.12: Note on the Next Step (Textual Process Description) - III

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If you cannot see the textual process description, click here.

Warehouse Process - Textual Description

The process begins by taking an order. Afterwards, the warehouse worker checks the picking possibilities that are available. He may choose between two options:

- The **automatic picking system** or
- the **forklift**.

If the automated picking method is selected, the system starts to get everything.

If the employee has decided to use the forklift instead, he will start to pick up the items subsequently. First, he will pick up the drones and the teddy bear and deposits them respectively. Afterwards, he may pick up the displays and the headphones, deposit it respectively and continue to get the PlayStation 4 consoles and the smartphones and deposit it respectively as well.

After he got all the goods (independent of the selected pick up possibility), he will check and count the headphones, the smartphones, the displays, the PlayStation 4 consoles, the drones, and the supersized teddy bear successively.

Afterwards, he needs to package the goods in separate boxes. For the packaging, two small boxes, three medium boxes, and last but not least one large box is needed. Subsequently, he starts to package the headphones and the smartphones into the respective boxes. Then, he continues to package the displays and the PlayStation 4 consoles. After he has finished packaging the four goods, he will first packages the supersized teddy bear and then the drones.

Figure B.13: Treatment: Textual Process Description - Part I

Afterwards, all the goods need to be palletized. The drones, the supersize teddy bear, the displays, the headphones, the smartphones and the PlayStation 4 consoles can be palletized in any order. The next step is to check the available transport possibilities.

He may choose between two options:

- Use the **automatic loading system** to transport the pallets to the shipping area or
- use the **forklift** to transport the pallets to the shipping area.

If he has chosen to use the automatic loading system, he can start the loading sequence which will transport the pallets in the respective area. In the meantime, he can print the required delivery documents: the bill of delivery and the pallet receipts.

If he has chosen to use the forklift instead, he needs transport all the pallets with the forklift and print the required documents afterwards.

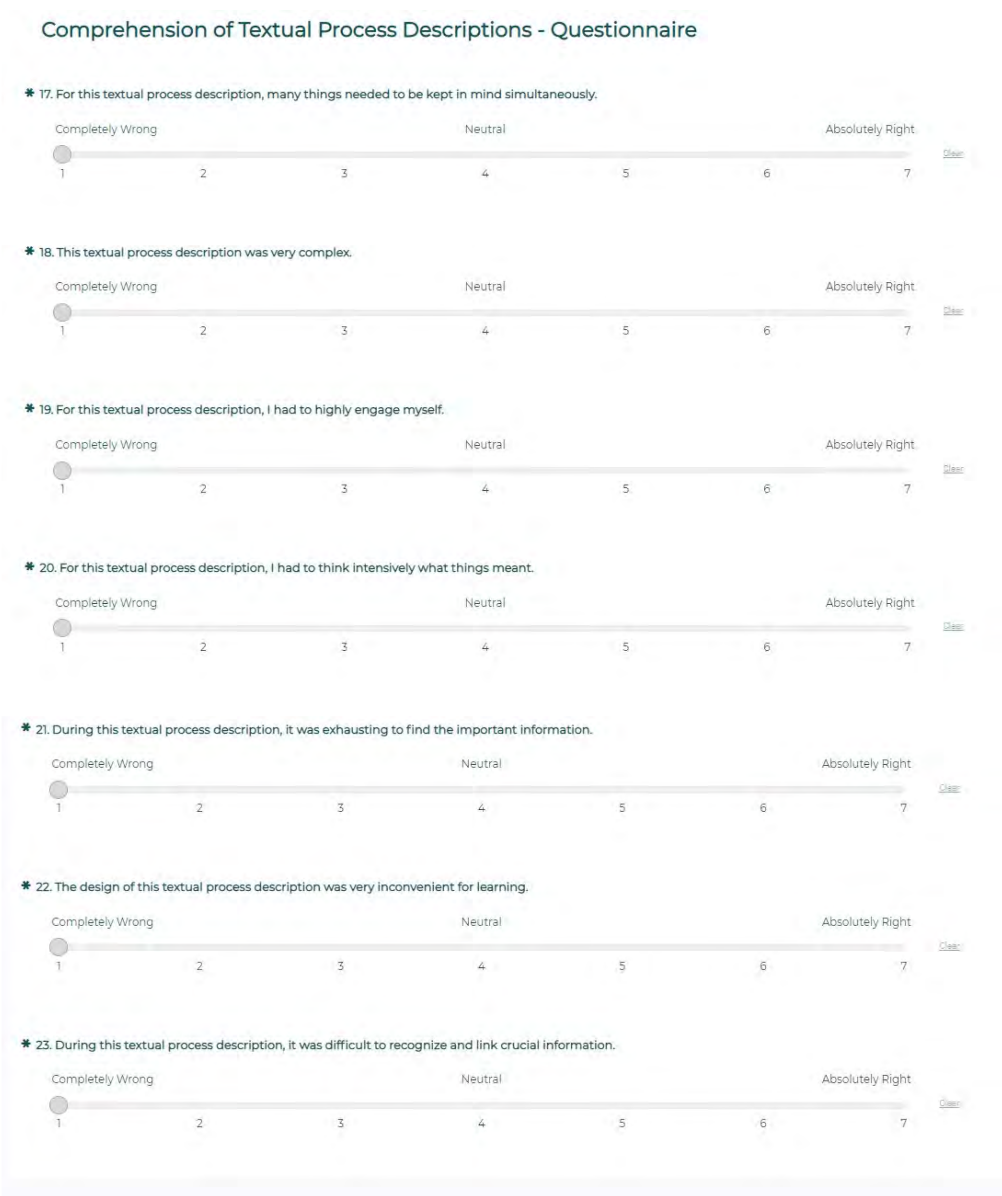
After all the pallets are transported and the required delivery documents are printed, the warehouse worker needs to label the pallets. First, Pallet 1 and Pallet 2 are labeled followed by Pallet 3 and Pallet 4.

