Diplomarbeit

Design of a Procedural Model for Extracting and Specifying Requirements of Gamification Tools and Features in Industrial Maintenance

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Ich habe zur Kenntnis genommen, dass ich zur Drucklegung meiner Arbeit unter der Bezeichnung

Diplomarbeit

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Wien, im September 2020

Lukas Weinwurm

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Kurzfassung

Die Prozesse in der industriellen Instandhaltung ändern sich aufgrund der stetig steigenden Komplexität und Automatisierung von modernen Produktionsanlagen erheblich. Dies stellt eine Herausforderung für das Instandhaltungspersonal eines Unternehmens dar, dessen Tätigkeitsprofil laufend an diese Entwicklung angepasst werden muss. Folglich müssen die Mitarbeiter auf diese neuen Anforderungen vorbereitet und entsprechend qualifiziert werden. Gamifizierung bietet einen neuartigen und vielversprechenden Ansatz zum Füllen von Kompetenzlücken im Zuge der beruflichen Aus- und Weiterbildung. Literatur zu dessen Anwendung in der industriellen Instandhaltung ist allerdings kaum vorhanden.

Das Ziel dieser Arbeit ist es, die notwendigen Schritte zu identifizieren, um die Anforderungen einer gamifizierten Anwendung für die Aus- und Weiterbildung in der industriellen Instandhaltung zu spezifizieren. Eine der folgenschwersten Entscheidungen bei der Entwicklung einer solchen Anwendung muss in Bezug auf den Zweck (d.h. Ausbildung, Weiterbildung oder Umschulung) und die Art der Ausbildung (Training on-the-job oder off-the-job) getroffen werden. Diese Festlegung hat insbesondere Einfluss auf die Gestaltung der Lerninhalte. Daher wurde die folgende Hauptforschungsfrage definiert: Welches ist ein geeignetes, schrittweises Vorgehen, um die Anforderungen an ein gamifiziertes Lernprogramm und seine Eigenschaften im Hinblick auf die betriebliche Weiterbildung in der industriellen Instandhaltung zu erheben und zu spezifizieren?

Zur Beantwortung dieser Forschungsfrage wurde eine umfassende Literaturrecherche über menschliches Lernen, die Entwicklung von gamifizierten Anwendungen und Software, sowie zur technischen Anforderungserhebung durchgeführt. Auf dieser Grundlage wurden eine Morphologie zur Bestimmung der Spezifikationen einer gamifizierten Trainingsanwendung und ein Vorgehensmodell für dessen Entwicklung und Implementierung kreiert. Die Morphologie fasst alle signifikanten Merkmale eines gamifizierten Programms für Trainingszwecke in Kategorien zusammen und ordnet ihnen alle denkbaren Merkmale zu. Die vorgeschlagene Morphologie ist daher nicht nur ein Werkzeug zur Beschreibung eines Systems, sondern auch ein nützliches Werkzeug für den Entwurfsprozess. Insbesondere in Kombination mit dem entwickelten Vorgehensmodell hilft diese Morphologie, alle notwendigen Anforderungen an die Anwendung zu erfassen. Die verflochtene Anwendung der Morphologie und des Vorgehensmodells schafft somit die Grundlage für den Entwurf und die Entwicklung einer gamifizierten Anwendung für Trainingszwecke in der industriellen Instandhaltung.

Die entwickelte Morphologie und das Vorgehensmodell wurden durch eine Umfrage evaluiert und das generierte Expertenfeedback wurde genauestens analysiert. Auf dieser Grundlage wurden Verbesserungen an der Morphologie vorgenommen. Das Konzept des Vorgehensmodells konnte durch die Umfrage validiert werden.

Diese Arbeit trägt daher zum aktuellen Forschungsstand bei, indem sie zwei wesentliche Ergebnisse liefert: eine Morphologie, die wichtige Gamification Attribute für Trainingszweche in der Instandhaltung beinhaltet, sowie ein Vorgehensmodell zur Entwicklung und Implementierung einer gamifizierten Trainingsanwendung. Mit der Methodik dieser Arbeit wurde sichergestellt, dass sowohl die Morphologie als auch das Vorgehensmodell in einem Zustand sind, worauf weitere Forschungsarbeiten aufbauen können. Die Morphologie und das Vorgehensmodell sind bereit für eine Pilotanwendung und eine Erprobung in der betrieblichen Weiterbildung in der industriellen Instandhaltung. Die durch diese erste Anwendung gewonnenen Erkenntnisse können die Quelle für weitere Verbesserungen sein.

Abstract

Processes in industrial maintenance are changing substantially as a result of increasing complexity and automation in modern factories. This poses a challenge to a company's maintenance staff, whose job profile has to be adjusted to this development. As a result, employees must be prepared and trained for consequential new requirements. Gamification offers a novel and promising approach for filling competence gaps in the course of professional training. Literature on its application in industrial maintenance, however, is rare.

The aim of this thesis is to identify the necessary steps to specify requirements of a gamified application for professional training in industrial maintenance. One of the most consequential decisions in the development of a Gamification application for training has to be made regarding its purpose (i.e. skilling, upskilling or reskilling) and the type of training (on-the-job training or off-the-job-training). This specification has an influence on the design of the learning content in particular. Therefore, the following main research question has been defined: What is an appropriate step-by-step approach to extract and specify requirements of a gamified learning tool and its features with regard to professional training in industrial maintenance?

To answer this research question, a comprehensive literature research has been conducted on human learning, Gamification and software design, and requirements engineering. On this basis, a morphology for determining the specifications of a gamified training application and a procedural model for its development and implementation were developed. The morphology clusters all significant attributes of Gamification applications for training purposes into categories and ascribes all conceivable characteristics to them. Hence, the proposed morphology is not only a tool for describing a system, but also one that is useful in the design process. Especially in combination with the developed procedural model, this morphology helps to gather all necessary requirements to the application. The intertwined application of the morphology and the procedural model therefore creates the basis for designing and developing a Gamification application for trainings purposes in industrial maintenance.

The developed morphology and procedural model were evaluated by a questionnaire survey and the generated expert's feedback was analyzed in detail. Based on the results, improvements have been made to the morphology. Furthermore, the concept of the procedural model could be proven.

Hence, this work contributes to the field of gamified training in industrial maintenance by providing two main results: a morphology of Gamification attributes and a procedural model for the development and implementation of a gamified application. The methodology of this work ensured that both morphology and procedural model are in

a state that future research can build upon. Morphology and procedural model are ready for a pilot application and testing in professional training in industrial maintenance. The insights gathered through this initial application could be the source for further improvements.

Contents

1 Introduction

In this introductory chapter, the problem definition and the research goal will be outlined. The main research question, along with sub-questions and objectives, will set the framework of this master's thesis. In Chapter 1.2, the methodology and structure of the work will be described respectively.

1.1 Problem Definition and Research Objectives

Presently, operational maintenance is gaining significant importance for a company's productivity and profitability due to intensified market conditions[1]. At the same time, however, processes in industrial maintenance are changing substantially as a result of increasing complexity and automation in modern factories. This poses a challenge to a company's maintenance staff, whose job profile is changing. The respective qualifications and learning requirements have to be adjusted to this development as a result (Problem 1). In order to derive a suitable maintenance strategy, staff members must be able to interpret a variety of automatically collected data. Qualified employees need to understand production processes in their entirety in order to act effectively in case of an incident. This shows that employees must be trained for these new requirements[2], such as the ability to break down complex concepts into realistic work packages and flexibility in problem-solving[3].

In order to acquire the necessary skills to carry out maintenance tasks independently the training has to be practically oriented[4]. A significant amount of professional competences is acquired beyond off-the-job training but through experience within the work process (on-the-job training)[5]. However, machine failures are decreasing due to technological improvements. Therefore, learning opportunities are rare and it is getting more and more difficult to acquire the application-specific skills necessary in case of machine failure (Problem 2)[6]. As a result, there is a considerable danger of losing application knowledge and experience in industrial maintenance.

Furthermore, the use of technology-enhanced learning systems is recently getting particular attention. This concept describes the use of a wide range of information and communication technologies to enhance the learning process[7]. The appropriate design of such learning applications presents a major challenge (Problem 3). In fact, these applications must be designed to foster the acquisition of problem-solving skills. Even

[1] cf. Matyas, 2018, p. 30 f.
[2] cf. Haase & Termath, 2018, p. 223 f.
[3] cf. Erol, Jäger, Hold, Ott, & Sihn, 2016
[4] cf. Beuting & Termath, 2018, p. 267
[5] cf. Beuting & Termath, 2018, p. 269
[6] cf. Haase & Termath, 2018, p. 226
[7] cf. Sen & Leong, 2019

though learning of this character takes place in an environment different from reality, the specialists must still keep enough freedom to generate process-specific expert knowledge and to be able to access this knowledge situationally at a later date[8]. Also, through the technology induced shift from routine tasks to non-routine tasks[9] it is getting harder to determine the specific level of experience and competencies of a worker. But still, in order for upskilling measures to be effective, the individual knowledge of an employee must be taken into account[10].

In sum, the problems addressed in this thesis can be summarized as:

- P1: The qualifications and learning requirements of maintenance staff have to be adjusted to the developments in modern factories.
- P2: Learning opportunities in maintenance are getting rare due to technological improvements and it is getting more and more difficult to acquire the application-specific skills necessary in case of machine failure.
- P3: The appropriate design of technology-enhanced learning applications presents a major challenge.

The concept of gamification offers a novel and promising approach for professional training in maintenance. It uses elements of games in a non-gaming environment to enhance user experience and motivation. This method has already been successfully implemented for training purposes in areas such as healthcare and education[11]. Scientific research in these areas is already providing comprehensive insights into the practical use of applications of that kind. However, only little research has been conducted on gamification in the sector of industrial production and especially in maintenance[12].

Therefore, the aim of this work is to contribute to that field by providing both a morphology of Gamification attributes and a procedural model for the development and implementation of a gamified application. The main focus is to find out how the requirements of a gamification tool, that provides a training service to workers both on- and off-the-job, can be identified. The successful implementation of such a tool demands a deep understanding and analysis of possible requirements. The latest state of the art research does not provide a procedural model for defining requirements for a gamification tool for training purposes in industrial maintenance. This issue will be examined in the course of this master's thesis.