The last step is to load each pallet into the trailer and then place the delivery bill inside the trailer. The loading of the pallets is not bound to a specific order. The process is finished by closing the doors of the trailer.

* 16. Does this textual process description correspond adequately and completely to the process shown in the video you watched before?

- ○ Yes
- ○ No
- ○ Unsure

Figure B.14: Treatment: Textual Process Description - Part II



Comprehension of Textual Process Descriptions - Questionnaire

* 17. For this textual process description, many things needed to be kept in mind simultaneously.

Completely Wrong | Neutral | Absolutely Right

1 2 3 4 5 6 7 Clear

* 18. This textual process description was very complex.

Completely Wrong | Neutral | Absolutely Right

1 2 3 4 5 6 7 Clear

* 19. For this textual process description, I had to highly engage myself.

Completely Wrong | Neutral | Absolutely Right

1 2 3 4 5 6 7 Clear

* 20. For this textual process description, I had to think intensively what things meant.

Completely Wrong | Neutral | Absolutely Right

1 2 3 4 5 6 7 Clear

* 21. During this textual process description, it was exhausting to find the important information.

Completely Wrong | Neutral | Absolutely Right

1 2 3 4 5 6 7 Clear

* 22. The design of this textual process description was very inconvenient for learning.

Completely Wrong | Neutral | Absolutely Right

1 2 3 4 5 6 7 Clear

* 23. During this textual process description, it was difficult to recognize and link crucial information.

Completely Wrong | Neutral | Absolutely Right

1 2 3 4 5 6 7 Clear

Figure B.15: Treatment: Textual Process Description (Cognitive Load Questionnaire) - Part III

Treatment: Process Model extended with Graphics

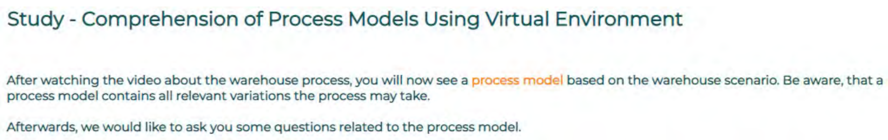


Figure B.16: Note on the Next Step (Process Model extended with Graphics) - III

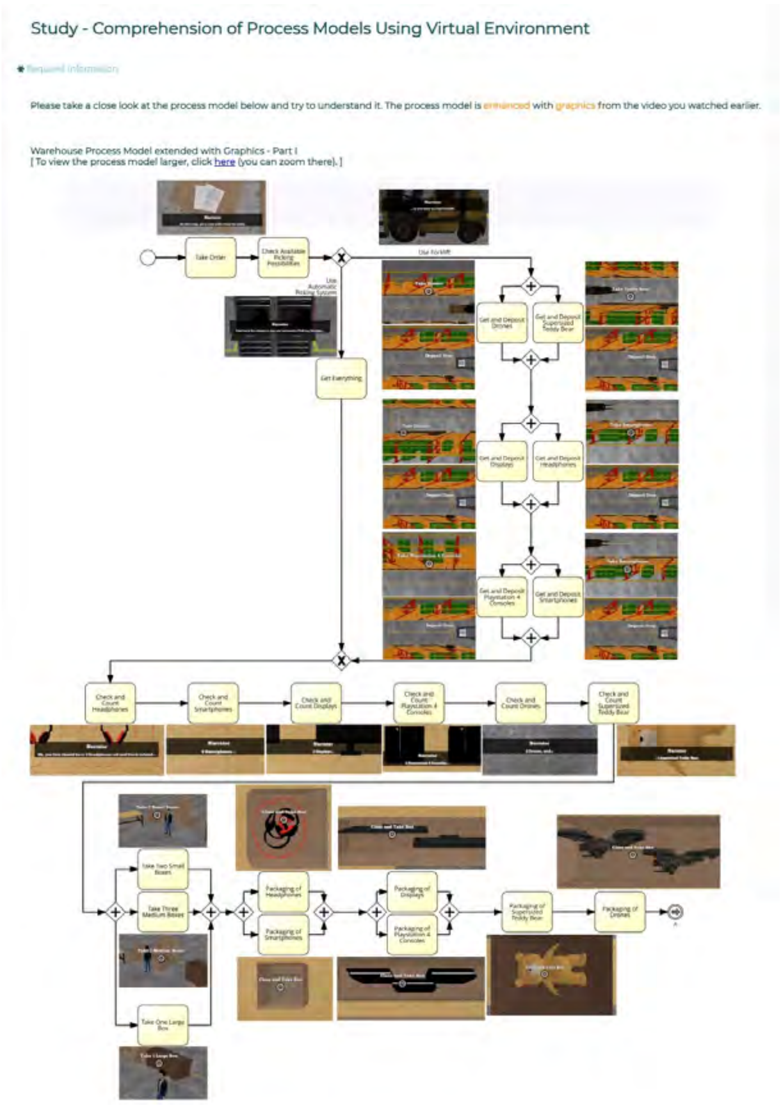
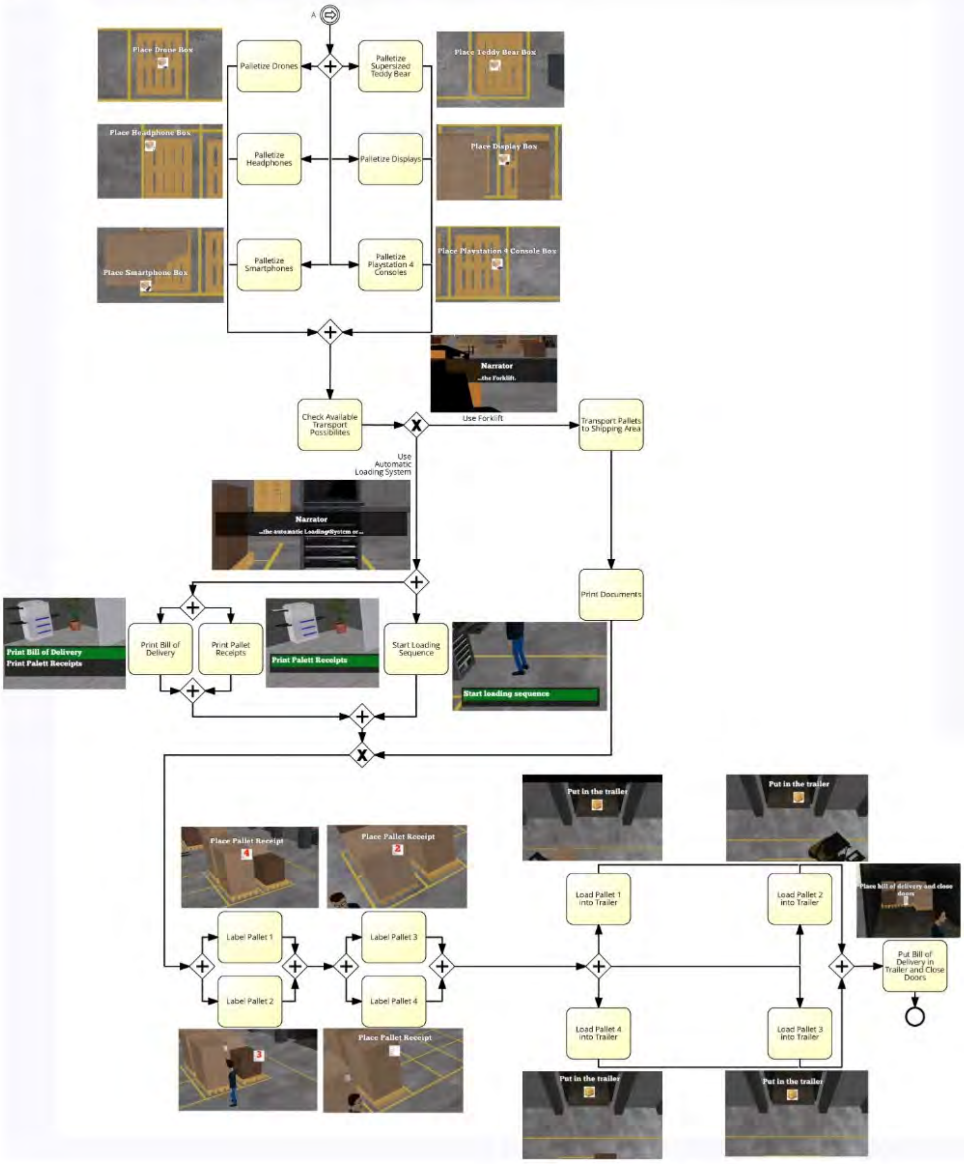


Figure B.17: Treatment: Process Model extended with Graphics - Part I

Due to the size of the process model, the model is split up into two parts. The second part of the process is shown below.

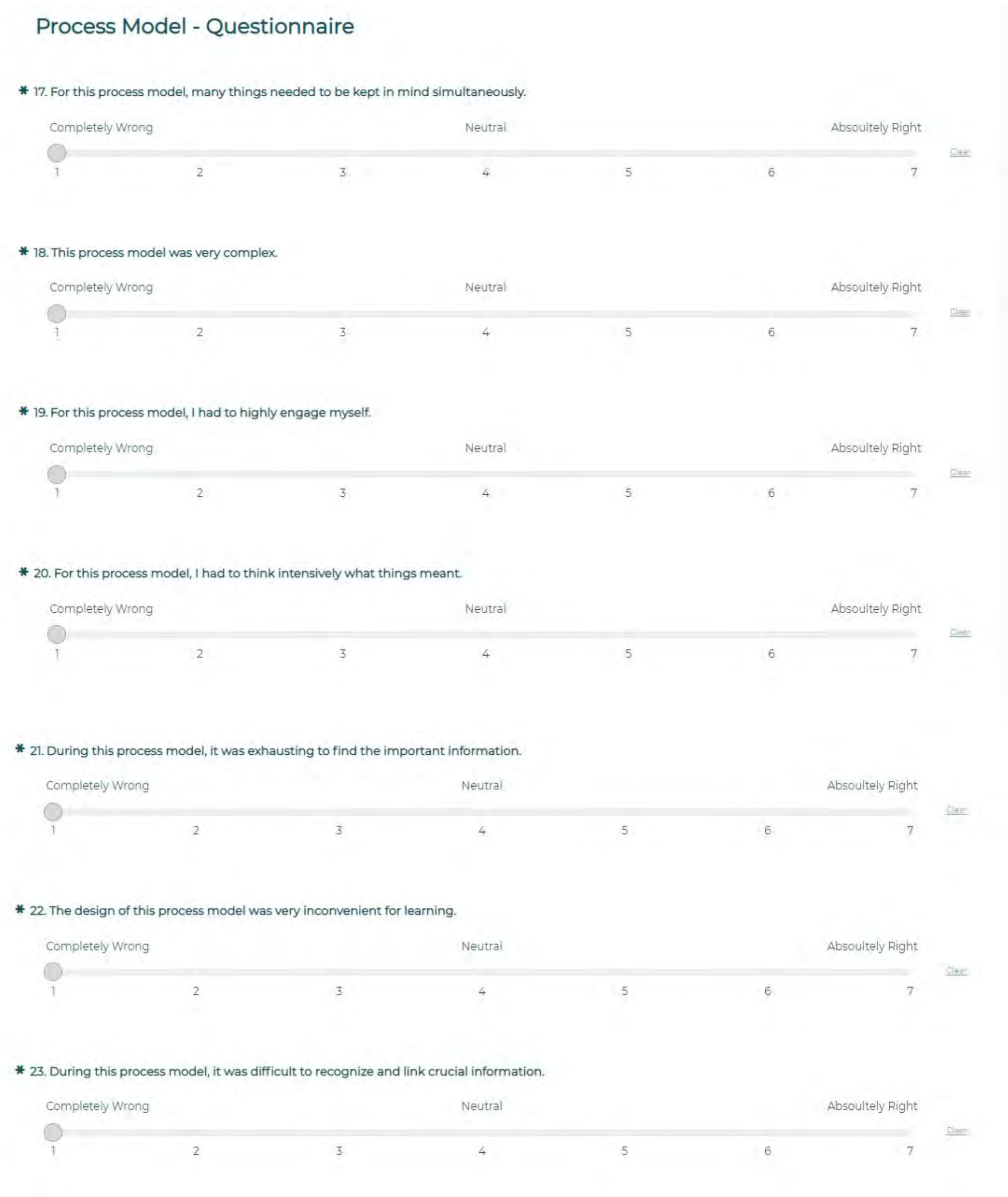
Warehouse Process Model extended with Graphics - Part II
[To view the process model larger, click here (you can zoom there).]