[8] cf. Haase & Termath, 2018, p. 226 f.
[9] cf. Mayrhofer, Ansari, Sihn, & Schlund, 2019, p. 5
[10] cf. Hailikari, Katajavuori, & Lindblom-Ylanne, 2008
[11] cf. Korn, Funk, & Schmidt, 2015b, p. 84
[12] cf. Warmelink, Koivisto, Mayer, Vesa, & Hamari, 2018, p. 1108

The problem definition resulted in a list of objectives of the thesis:

- Classification of gamification types, tools, features and application areas
- Description of serious games/gamification design and development methodologies
- Description of successfully implemented gamification applications in the industrial sector as well as in other sectors
- Identification of relevant methods and procedures for requirement analysis
- Design of a morphology and a procedural model for identifying requirements of Gamification tools and features in industrial maintenance with regard to personnel training
- Gathering expert feedback on the designed morphology's and procedural model's ability to define specific requirements and develop a Gamification application for training purposes in industrial maintenance

Based on the objectives of this thesis, the research question has been posed as follows:

What is an appropriate step-by-step approach to extract and specify requirements of a gamification tool and its features with regard to on- and off-the-job training in industrial maintenance?

The corresponding sub questions for P1, P2 and P3 are:

- How can gamification resolve the problem of changing learning requirements of workforces when skilling, upskilling or reskilling maintenance staff in a modern industrial environment?
- How can gamification provide maintenance staff with skilling, upskilling or reskilling opportunities?
- How to design and develop a gamification application for skilling, upskilling or reskilling maintenance staff?

Given the problem definitions, the research questions and the above defined objectives of the thesis, the following results of this work can be expected:

- A morphology that summarizes all essential attributes and characteristics of a gamified training application in a maintenance context.

- The application of this morphology as part of a procedural model that provides assistance in developing and implementing a gamification learning tool in the aforementioned context.

1.2 Methodology of Research

The methodology of this thesis is based on the design science research approach by Hevner et al.[13]. Following Hevner's guidelines, a thorough literature research to determine the need for such a morphology and procedural model has been carried out at the beginning. The non-existence of a morphology and procedural model of this kind ensures the problem relevance of this work. Based on the evaluated literature, the theoretical background on industrial maintenance, gamification, morphologies and requirements engineering has been described. The statements on industrial maintenance and gamification set the framework for the following chapters. Relevant methods for requirements analysis have been identified and their application have been described in detail.

The knowledge base, gathered from the literature research, has been the basis for the following design process. The insights into industrial maintenance and gamification, given the context of personnel training, in combination with the identified and suitable methods of requirements engineering has been used for designing the specific morphology and procedural model. This has led to a multi-step and problem-specific approach.

A morphology is a method that can be used for describing complex systems in a clearly arranged form. It gathers all significant attributes of a system and ascribes all conceivable features and characteristics to them. Thereby, a holistic and generic view of the system can be created[14]. Furthermore, it allows for classification of a particular system and illustration of correlations between all possible forms of a system[15]. This method has been used for gathering all identified and relevant characteristics concerning a gamified training application in maintenance.

In general, a procedural model is a description of a coordinated approach to the execution of a project. It defines both the input, which is necessary for completing the project, and the output, which is produced as a result of the project. A procedural model defines activities and specifies products that are the result of these activities. It also determines a certain order in which these activities are to be processed[16]. Thus, a procedural model provides direction and assistance in the implementation of a project.

[13] cf. Hevner, March, Park, & Ram, 2004
[14] cf. Ranz et al., 2018, p. 100
[15] cf. Abele et al., 2015, p. 3
[16] cf. Versteegen & Chughtai, 2002, p. 29

This method has been used for describing the necessary steps in the development and implementation of a gamified learning application in maintenance.

Subsequently, the quality and applicability of the morphology and procedural model has been rigorously demonstrated using a survey approach. For this purpose, a set of questions has been created to generate feedback on the work. The participants of the survey have been clustered according to their respective professional fields. Based on their field of expertise, the participants have been asked questions associated to their respective expert knowledge in order to increase the quality of the feedback. After that, the results of the survey have been interpreted and discussed and the quality and applicability of the designed morphology and procedural model will be proved.

This work is structured as follows: To establish the theoretical foundations, a comprehensive literature research was conducted. The results are described in detail in Chapter 2. This chapter covers relevant aspects of human learning, general aspects of Gamification and Gamification design, the basics of software development, morphologies and requirements engineering.

The practical part of this work includes the Chapters 3, 4 and 5. In Chapter 3, the morphology on Gamification, that has been developed in the course of this thesis, is presented. Chapter 4 describes the developed procedural model in detail. Chapter 5 focuses on the survey and the subsequent changes made to the morphology. In Chapter 6 the main findings are summarized in a conclusion and an outlook is presented. Figure 1 shows an overview of the chapters of this thesis and their interdependencies.

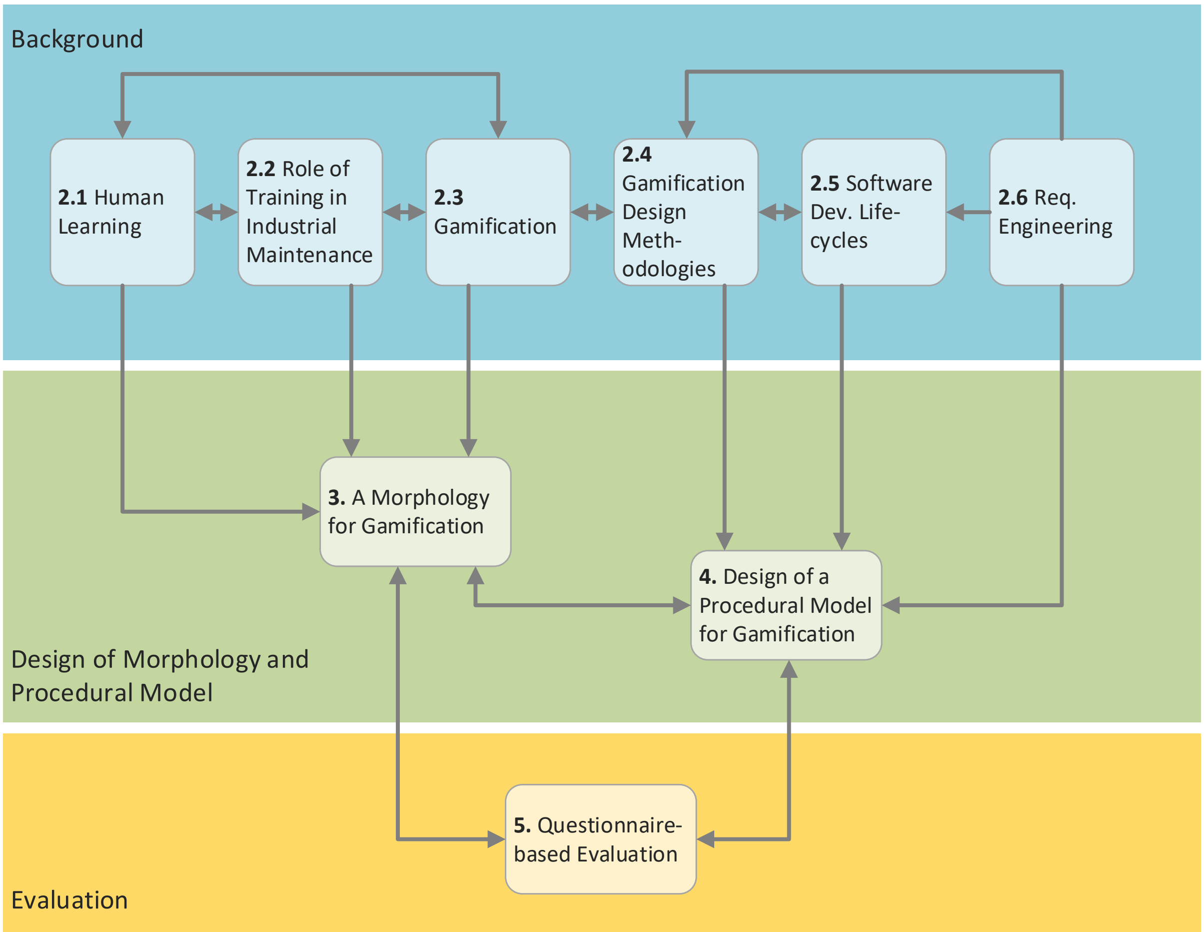

Figure 1: Overview and interdependencies of chapters

2 Theoretical Background and State-of-the-Art

In this chapter, the basis for developing the results (Chapter 3, Chapter 4 and Chapter 5) of the diploma thesis is created. At the beginning, the basics of human learning will be described. Afterwards, Gamification will be defined, described and popular application areas will be outlined. Methodologies for Gamification and software development will be described. Finally, the basics of requirements engineering will be presented.

2.1 Human Learning

Schunk defines learning as follows:

> *"Learning is an enduring change in behavior, or in the capacity to behave in a given fashion, which results from practice or other forms of experience."*[17]

The use of the term "behavior" already indicates the strong connection to the field of psychology in the context of human learning. Therefore, the beginning of this chapter will focus on the psychology of learning. Later, human labor productivity and failure will be described.

The learner's motivation to learn is a critical factor for successful education. Yet, cultivating this motivation is one of the most difficult tasks for instructors[18]. Therefore, a basic understanding for the mechanisms of human learning and motivation is inevitable when designing gamified learning modules. In the following, a few of the most essential motivational theories will be outlined, i.e. Maslow's hierarchy of needs, the ARCS model of motivational design, the self-determination theory, Fogg's behavioral model and the flow theory.

Maslow's hierarchy of needs[19]: Needs motivate people into actions. Maslow's hierarchy of needs is usually depicted as a pyramid with 5 levels (see Figure 2). The lower two levels are the basic needs, which are needs (e.g. food and safety) that have to be satisfied before needs of a higher level will influence the behavior. Level three and four are the so-called physiological needs (e.g. relationships and accomplishment), which become relevant once the basic needs are satisfied. On the top level are the self-fulfillment needs, that motivate an individual to pursue some kind of self-actualization. In a modern, western society, the lower levels of the pyramid are typically satisfied, which means that people are more driven by intrinsic motivators like autonomy, mastery and purpose.