* 16. Does this process model correspond adequately and completely to the process shown in the video you watched before?

- Yes
- No
- Unsure

Figure B.18: Treatment: Process Model extended with Graphics - Part II



Process Model - Questionnaire

* 17. For this process model, many things needed to be kept in mind simultaneously.

Completely Wrong | Neutral | Absoultely Right
1 2 3 4 5 6 7 Clear

* 18. This process model was very complex.

Completely Wrong | Neutral | Absoultely Right
1 2 3 4 5 6 7 Clear

* 19. For this process model, I had to highly engage myself.

Completely Wrong | Neutral | Absoultely Right
1 2 3 4 5 6 7 Clear

* 20. For this process model, I had to think intensively what things meant.

Completely Wrong | Neutral | Absoultely Right
1 2 3 4 5 6 7 Clear

* 21. During this process model, it was exhausting to find the important information.

Completely Wrong | Neutral | Absoultely Right
1 2 3 4 5 6 7 Clear

* 22. The design of this process model was very inconvenient for learning.

Completely Wrong | Neutral | Absoultely Right
1 2 3 4 5 6 7 Clear

* 23. During this process model, it was difficult to recognize and link crucial information.

Completely Wrong | Neutral | Absoultely Right
1 2 3 4 5 6 7 Clear

Figure B.19: Treatment: Process Model extended with Graphics - Part III (Cognitive Load Questionnaire)

Section 5: Preference for one Process Documentation

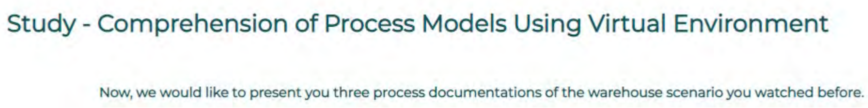


Figure B.20: Note on the Next Step - IV

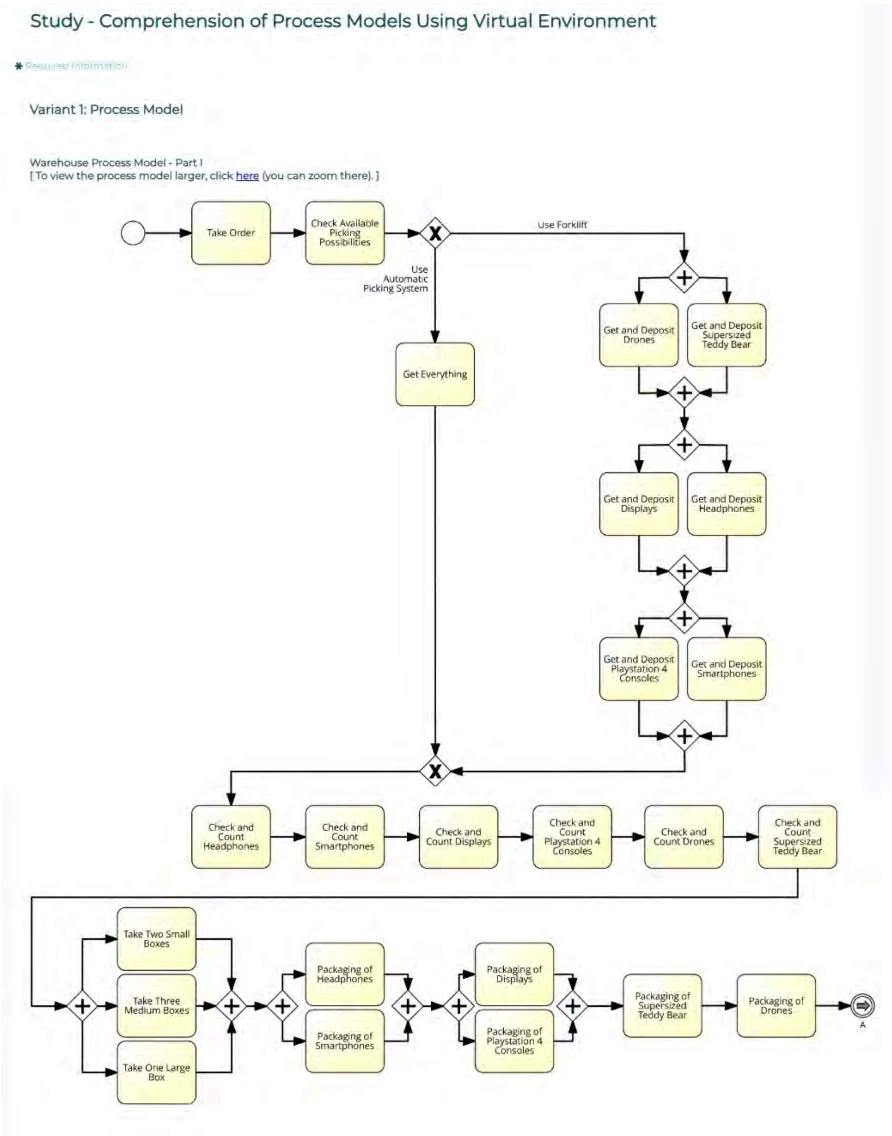


Figure B.21: Variant I: Process Model - Part I

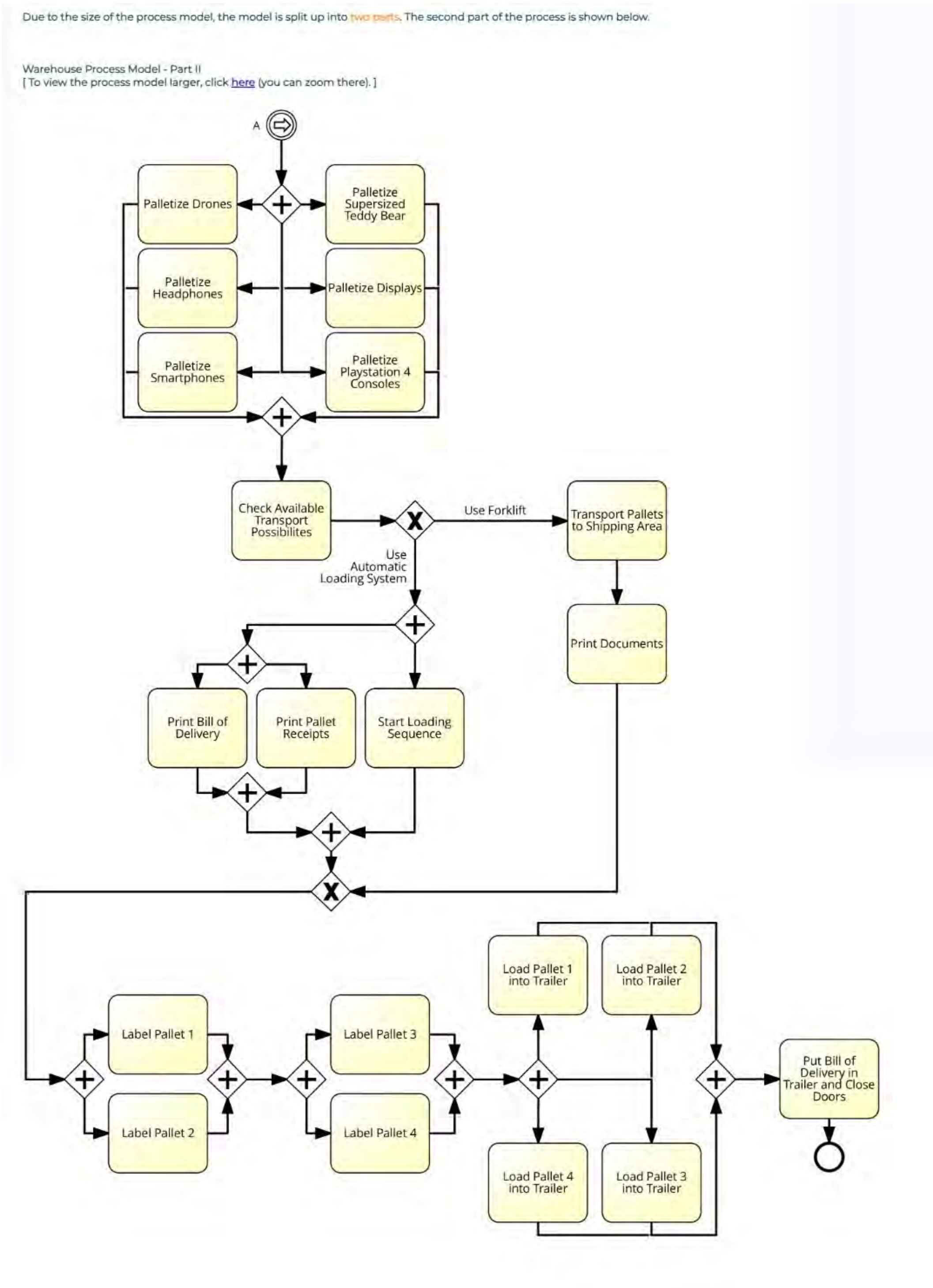


Figure B.22: Variant I: Process Model - Part II

Variant 2: Process Model extended with Graphics

Warehouse Process Model extended with Graphics - Part I
[To view the process model larger, click here (you can zoom there).]