[17] cf. Schunk, 2012, p. 3
[18] cf. Dichev, Dicheva, Angelova, & Agre, 2014, p. 82
[19] cf. Dichev et al., 2014, p. 82 f.; McLeod, 2007, p. 1 f.; Poston, 2009, p. 347 f.

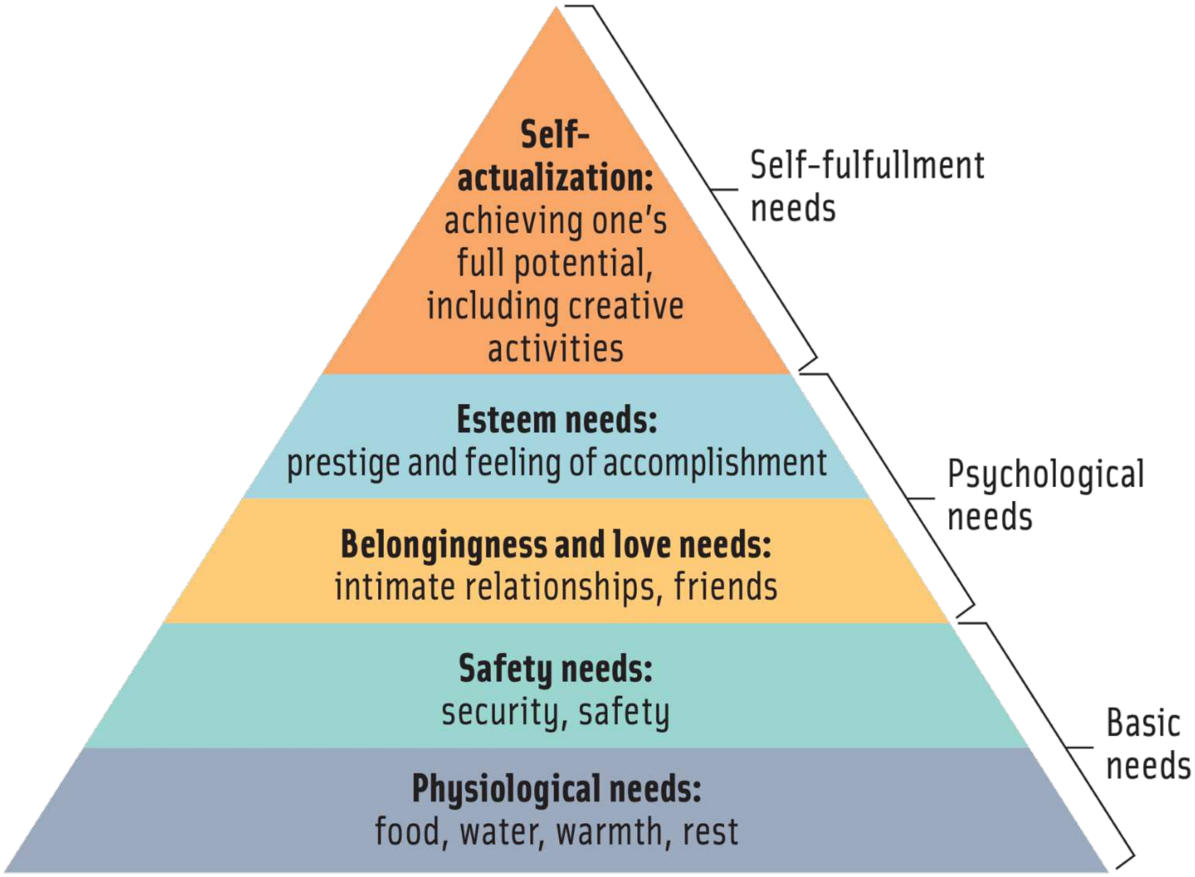

Figure 2: Maslow's hierarchy pyramid[20]

***ARCS model of motivational design**[21]:* The ARCS (attention, relevance, confidence, and satisfaction) model aims at building motivation in the context of instructional design. It provides a guideline on how specific motivational problems can be solved in the design process: The interest of learners must be captured, and their curiosity must be stimulated (attention). The learning content must meet personal needs and provoke a positive attitude (relevance). Furthermore, the learners must believe they are in control of their success (confidence). Finally, certain accomplishments have to be reinforced with rewards (satisfaction).

Self-determination theory: Based on this theory, humans continuously seek new challenges and experiences. This is because of the innate psychological needs of competence (i.e. need to control the outcome and experience mastery), relatedness (i.e. universal wish to interact) and autonomy (i.e. universal urge to be in charge of one's own life). Once these needs are satisfied, the individual will show higher levels of performance, persistence and creativity. The social environment, therefore, needs to nurture those needs[22].

[20] cf. Poston, 2009, p. 348
[21] cf. Dichev et al., 2014, p. 83 f.; Keller, 1987, p. 2 f.
[22] cf. Dichev et al., 2014, p. 84; Gagné & Deci, 2005, p. 336 f.

As mentioned in the definition of learning, behavioral change is the integral part of human learning. Both intrinsic and extrinsic motivation are driving forces behind behavior. Instructional design therefore requires a basic understanding of the theories of human behavior[23]. Some of the most essential theories are described below.

***Fogg's behavioral model**:* According to Fogg's behavioral model, behavior change is a function of three elements: motivation, ability and trigger[24]. The depiction of this model can be seen in Figure 3.

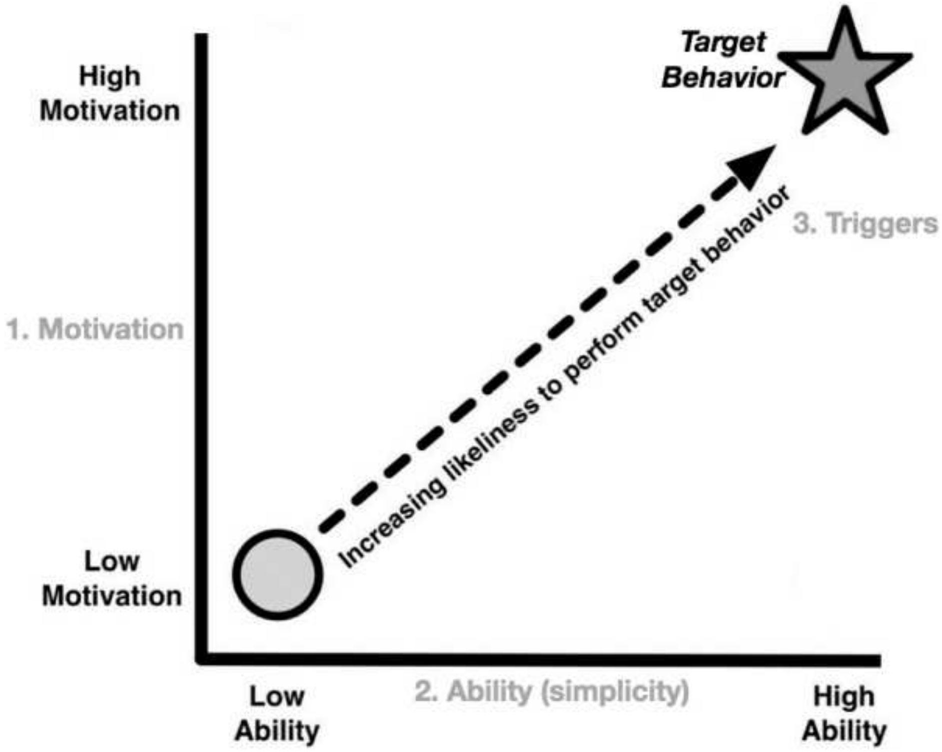

Figure 3: Fogg's behavioral model[25]

In order to change the behavior, an individual must be sufficiently motivated, must have the ability and must be triggered to change the behavior. All these factors must exist at the same time for successful behavioral change[26].

The goal of motivational design is to shift a user's state to the upper right. Insufficient motivation can be compensated by high ability to a certain degree. Vice versa, the likelihood for behavior change in the case of low ability can be increased by increasing the motivation. This implies that a trade-off between motivation and ability can be made to some extent. Without a trigger, however, the behavior will not be stimulated[27].

[23] cf. Dichev et al., 2014, p. 85
[24] cf. Fogg, 2009, p. 2
[25] cf. Fogg, 2009, p. 2
[26] cf. Fogg, 2009, p. 1
[27] cf. Dichev et al., 2014, p. 85 f.; Fogg, 2009, p. 2

Flow theory: In order to reach a motivational state of flow, certain conditions have to be met[28]:

- The activity has to have a clear set of goals, which gives it direction and structure.
- There has to be a balance of task difficulty and required skills. If one exceeds the other, the user might experience boredom or anxiety respectively.
- Clear and immediate feedback is given, which allows to adjust the actions while maintaining the flow state.
- The task is intrinsically rewarding.

During this flow, the user is in an optimal state, which is characterized by peak creativity and performance, immersion in the experience and gratification[29]. The user feels energized and believes in the success of the activity[30].

Table 1 shows a summary of this introduction to motivational theories.

Table 1: Summary of motivational theories

	Maslow's pyramid	ARCS model	Self-determination theory	Fogg's behavioral model	Flow theory
Main focus	Categorization and hierarchy of human needs	Motivational model for instructional design	Impact of psychological needs on human actions	Modelling the reasons for behavioral change	Description of a mental state causal for peak performance
Description	Five-tier hierarchical model of human needs, which categorizes all human needs from basic physiological needs (lowest level) to self-fulfillment needs	Guideline for solving motivational problems in the design process, from stimulating curiosity to rewarding accomplishments	The three innated psychological needs (competence, relatedness, autonomy) lead to desire for new challenges	Three elements (motivation, ability, trigger) are decisive of behavioral change. The model allows to understand and influence this process.	Once a task fulfills certain conditions, the task executor reaches a state of flow, where he/she experiences peak performance and gratification.

After this introduction to the basic concepts of human motivation, the focus is now moved to a more practical concept associated with human learning, i.e. the learning curve. Learning curves are a mathematical representation of the learning process that

[28] cf. Csikszentmihalyi, Abuhamdeh, & Nakamura, 2014, p. 232 f.
[29] cf. Dichev et al., 2014, p. 86 f.
[30] cf. Korn, 2012, p. 315

takes place during constant task repetition. With every iteration, the worker tends to demand less time due to familiarity with the task[31]. This way, the learning curve can be seen as a mathematical observation of continuous improvement[32]. Since the emergence of learning curves, they have been used for a variety of reasons in industrial work. The control of productive operations, the optimal allocation of tasks to workers based on their learning profiles and the measurement of production costs are among the most prominent application areas of learning curves[33].

Usually, learning curves are either displayed on an arithmetic scale using linear coordinates (curve) or on a double logarithmic scale (straight declining line)[34]. Two examples of these types of learning curves are shown in Figure 4.

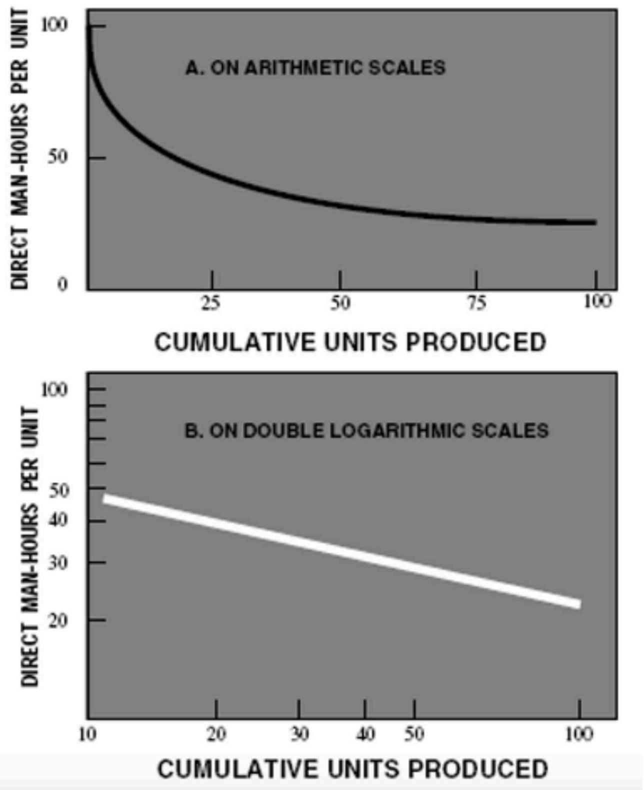

Figure 4: Example of learning curves[35]

The slope of the learning curve is affected by the capacity for learning in a process, which is the amount of direct human labor versus machine work. The higher the proportion of human work, the stepper the decline of the slope, because of higher learning capacity[36].

[31] cf. Anzanello & Fogliatto, 2011, p. 573 f.
[32] cf. Zangwill & Kantor, 1998, p. 910
[33] cf. Anzanello & Fogliatto, 2011, p. 580
[34] cf. Hirschmann, 1964, p. 3
[35] cf. Hirschmann, 1964, p. 3
[36] cf. Hirschmann, 1964, p. 4 f.

In industrial maintenance, learning curves are commonly used as well. The repetitive nature of maintenance work and the continuous efforts for more efficiency are the main reasons why maintenance departments usually show progressive learning[37]. Figure 5 shows two examples from the early days of learning curves in industrial maintenance. The left graph shows the declining man hours used for maintenance and shutdowns in a refinery. The right depiction shows the learning process of a maintenance department at an electric plant. With increasing number of replacements, the average time for a replacement decreases.

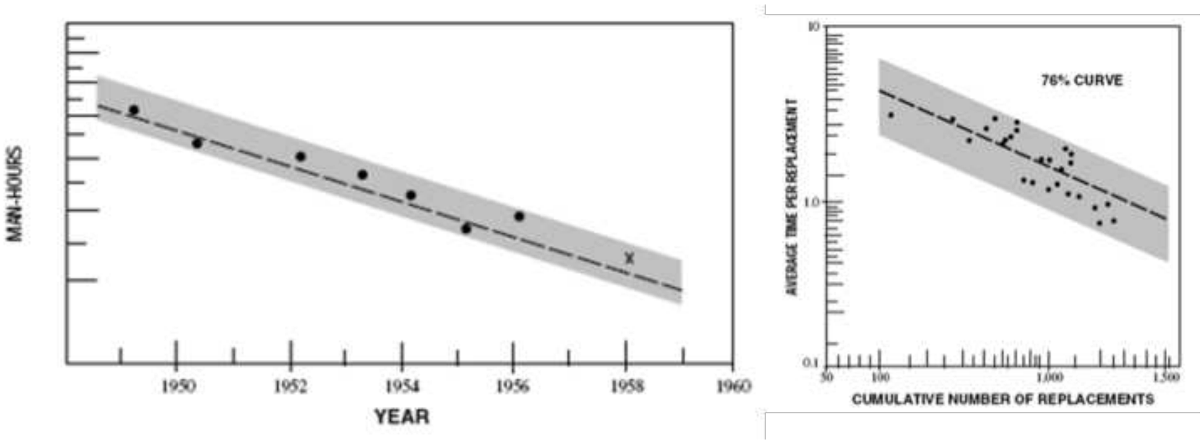

Figure 5: Examples of learning curves in industrial maintenance[38]

However, learning in a modern industrial context has become more complex. The emergence of collaborative robotics, data science and the Internet of Things has led to more automation and so called “Smart Factories”. As machines carry out more manual and cognitive tasks, human work needs to be more flexible and learning in factories has to be adapted to a concept of mutual learning. Digital learning profiles can be created for both human workers and machines, and their individual learning progress can be tracked, analyzed and estimated. The collection of data via sensors, monitoring systems and feedback provides the opportunity to identify and predict learning curves of human and machine workforces over time[39].

2.1.1 Human Labor Productivity and Failure

In general, human labor productivity describes the extent to which a firm’s workforce is efficiently creating output[40]. Very similar to the definition of labor productivity is the definition of labor performance, which determines the quality of work attained in a defined period of time[41]. There are a variety of performance shaping factors, both internal and external, that influence a human’s capability to reliably accomplish a given

[37] cf. Hirschmann, 1964, p. 15
[38] cf. Hirschmann, 1964, p. 15 f.
[39] cf. Ansari, Hold, Mayrhofer, Schlund, & Sihn, 2018, p. 62 f.
[40] cf. Datta, Guthrie, & Wright, 2005, p. 138
[41] cf. VDI, 2002, p. 3

task. Internal performing shaping factors relate to human physiological capacity (e.g. constitution and talent) and readiness (e.g. condition and motivation). The external factors describe the organizational (e.g. working hours, remuneration) and technical (e.g. machinery, task content) prerequisites[42].

In VDI 4006, human reliability is defined as follows[43]:

> *"Human reliability is the ability of a human being to perform a task in a given acceptance limit under predetermined conditions for a given time interval."*

A human working error then is any human action that exceeds these defined acceptance limits[44]. Based on these definitions two simple parameters can be derived, the human error probability (HEP) and the human reliability probability (HRP):

$$HEP = \frac{number\ of\ observed\ errors}{number\ of\ possibilites\ for\ an\ error}$$

Equation 1: Human error probability (HEP)

$$HRP = 1 - HEP$$

Equation 2: Human reliability probability (HRP)

The use of these parameters, however, requires a classification of possible human errors in an industrial context. Dhillon and Liu proposed a classification into six categories[45]:

1. Operating errors
2. Assembly errors
3. Design errors
4. Inspection errors
5. Installation errors
6. Maintenance errors

Kumar and Gandhi came up with a specific classification of maintenance errors[46]. This classification is shown in Figure 6.

[42] cf. VDI, 2002, p. 11 f.
[43] VDI, 2002, p. 11
[44] cf. VDI, 2002, p. 10
[45] cf. Raouf, Duffuaa, Ben-Daya, Dhillon, & Liu, 2006, p. 22
[46] cf. Aju Kumar & Gandhi, 2011, p. 1147 f.

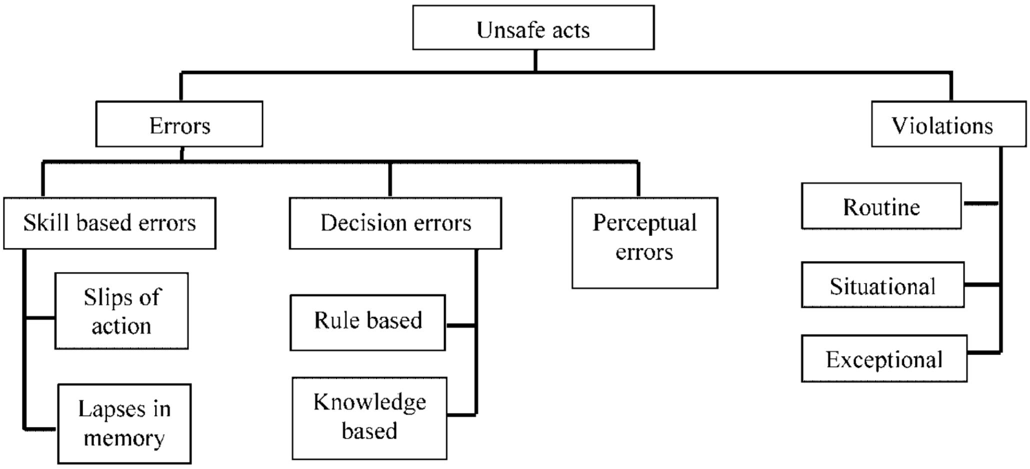

Figure 6: Classification of human error in industrial maintenance[47]

Human errors in industrial maintenance include three basic error types: Skill-based errors, decision errors and perceptual errors. Skill-based errors occur when the execution of well-rehearsed actions fails (e.g. incorrect sequence in a procedure, incomplete installation after repair, etc.). Decision errors can happen when a method has to be chosen to be applied to a certain situation (e.g. wrong procedure applied due to misdiagnosis). Perceptual errors usually occur when distance, speed, depth etc. is being misjudged. Violations, as opposed to human errors, are deliberate violations from procedure and therefore not classified under errors[48].