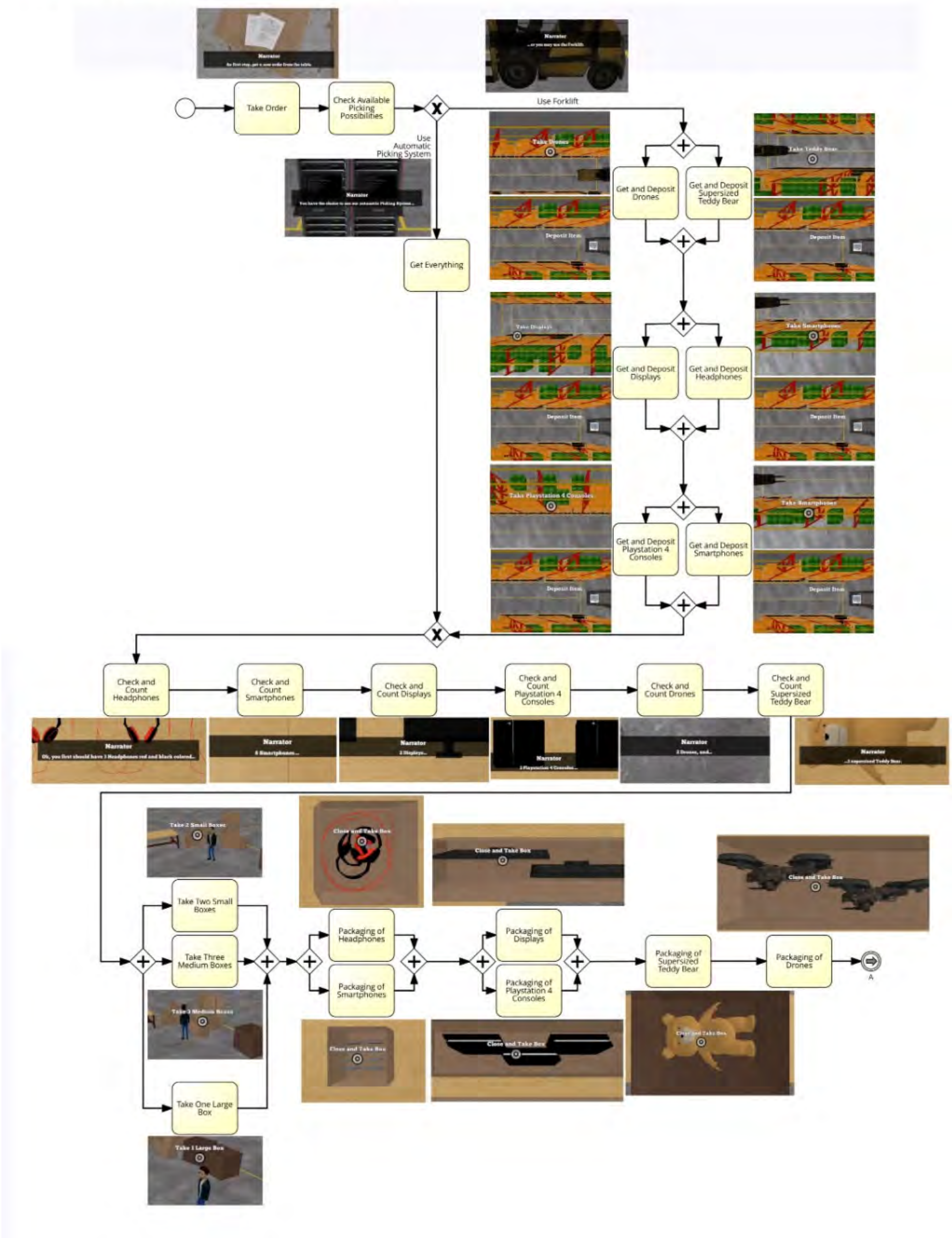


Figure B.23: Variant II: Process Model extended with Graphics - Part I

Due to the size of the process model, the model is split up into two parts. The second part of the process is shown below.

Warehouse Process Model extended with Graphics - Part II
[To view the process model larger, click here (you can zoom there).]