2.1.2 Acquisition of skills

According to Dreyfus, the process of adult skill acquisition takes place in five stages (see Figure 7)[49]. Whenever a learner is new to a task, the learning process starts at the “Novice” stage. At this stage, he or she has to learn and understand the facts and rules determining the action in a safe environment, without taking responsibility[50]. This knowledge will be applied to real situations in the next stage (Advanced Beginner). This gives the learner the chance to associate the facts and rules with context[51]. In stage three (Competence), the learner is turned loose. Having to make own decisions, he or she gets emotionally invested in the learning process, which leads to taking responsibility for unsuccessful choices, brooding over mistakes and increased motivation[52]. The main element of stage four (Proficiency) is experience. As risk-taking and commitment increase, the learner can more and more rely on made experiences in the decision-making process[53]. On the highest stage (Expertise) the skill has been

[47] Aju Kumar & Gandhi, 2011, p. 1148
[48] cf. Aju Kumar & Gandhi, 2011, p. 1147 f.
[49] cf. Dreyfus, 2004
[50] cf. Dreyfus, 2004, p. 177
[51] cf. Dreyfus, 2004, p. 177
[52] cf. Dreyfus, 2004, p. 178 f.
[53] cf. Dreyfus, 2004, p. 179

mastered and he or she usually responds intuitively to situations and knows immediately how to achieve the goal[54].

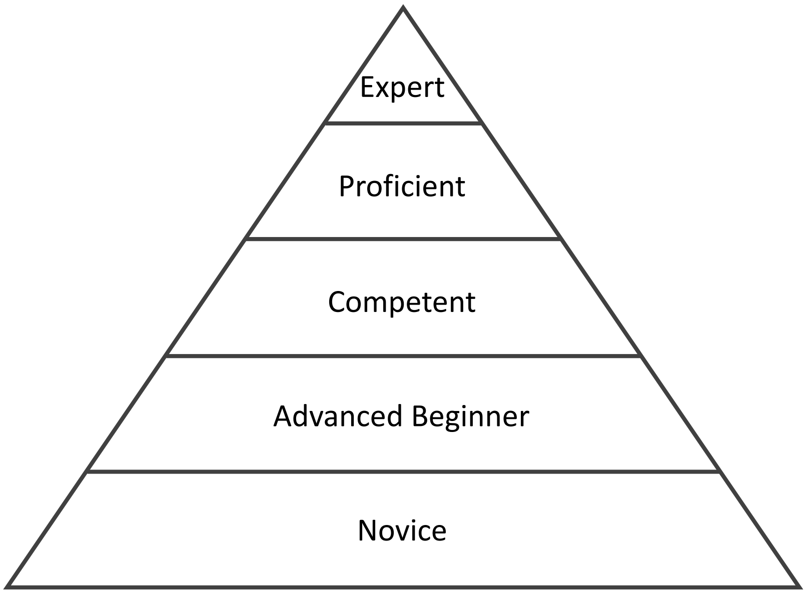

Figure 7: The Five Stages of Skill Acquisition[55]

This model gives a good understanding of the cognitive and emotional processes underlying adult skill acquisition. It explains how the gained experiences in the early stages of the learning process have an impact on the learner in the perfection of a skill. This model can also be used as a basis for designing difficulty levels of learning modules. For example, the first level would address a learner's novice stage and would give him or her the freedom to try things without having to take responsibility for the outcome. As the learner progresses through the levels, he or she faces reduced assistance, the motivation increases, and experience is gained. By completion of the last level, the learner should have mastered the skill and have the confidence to use the skill in reality.

In this sense, every process of skill acquisition consists of learning experiences. A learning experience describes any experience an individual can learn from. It can take place at any real-world location, as well as in any virtual environment or even in a combination of both. It can be completely spontaneous or fully designed, as long as is provides a learning outcome[56].

Learning objectives: The learning outcome is what a learner is expected to know, do or understand at the end of a learning process. The definition of a learning outcome takes into account the intended knowledge, skills and competencies[57]. The formulation of these competencies should always be phrased in a way that they can be used as

[54] cf. Dreyfus, 2004, p. 179 f.
[55] Own representation based on Dreyfus, 2004
[56] cf. https://lxd.org/fundamentals-of-learning-experience-design/ (accessed 7 September 2020)
[57] cf. European Centre for the Development of Vocational Training, 2017, p. 13 f.

learning objectives[58]. Such learning objectives describe the targeted learning outcome and the intended knowledge, skills and attitudes a person should have after the learning process[59]. The phrasing should ensure SMART (specific, measurable, achievable, relevant and timely) objectives[60].

Enke et al. developed a taxonomy for the formulation of learning objectives. In addition to the knowledge content, a learning objective contains a verb that describes the associated cognitive process. That means, the chosen verb expresses what the learner should actually be able to do with the learning content[61]. Figure 8 shows the mentioned taxonomy.

Complexity and action-orientation	level	description	verbs	
↑	create	organization of single elements to an ensemble, development of approaches and solutions	develop, create, plan, elaborate, design, produce	Address conceptual knowledge
	evaluate	carry out evaluations based on criteria and standards	evaluate, check, discover, test	
	analyze	segmentation of an object into its elements and analysis of relations between the parts	distinguish, differentiate, select, structure, contrast	
	apply	application of methods and approaches in a given situation	carry out, utilize, implement	Address technical and process knowledge
	understand	establishing connections between old and new knowledge, explain circumstances and give examples, compare objects	depict, illustrate, translate, conclude, assign, compare, explain	
	remember	repetition of learned information (facts, definitions, etc.)	name, list, repeat, describe	

Figure 8: Learning objective taxonomy[62]

[58] cf. Abel, Czajkowski, Faatz, Metternich, & Tenberg, 2013, p. 241
[59] cf. Enke, Kraft, & Metternich, 2015, p. 9; Northern College, p. 2
[60] cf. Northern College, p. 4
[61] cf. Enke et al., 2015, p. 9
[62] Enke et al., 2015, p. 9

In this taxonomy, the complexity level rises from bottom to top and various levels of knowledge are taken into account. By using these levels and key verbs in the formulation of learning objectives and competencies, they can be assigned different complexity levels[63]. For example, “evaluating a maintenance concept” requires a higher level of expertise and knowledge than “describing a maintenance concept”.

When designing learning modules for upskilling, the use of a taxonomy can guarantee the linguistic consistency in the formulation of targeted skills. Furthermore, such a taxonomy can make the comparison between a learner’s actual and target state of knowledge possible[64]. By associating one of the mentioned key verbs with the learner’s progress, the knowledge level can be classified.

On a political scale, the European Union is actively working on further developing standards for vocational education and trainings (VET). The European Union’s reference center for vocational education and training (Cedefop) is supporting the development of European vocational education and training policies and contributing to their implementation[65]. Especially the established European Credit System for Vocational Education and Training (ECVET) makes it easier for VET graduates to get validation and recognition of work-related skills and knowledge in other systems and countries[66]. The Cedefop furthermore developed a handbook for defining, writing and applying learning outcomes that aims at increasing transparency offered by learning outcome statements[67].

2.2 Role of Training in Industrial Maintenance

The field of activity of a maintenance technician is characterized by a high degree of heterogeneity, due to the large number of technologically different systems and the variety of work situations. The maintenance technician is also a decisive factor for a safe working environment. The broad spectrum of work situations can be characterized by a low degree of standardization of the activities, acute time pressure in troubleshooting, a high proportion of improvised actions and a low repetition rate. The high relevance of empirical knowledge and the few opportunities for the interpersonal exchange of these experiences therefore make ongoing training of maintenance personnel necessary[68].

Additionally, technological progress has changed working environments all the time. Obviously, insufficient training and skilling of personnel plays a significant role in the

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[63] cf. Enke et al., 2015, p. 9
[64] cf. Enke et al., 2015, p. 9
[65] cf. https://www.cedefop.europa.eu/files/8083_en.pdf (accessed 7 September 2020)
[66] cf. https://ec.europa.eu/education/resources-and-tools/the-european-credit-system-for-vocational-education-and-training-ecvet_de (accessed 7 September 2020)
[67] cf. European Centre for the Development of Vocational Training, 2017
[68] cf. Reichel, Müller, & Haeffs, 2018, p. 167 f.

occurrence of maintenance errors. Through training, companies can ensure that standard work practices are followed and less errors occur[69]. More than ever, the recent technological changes call for new competencies of workers in industrial environments[70].

Competencies of future production: Manufacturing processes are currently undergoing significant change. Concepts like the Internet of Things, Cloud-based Manufacturing and Smart Manufacturing are the drivers of a transformation towards full digitalization and intelligentization[71]. In 2014, Cedefop quantified the share of science and engineering professionals who experienced changes in the technologies used in the workplace within the past five years with 57%[72]. Furthermore, Cedefop lists both production workers, and science and engineering professionals as occupational groups with changing skills profiles[73]. This change requires human actors to adapt to these new requirements and acquire specific competencies. Erol et al. developed a competency catalog that distinguishes between different competence classes (such as personal, social, action-related and domain-related competences)[74]. Within every competence class, several required competencies for a future production requirement and their respective triggers are listed. A representation of this competency catalog is shown in Table 2.

Occupation standards: Another approach to classify a learner's competency level is the use of occupation standards. In Austria, Statistik Austria issues the Ö-ISCO 08, an adapted version of the ISCO (International Standard Classification of Occupations), tailored to Austrian demands[75]. This classification is based on two concepts: firstly, the concept of professional activity which is a set of tasks and duties that have to be carried out. Secondly, the concept of skills which are assigned a certain skill level. Ö-ISCO 08 contains four skill levels for the classification of professional activities and the consequential assignment to a professional group:

- Skill level 1: Professions at skill level 1 require the performance of simple, routine, manual tasks.
- Skill level 2: Professions at skill level 2 typically include the performance of the following tasks: operating machinery and electronic equipment; driving vehicles; repairing and maintaining electrical, electronic and mechanical equipment; and handling, organizing and storing information. Advanced writing and arithmetic skills and well-trained interpersonal communication skills are also required.

[69] cf. Dhillon, 2002, p. 128 f.
[70] cf. Erol et al., 2016, p. 6
[71] cf. Erol et al., 2016, p. 1
[72] cf. Cedefop, 2018, p. 23
[73] cf. Cedefop, 2018, p. 27
[74] cf. Erol et al., 2016, p. 2
[75] cf. Statistik Statistik Austria, 2008

Table 2: Classification and description of competencies for future production (Own representation based on Erol et al.[76])

Competency Classification	Level	Competency	Trigger
Personal	Worker / Engineer / Manager	Ability to see the opportunities fore one's own development	Present tasks will no longer exist in the future
		Commitment to lifelong learning	
		Critical attitude towards technological developments	
		Personal flexibility with regard to work time, work content and work place	Prerequisite for an agile production
Social / Interpersonal	Worker / Engineer / Manager	Ability to understand relations between processes, the information flows, possible disruptions and possible solutions	Integration and automation of processes leads to a responsibility for a broader scope of processes
		Flexibility in problem solving and creativity	Increasing scope and complexity requires networks of experts for solution finding and a social setting for creative activities
		Ability to communicate complex problems in different languages	
	Engineer / manager	Ability to build or act as mediators that enable social processes	
		Literacy with the different flavors of technical communication and cooperation systems	
Action-related	Worker / Engineer / Manager	Strong interdisciplinary "out-of-the-box" orientation	Facilitates solution finding in complex environments
	Engineer / Manager	Strong analytical skills	Digitalization of production leads to high financial and technological efforts
		Ability to find domain-specific and practicable solutions without losing the overall goal	
		Ability to break down complex concepts into realistic work packages	
		Ability to find and assign appropriate people and teams	
		Willingness to taking new routes while taking into account risk of failure	Industry 4.0 is no straight forward methodology
Domain-related	Worker / Engineer / Manager	Ability to understand the basics of network technologies and data processing	Production processes are digitalized and managed intelligently
		Ability to evaluate whether subsystems are functioning as expected and to interact with these systems through appropriate interfaces	
		Ability to analyze complex systems through specialized software	
	Engineer / Manager	Deep understanding of interrelations between electrical, mechanical and computer components	Necessary for developing innovative products and processes and to solve related problems in quality
		Ability towards abstract thinking and modeling with support of specialized software	Products and processes will increasingly be engineered through virtual representations
		Knowledge about state-of-the-art software architectures, modeling and programming techniques	Software and data are key elements for intelligent planning and control of machines and factories of the future
		Ability to use statistical methods and data mining techniques	
		Skills regarding new production processes	Advances in material technology
		Lean principles	

- Skill level 3: Professions of skill level 3 include the execution of complex technical and practical tasks, which require factual, technical and procedural knowledge in special areas.
- Skill level 4: Professions at skill level 4 include the completion of tasks that require complex problem solving and decision making, for which comprehensive theoretical and factual knowledge in specific areas is required (i.e. analysis, research and development; sharing knowledge with others; design of buildings

[76] cf. Erol et al., 2016

or machines and of processes). Skill level 4 usually requires three to six years of study.

From a maintenance standpoint and for the context of this work, workers of skill levels 2 to 4 are the most likely users of a gamified training application. The relevant profession groups of these levels are therefore briefly described in the following. Among graduate professions (skill level 4) Ö-ISCO 08 lists industrial and production engineers. They carry out research and design work and organize and monitor the construction, operation and maintenance of industrial production plants and the associated production processes. They are especially responsible for:

- Definition of programs for the coordination of production processes and assessment of cost-effectiveness and safety
- Setting standards and guidelines for installation, modification, quality assurance, testing, inspection and maintenance in accordance with engineering principles and safety regulations
- Performance of complex fault diagnosis and documentation of results
- Inspection of equipment to improve and maintain performance
- Managing the maintenance of plants and equipment and coordinating requirements for new designs, studies and maintenance plans

Mechanical technicians are assigned skill level 3. They perform technical tasks to support mechanical engineering research and planning, production, assembly, design, operation, maintenance and repair of machines, components and mechanical equipment. In detail, this group is responsible for:

- Technical support for research and development of machines and mechanical installations, equipment and components, or testing of prototypes
- Design and layout planning of machines and mechanical installations, equipment and components according to given specifications
- Monitoring the technical aspects of manufacturing, use, maintenance and repair of machinery and mechanical installations, equipment and components to ensure satisfactory performance and compliance with specifications and regulations
- Applying computer-aided maintenance systems, and calculating preventive maintenance intervals and technically implementing them in the procedures
- Carry out retrofits according to technical drawings, sketches and instructions
- Performing tests of mechanical systems, collecting and analyzing data, and assembling and installing mechanical components to support mechanical engineers

Skill level 2 includes plant operators. This group operates and monitors machines and systems with simple process control. Plant operators are specifically responsible for:

- Setting up, preparing and adjusting machines
- Coordination and monitoring of machine operations
- Checking the system for errors and monitoring the displays
- Conducting routine operational tests and organizing maintenance measures
- Recording data and keeping production records

The EU developed the European Qualifications Framework (EQF)[77] as a translation tool to make national qualifications easier to comprehend and compare. The EQF is an 8-level, learning outcomes-based framework for all types of qualifications that helps improving transparency and portability of people's qualifications across borders. The level increases according to the level of proficiency, with level 1 being the lowest and 8 the highest level. In order to provide the required comparability, the EQF is closely linked to national qualifications frameworks. In collaboration with the respective countries, the EU publishes "Referencing reports" for referencing the national qualifications frameworks to the EQF[78]. Table 3 shows an overview of the professional groups mentioned in Ö-ISCO 08 and their respective skill levels, both in Ö-ISCO 08 and the EQF.

Table 3: Overview of professional groups and titles with their respective skill levels

Professional group (Ö-ISCO 08)	Production- & maintenance-specific job titles (examples)	Skill level (Ö-ISCO 08)	EQF level
Managers	Managers in production and logistics	3 + 4	7 - 8
Graduate professions	Industrial & production engineers Mechanical engineers	4	6 - 8
Technicians	Mechanical technicians	3	5 - 6
Machine & plant operators	Machine operators Assembly technician	2	3 - 4
Auxiliary workers	All kinds of auxiliary workers Cleaning staff	1	1 - 2

In Germany, the Federal Employment Agency and the Institute for Employment Research publish an independent occupation standard, the KldB (Klassifikation der Berufe)[79]. The Kldb 2010 distinguishes between four different groups of workers in industrial maintenance, based on the respective competence level[80]. For every group,

[77] cf. https://europa.eu/europass/en/european-qualifications-framework-eqf (accessed 10 September 2020)
[78] cf. https://europa.eu/europass/en/reports-referencing-national-qualifications-frameworks-eqf (accessed 10 September 2020)
[79] cf. Bundesagentur für Arbeit, 2011
[80] cf. Bundesagentur für Arbeit, 2011, p. 304 f.

the required skills and tasks to be performed are listed. These range from simple assistance activities to highly complex tasks in the highest group.

So on the one hand, these occupation standards can be used for classifying a workers skill level. On the other hand, they can be used for extracting the required skills of maintenance personnel as input for designing the content of training modules.

2.3 Gamification

Collins dictionary defines the term "game" as follows[81]:

> *"A game is an activity or sport usually involving skill, knowledge, or chance, in which you follow fixed rules and try to win against an opponent or to solve a puzzle."*

After describing the meaning of the keyword "game", the term "Gamification" can be defined. The definition provided by Deterding et al. is[82]:

> *"Gamification is the use of game design elements in non-game contexts."*

The term "Gamification" emerged from the digital media industry in 2008[83]. Ever since, the market for the use of Gamification in an operational environment has grown rapidly. According to Google Trends[84], the number of search queries skyrocketed in the middle of 2010 and has continuously been on a high level since then. Companies identified Gamification as a concept that is capable of increasing the efficacy and effectiveness of their personnel and triggering customer activity[85]. The location-based social networking service "Foursquare"[86], whose purpose is sharing information about businesses and attractions, has been among the first companies to use the concept of Gamification for increasing user activity and retention[87].

Gamification is about understanding people's behavior, engaging people on an emotional level and motivating them to achieve set goals[88]. In order for behavior to change, Gamification must consider three aspects: a trigger, ability levels and motivation. The last two, however, are linked via a tradeoff. For example, if you have less ability, you have to have more motivation to change your behavior or to fulfill a task[89].

The underlying motivation system of Gamification is both extrinsic and intrinsic. It is extrinsic in a way that there are external influences like set goals or expectable rewards for completing tasks successfully. Intrinsic motivation in the context of Gamification comes from human needs like mastering certain skills, meeting challenges or doing something useful[90].

[81] cf. https://www.collinsdictionary.com/de/worterbuch/englisch/game (accessed 11 September 2020)
[82] cf. Deterding, Dixon, Khaled, & Nacke, 2011, p. 10
[83] cf. Deterding et al., 2011, p. 9
[84] cf. https://trends.google.de/trends/explore?date=2008-01-01%202020-09-11&q=Gamification (accessed 11 September 2020)
[85] cf. Strahringer & Leyh, 2017, p. 4
[86] cf. https://de.foursquare.com/ (accessed 11 September 2020)
[87] cf. Deterding et al., 2011, p. 9
[88] cf. Dale, 2014, p. 89
[89] cf. Dale, 2014, p. 85
[90] cf. Wiegand & Stieglitz, 2014, p. 325

The importance of a purposeful motivation and influence of the user on the successful application of Gamification is indicated by the variety of game design features (see Chapter 2.3.2). The use of these features and the related game design is crucial for bringing about "gameful" experience and other desirable psychological changes among users[91]. Landers et al. define the term "gameful experience" as follows[92]:

> *"A psychological state resulting from the interaction of three psychological characteristics: perceiving presented goals to be non-trivial and achievable, being motivated to pursue those goals under arbitrary, externally-imposed constraints, and the belief that their actions within these constraints are volitional."*

It should be noted though that Gamification can lead to gameful experiences with one user but does not do so with another user. This might be due to differences in skill levels of the two users[93].

2.3.1 Delimitation of other Applied Game Forms

The delimitation of the term "Gamification" to other forms of applied gaming is essential. Only through a sharp definition it is possible to illustrate the differences and to deduce optimal areas of application. The related terms that make a delimitation necessary are "Game-Based Learning" and "Serious Games"[94].

Game-Based Learning describes the basic concept of conveying learning content via a game or a simulation. Examples for this concept are strategy games, which train strategic thinking and a rational use of resources, and role-playing games, which teach different behavior patterns and the ability to understand different point of views. What's more is the opportunity to train social interaction, which is, to some extent, part of any game[95].

Serious Games are a variation of Game-Based Learning[96]. The term usually describes software-based games, which are used for training, instruction or simulation purposes[97]. Prominent examples for Serious Games are flight simulators in pilot training or virtual operating rooms for simulating difficult surgical procedures[98].