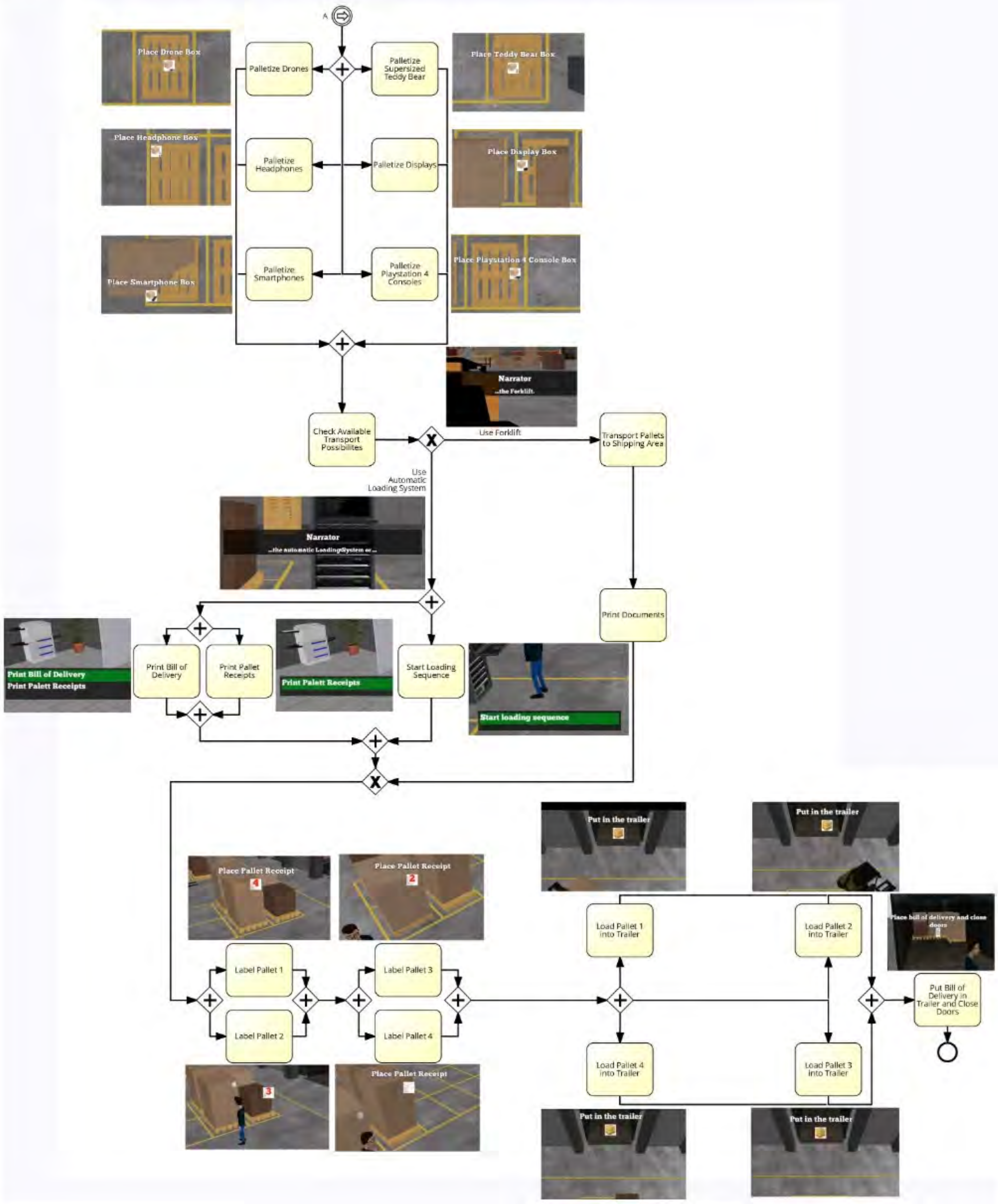


Figure B.24: Variant II: Process Model extended with Graphics - Part II

Variant 3: Textual Process Description

If you cannot see the textual process description, click here.

Warehouse Process - Textual Description

The process begins by taking an order. Afterwards, the warehouse worker checks the picking possibilities that are available. He may choose between two options:

- The **automatic picking system** or
- the **forklift**.

If the automated picking method is selected, the system starts to get everything.
If the employee has decided to use the forklift instead, he will start to pick up the items subsequently. First, he will pick up the drones and the teddy bear and deposits them respectively. Afterwards, he may pick up the displays and the headphones, deposit it respectively and continue to get the PlayStation 4 consoles and the smartphones and deposit it respectively as well.

After he got all the goods (independent of the selected pick up possibility), he will check and count the headphones, the smartphones, the displays, the PlayStation 4 consoles, the drones, and the supersized teddy bear successively.

Afterwards, he needs to package the goods in separate boxes. For the packaging, two small boxes, three medium boxes, and last but not least one large box is needed. Subsequently, he starts to package the headphones and the smartphones into the respective boxes. Then, he continues to package the displays and the PlayStation 4 consoles. After he has finished packaging the four goods, he will first packages the supersized teddy bear and then the drones.

Afterwards, all the goods need to be palletized. The drones, the supersize teddy bear, the displays, the headphones, the smartphones and the PlayStation 4 consoles can be palletized in any order. The next step is to check the available transport possibilities.

He may choose between two options:

- Use the **automatic loading system** to transport the pallets to the shipping area or
- use the **forklift** to transport the pallets to the shipping area.

If he has chosen to use the automatic loading system, he can start the loading sequence which will transport the pallets in the respective area. In the meantime, he can print the required delivery documents: the bill of delivery and the pallet receipts.

Figure B.25: Variant III: Textual Process Description - Part I

If he has chosen to use the forklift instead, he needs transport all the pallets with the forklift and print the required documents afterwards.

After all the pallets are transported and the required delivery documents are printed, the warehouse worker needs to label the pallets. First, Pallet 1 and Pallet 2 are labeled followed by Pallet 3 and Pallet 4.