The delimitation of Gamification of the concept of Game-Based Learning is based on a subtle but momentous difference. While games are the basis of all learning and

[91] cf. Landers et al., 2019, p. 91
[92] cf. Landers et al., 2019, p. 84
[93] cf. Huotari & Hamari, 2012, p. 19
[94] cf. Strahringer & Leyh, 2017, p. 97
[95] cf. Strahringer & Leyh, 2017, p. 97 f.
[96] cf. Strahringer & Leyh, 2017, p. 99
[97] cf. Susi, Johannesson, & Backlund, 2007, p. 3
[98] cf. Strahringer & Leyh, 2017, p. 100

training activities with Game-Based learning, the concept of Gamification only uses certain game design elements, which are deployed in a value creation process and therefore in a non-game context[99]. Hence a Gamification application usually has no true storyline, unlike a Serious Game. The game design elements are usually integrated into an existing process or operation, without designing a whole game.

The following table presents a summary of the essential definitions which were introduced in the last chapters.

Table 4: Summary of the introduced game-related terms

Keyword	**Game**	**Gamification**	**Game-based Learning**	**Serious games**
Definition	A game is an activity or sport usually involving skill, knowledge, or chance, in which you follow fixed rules and try to win against an opponent or to solve a puzzle.	Gamification is the use of game design elements in non-game contexts.	Game-Based Learning describes the basic concept of conveying learning content via a game or a simulation (e.g. strategy games).	The term Serious Games, as a variation of Game-Based Learning, usually describes software-based games, which are used for training, instruction or simulation purposes.
Comparison	The concept of games is the basis for concepts like Gamification, Game-based Learning and Serious Games.	Gamification uses game design elements for increasing user activity for all kind of purposes and is deployed in a value creation process.	Game-based Learning is used for learning purposes, but ,unlike Gamification, it is not embedded in real processes.	Serious games adds technology and software to Game-based Learning.
Example	Sports, board games	Foursquare	Strategy games	Flight simulator

2.3.2 Game Features

Game elements are in literature usually referred to as game design features. There exists a variety of game design features that can be implemented in a Gamification application. Bharathi et al. have listed and defined the most commonly used game elements (see Table 5). Awarding points for certain achievements, the use of leaderboards, reaching higher levels, progress indicators and receiving badges are amongst the most prominent design elements used in practice[100].

[99] cf. Strahringer & Leyh, 2017, p. 97
[100] cf. Hamari, Koivisto, & Sarsa, 2014, p. 3 f.

Table 5: Definition of common game design features[101]

Game design feature	Definition
Achievements	A form of reward attached to performing specific actions
Avatars	Visual representations of players' characters
Badges	Visual representations of achievements
Boss Fights	Especially hard challenges at the culmination of a level
Challenges	Puzzles or other tasks that require effort to solve
Chance	Involvement of luck from a random mechanism
Collections	Set of items or badges to accumulate
Competition	Getting players to compete against one another
Content unlocking	Unlocks new levels/new features when players reach specific objectives
Cooperation	Getting players to work together to achieve a shared goal
Feedback	Information about how the player is doing
Freedom to fail	Failure is not penalized, but seen as part of the process
Gifting	Gives an opportunity to gift things such as lives/points to other players
Leaderboards	Visual displays of player progression and achievements
Levels	Defined steps in player progression
Points	Numerical representation of game progression
Progression	Game advancement is monitored over time
Quests	Predefined challenges with objectives and rewards
Resource acquisition	Obtaining a useful or collectible item
Rewards	Some benefits that go together for some action or achievement in the game
Social graph	Ability to track progress of friend and enables interaction
Storytelling	Some kind of narrative in the game
Teams	Defined group of players working towards a common goal
Transactions	Buying, selling or trading with other human players or automated players
Turns	Sequential participation by alternating players
Virtual Goods	game assets with perceived or real money value
Win states	The state that defines winning the game

In general, these game design features have the purpose of influencing the player's behavior. The player usually has to complete tasks which are directly linked to the objective of the Gamification application. By embedding game design features in the application, however, tasks are integrated that do not contribute directly to the achievement of the objective. But these features motivate the player to continue working on the tasks that are essential for reaching the application's objective[102].

Yet, some of these game design features are better suited than others for educational purposes. Especially five features are standing out in this context[103]:

- Freedom to fail: This feature provides an authentic learning environment. In the process of learning, failure is often more valuable than immediate success.

[101] cf. Bharathi, Singh, Tucker, & Nembhard, 2016, p. 364; Dichev et al., 2014, p. 92; Lopez & Tucker, 2017, p. 45
[102] cf. Lopez & Tucker, 2017, p. 43
[103] cf. Dichev et al., 2014, p. 92 f.

Thereby the learner is encouraged to take risks and experiment, and the focus is taken off the final result and put on the learning process.

- Rapid feedback: Immediate feedback allows the user to alter the behavior and achieve better results.
- Progression: Tracking the progression gives the user insight into his/her goals, behaviors and impact of actions. Progress visualizations are a key factor in motivating the user to stay committed.
- Rewards: The idea behind handing out rewards to the user is twofold. On the one hand, the anticipation of a reward should motivate the user prior to receiving the rewards. On the other hand, the user should feel satisfaction once he/she received the reward.
- Storytelling: A story provides the whole learning experience with relevance, meaning and some kind of structure. A story is also capable of creating a realistic context to the learning application.

2.3.3 Gamification Application Areas

Gamification can be applied in a variety of fields and for different purposes, as the following chapter will point out. Gamification applications have been successfully implemented in health, educational and industrial contexts. While Gamification in education has received a lot of attention in the past years, the number of works on Gamification in the industrial context is limited. As those two applications areas constitute the context of this work, insights into these two areas will be given in this chapter. In order to complete the picture of Gamification applications areas, prominent examples from health and business contexts will be given as well.

2.3.3.1 Gamification in Higher Education

The term "serious games" originated in education and was used for learning software with multimedia content and small educational games. Gamification also found its way into production, as the industry soon discovered the interesting opportunities of Gamification for educational purposes, especially for training and presenting instructions[104]. Nowadays, Gamification is widely used due to its high educational potential and its ability to motivate individuals[105].

In higher education, the ubiquitous presence of technology in classrooms has led to the digitalization of learning environments and to the possibility of incorporating game features into these environments[106]. Gamification as a tool for higher education is capable of increasing engagement, motivation, inspiration, and interest among students[107]. Furthermore, it can promote individual work and competition between

[104] cf. Korn, Funk, & Schmidt, 2015a, p. 2
[105] cf. Featherstone & Habgood, 2019, p. 150
[106] cf. Subhash & Cudney, 2018, p. 192
[107] cf. Fisher, Beedle, & Rouse, 2014

students[108]. In fact, studies have found that a gamified group within a classroom shows higher improvements in test scores[109] and practical assignments[110] as well as in perceived learning progress[111] than a non-gamified group. Regarding game features, Markopoulos et al.[112] determined achievements, levels, points, quests, status, and collaboration as most useful in the context of engineering courses.

In addition to higher education, there are nowadays a variety of applications and platforms the allow learners to educated themselves independently. Two prominent examples are Codecademy and Duolingo. Codecademy[113] is an example of a gamified online learning platform that teaches users to program in different languages (Java, Python, SQL, etc.). The progress of these coding classes is tracked by rewarding points and badges as well as by visualizing the user's learning progress. Duolingo[114] is another popular gamified learning platform that provides a variety of language courses. The platform is accessible via a website and a mobile app and allows to learn languages online, mobile and for free. It also uses a variety of game design features, like levels, streaks and points, to keep the user motivated long-term.

2.3.3.2 Gamification in an Industrial Context

The current body of literature on Gamification in the industrial context particularly focused on the execution and control of production and logistics processes, for example, seeking to influence workers completing their task in the actual production process[115]. The development of productivity-oriented technologies like industrial robots led to industrial work becoming simpler and more monotonous, which is detrimental for worker's motivation and increases the likeliness of mistakes[116]. Gamification has the ability to improve the working experience and motivation during repetitive tasks. It can increase the worker's intrinsic motivation by setting playful goals and giving constant feedback. It also allows for an improved flow experience with increased positive emotion and excitement level[117]. Furthermore, Gamification can serve as a social platform to encourage the exchange and expertise between workers with different skill levels and resulting in time-optimized instruction phases[118].

Using motion recognition, industrial work processes become more transparent and can be visualized in real-time. A vivid example is an assembly process which has been visualized in a Tetris-like game. During each assembly step, the color of the brick

[108] cf. De-Marcos, Domínguez, Saenz-de-Navarrete, & Pagés, 2014
[109] cf. Strmečki, Bernik, & Radošević, 2015
[110] cf. De-Marcos, Garcia-Cabot, & Garcia-Lopez, 2017
[111] cf. Stansbury & Earnest, 2017
[112] cf. Markopoulos, Fragkou, Kasidiaris, & Davim, 2015
[113] cf. www.codecademy.com (accessed 11 September 2020)
[114] cf. www.duolingo.com (accessed 11 September 2020)
[115] cf. Warmelink, Koivisto, Mayer, Vesa, & Hamari, 2020, p. 1 f.
[116] cf. Korn, 2012, p. 314; cf. Roh et al., 2016, p. 293
[117] cf. Roh et al., 2016, p. 293 f.
[118] cf. Lithoxoidou et al., 2020, p. 10

slowly changes from green to yellow and further to red and stops changing its color once the task is complete. In this way the user competes against his average task times. After a few process steps, the built brick rows disappear in an “explosion”, causing the user to earn points depending on the brick’s colors. Daily and weekly highscores can be tracked and the user can “level-up” as a representation of good work performance[119].

2.3.3.3 Gamification for Customer Activation and Retention

A lot effort has been made to integrate Gamification into business processes. Business paradigms, like “management by objectives”, already use Gamification elements like missions and goals implicitly, which ensures transparency and measurability and allows for easy visualization[120].

Gamification has also proven successful in increasing customer engagement by stimulating intrinsic and extrinsic motivations[121]. Gamification is a common tool in customer retention schemes like frequent flyer miles and supermarket loyalty cards. For example, loyal customers of Delta Airlines can earn points by using the company’s products (flights, credit card, etc.) and turn those points into real life rewards[122]. Another example is the Google Maps badge scheme, where users are encouraged to provide reviews, images and answer other user’s questions[123].