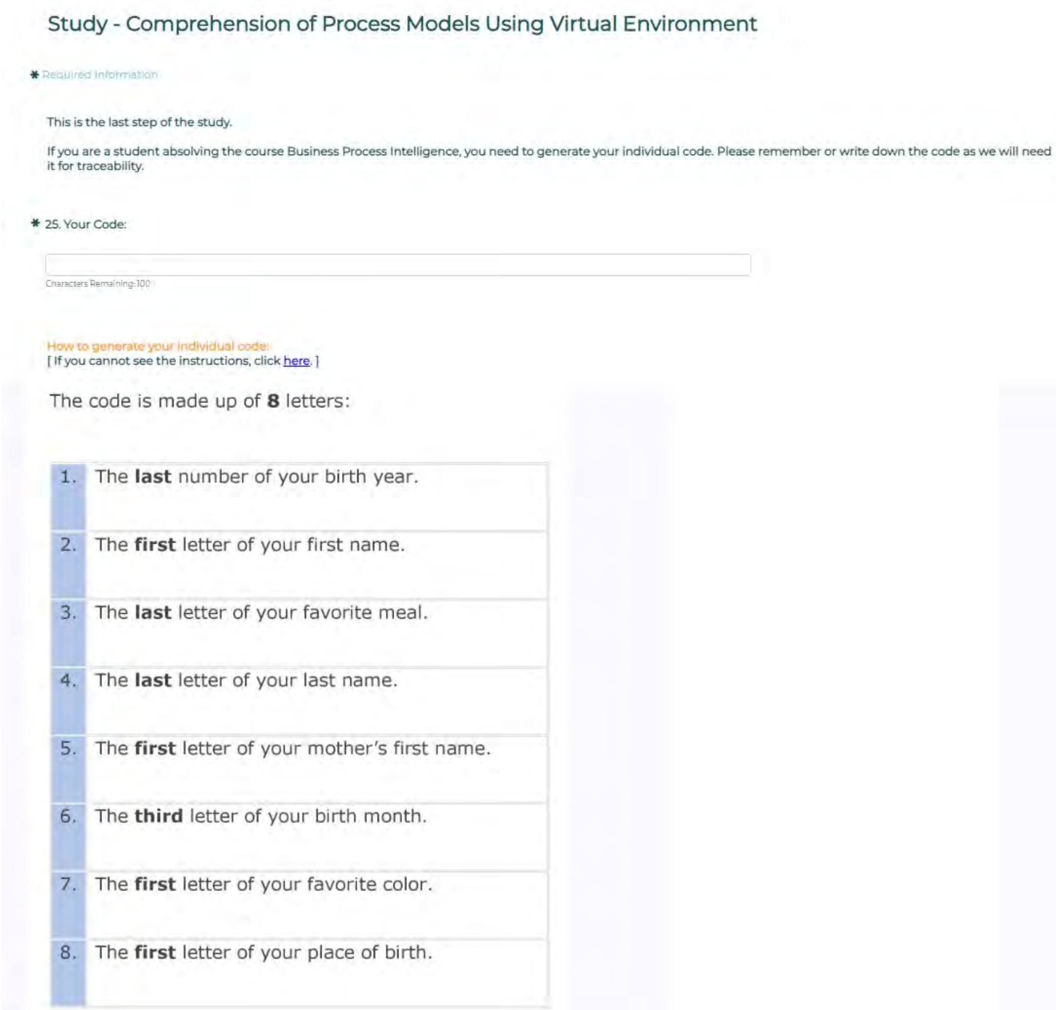
The last step is to load each pallet into the trailer and then place the delivery bill inside the trailer. The loading of the pallets is not bound to a specific order. The process is finished by closing the doors of the trailer.

* 24. Which of the variants do you personally find the best?

- Process Model
- Process Model extended with Graphics
- Textual Process Description

Figure B.26: Variant III: Textual Process Description - Part II

Section 6: Generation of the Individual Code



Study - Comprehension of Process Models Using Virtual Environment

* Required Information

This is the last step of the study.

If you are a student absolving the course Business Process Intelligence, you need to generate your individual code. Please remember or write down the code as we will need it for traceability.

* 25. Your Code:

Characters Remaining: 100

How to generate your individual code:
[If you cannot see the instructions, click here.]

The code is made up of **8** letters:

1.	The **last** number of your birth year.
2.	The **first** letter of your first name.
3.	The **last** letter of your favorite meal.
4.	The **last** letter of your last name.
5.	The **first** letter of your mother's first name.
6.	The **third** letter of your birth month.
7.	The **first** letter of your favorite color.
8.	The **first** letter of your place of birth.

Figure B.27: Instruction for Generating the Code - Part I

As an example: *Ben Dover* wants to generate his individual code.

1. The **last** number of your birth year: **7**
   → *Ben Dover is born on 15.09.199**7**.*

2. The **first** letter of your first name: **B**
   → *His first name is **B**en.*

3. The **last** of your favorite meal: **a**
   → *Ben loves pizz**a**.*

4. The **last** letter of your last name: **r**.
   → *His last name is Dove**r**.*

5. The **first** letter of your mother's first name: **E**.
   → *His mother's first name is **E**llie.*

6. The **third** letter of your birth month: **p**.
   → *Ben Dover was born in Se**p**tember.*

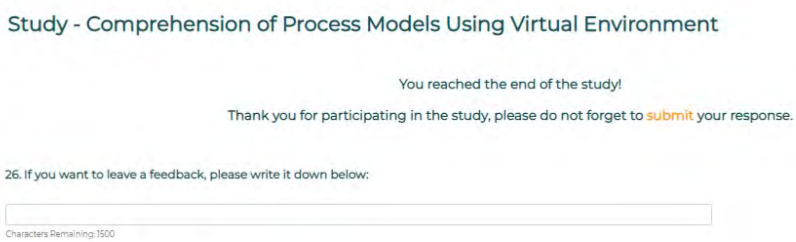
7. The **first** letter of your favorite color: **b**
   → *Ben Dover loves the color **b**lue.*

8. The **first** letter of your place of birth: **U**
   → *Ben Dover was born in **U**lm.*

Ben Dover's individual code: 7BarEpbU

Figure B.28: Instruction for Generating the Code - Part II

Section 7: Feedback and Acknowledgment



Study - Comprehension of Process Models Using Virtual Environment

You reached the end of the study!

Thank you for participating in the study, please do not forget to submit your response.

26. If you want to leave a feedback, please write it down below:

Characters Remaining: 1500

Figure B.29: Feedback and Acknowledgment for Participation

List of Figures

List of Tables

Name: Carina Spitzer | Matriculation number: 910620

Honesty disclaimer

I hereby affirm that I wrote this thesis independently and that I did not use any other sources or tools than the ones specified.

Ulm, ...

Carina Spitzer