In a business context there is a wide range of Gamification applications as well. Apps like Nike+[124], Mint[125] and Foursquare[126] are some of the more popular ones that promise to make tasks of everyday day life, like exercising, financial planning and socializing, more enjoyable by using Gamification features. These applications allow the user to set, track and achieve goals and earn rewards. For example, Nike+ collects data about the user’s training statistics. Challenges can be set and goals and higher levels can be reached. Sometimes the user earns virtual trophies and gets pre-recorded congratulation messages by professional sport stars to further boost the user’s motivation[127].

2.3.3.4 Gamification in the Health Sector

In the health sector and especially in rehabilitation, where repeated exercises are a key factor for success, the use of Gamification was the logical consequence. One of the best-known early health games that needs to be mentioned was “Re-Mission”. It

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119 cf. Korn, 2012, p. 315
120 cf. Korn et al., 2015a, p. 2
121 cf. Hammedi, Leclercq, & Poncin, 2019, p. 10
122 cf. Delta Air Lines Delta Air Lines Inc., 2020
123 cf. Android Android Headlines, 2017
124 cf. https://www.nike.com/at/membership (accessed 11 September 2020)
125 cf. https://www.mint.com/ (accessed 11 September 2020)
126 cf. https://play.google.com/store/apps/details?id=com.joelapenna.foursquared&hl=de_AT (accessed 11 September 2020)
127 cf. Whitson, 2013, p. 166 f.

was designed as a third-person shooter game where young cancer patients fought against virtual tumor cells. This game eventually led to a higher reliability in medicine intake and to a certain behavioral change and positive psychological effects[128].

In addition to that, Gamification has also been adopted into health education. The "Wissenspflege game"[129] is a gamified learning application for nursing students. It provides assessment of the student's knowledge level, collaboration with classmates and teachers as well as monitoring learning progress and getting recommendations on learning materials. The student's knowledge level is assessed, and knowledge gaps are identified, resulting in scores, badges and leaderboards[130].

With increasing technological progress, the development of body-related sensors, such as Nintendo Wii & Microsoft Kinect, led to the emergence of a new branch in gaming and to health games becoming more physical. These technologies allowed for an implicit and more natural interaction, as the user's body became the controller. This also paved the way for the use of gamification in production, as the user ultimately becomes more efficient in moving and working and does not have to interact with regular interfaces like a mouse or a keyboard anymore[131].

[128] cf. Korn et al., 2015a, p. 2
[129] cf. http://www.wissenspflege.de/devWS1718/ (accessed 11 September 2020)
[130] cf. Khobreh, Ansari, & Fathi, 2015, p. 385
[131] cf. Korn et al., 2015a, p. 2

2.4 Gamification Design and Development Methodologies

Designing successful Gamification applications is a complex task. In order to achieve the desired user behavior and engagement, user motivation and skills have to be taken into account and the design has to be realized accordingly[132]. A good game designer understands how game mechanics influence human behavior and how and when to use them to promote a desirable result[133].

When designing a Gamification application for learning purposes, the approach is to break down the long-term goal of learning success into smaller objectives. Hereby the learner can focus on the carefully planned next step, which increases engagement and prevents the user from feeling helpless and disoriented. This also helps to track the learner's progress, assess his/her areas of difficulties and to give immediate feedback. Real-time feedback allows the user to feel comfortable in trying something new and provides the opportunity to adjust accordingly. As the user's skills improve throughout the learning process, the difficulty of the learning steps should increase as well to prevent boredom and frustration[134].

In this chapter some useful methodologies for Game and Gamification design will be discussed and their applicability for designing Gamification applications for upskilling in industrial maintenance will be evaluated.

2.4.1 Human- and User-Centered Design

Traditionally system design was technology-centered, which means that information was centered around their source (e.g. sensors). This design approach turned out to be inappropriate for comprehensive and high-performance tasks, as it resulted in frequent human errors, also called design-induced errors[135]. On the contrary, user-centered design (UCD) processes the information in a way that fits the goals, tasks and needs of the user. The superior objective of UCD is to obtain an optimal functioning of the human-machine-system, which should result in reduced errors and improved productivity, user acceptance and satisfaction[136].

Although UCD and Human-centered design (HCD) are often mentioned separately, there is only a slight difference. In ISO 9241-210 HCD is defined as follows[137]:

> *"Human-centered design is an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and*

[132] cf. Dichev et al., 2014, p. 88
[133] cf. Dichev et al., 2014, p. 91
[134] cf. Dichev et al., 2014, p. 91
[135] cf. Endsley, 2016, p. 5 f.
[136] cf. Endsley, 2016, p. 7
[137] cf. DIN ISO/FDIS 9241-210:2019, 2019, p. vi

usability knowledge and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability; and counteracts possible adverse effects of use on human health, safety and performance."

It appears that these two approaches are very similar to each other, as each one seeks to provide the end-user (or human) with a beneficial design. But still, there is a subtle distinction. As UCD might be the less emotionally empathetic approach, focusing more on the tangible and physiological aspects of the design, HCD prioritizes emotional and psychological preferences of the user[138]. In Table 6, the similarities and differences of HCD and UCD are summarized.

Table 6: Comparison of HCD and UCD

	Human-centered Design	**User-centered Design**
Main Focus	Emotional and psychological preferences of the user	Physiological aspects of human-machine-system
Characteristics	Design should support human well-being and user satisfaction as well as effectiveness and efficiency of the human-machine-system	Design should support the goals, tasks and needs of the user in order to obtain an optimal functioning of the human-machine-system
Similarities	Focus of design on human as a user	
Differences	Psychological focus (human) vs. Physiological focus (user)	

However, for the specific use case of designing a Gamification application of upskilling in industrial maintenance, the ongoing distinction between HCD and UCD is of minor importance. The principles of these approaches strongly overlap, and, for the sake of simplicity, a joint set of design principles will be used for this thesis. The combination of these two approaches will be referred to as "Human-User Centered Design" (HUCD) going forward.

ISO 9241-210 provides HCD with six key design principles[139]:

1. The design should be based upon an explicit understanding of users, tasks, and environments.
2. User should be involved throughout design and development
3. The design should be driven and refined by user-centered evaluation.
4. The process should be iterative.
5. The design should address the whole user experience (UX).
6. The design team should be multidisciplinary in terms of skills and perspectives.

[138] cf. Kent State Kent State University, 2018
[139] cf. DIN ISO/FDIS 9241-210:2019, 2019, p. 6

For UCD, Endsley states three essential principles[140]:

1. Technology should be organized around the user's goals, tasks, and abilities.
2. Technology should be organized around the way users process information and make decisions.
3. Technology must keep the user in control and aware of the state of the system.

As seen in Figure 9, on a conceptual level, the HCD process consists of four activities: i) understanding and specifying the context of use, ii) specifying the user requirements, iii) producing design solutions and, finally, iv) evaluating the design.

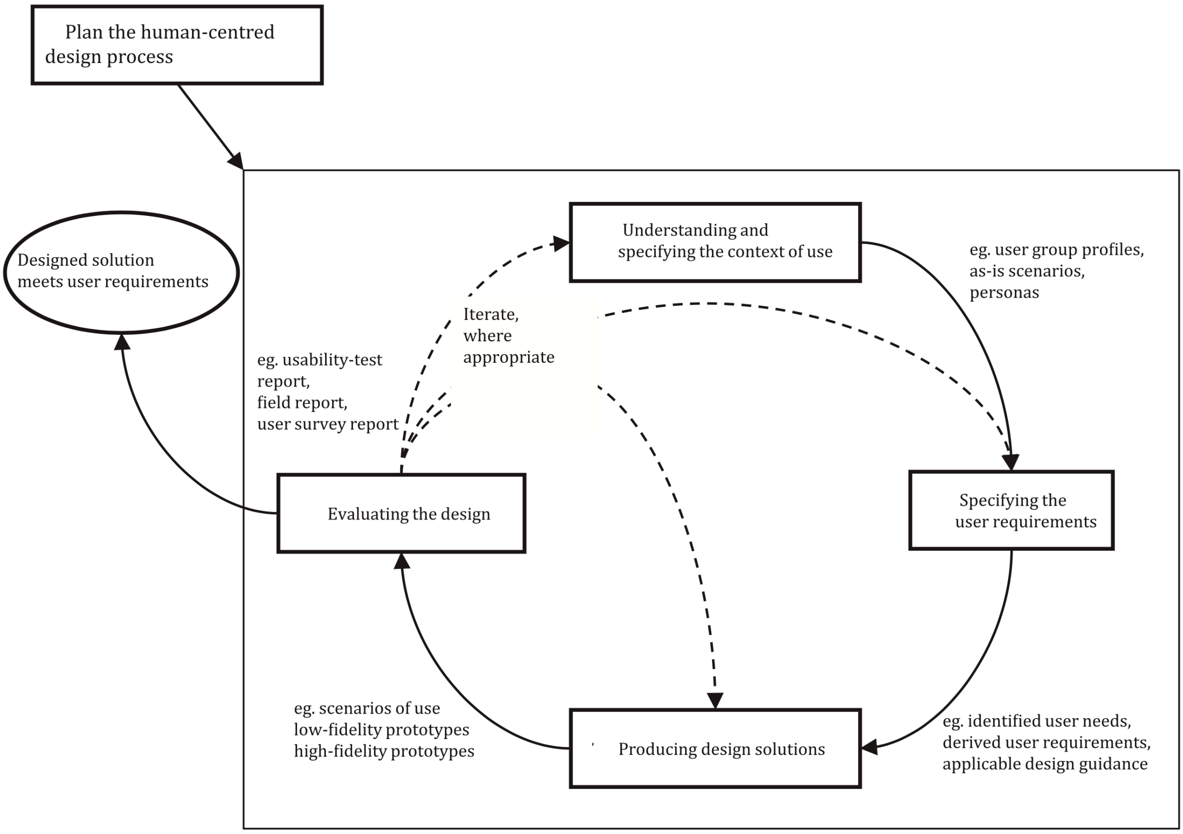


Figure 9: Activities in the development process[141]

For the design of training applications user focus naturally is essential. HUCD is applicable in diverse environments and is therefore able to manage diverse and potentially contradictory user requirements. The application of HUCD gives the design team the opportunity to take different user groups into account[142]. These are challenges and circumstances that would apparently apply to a training setting in an industrial context. Different user groups in a learning context emerge from different skill

[140] cf. Endsley, 2016, p. 9 f.
[141] cf. DIN ISO/FDIS 9241-210:2019, 2019, p. 12
[142] cf. DIN ISO/FDIS 9241-210:2019, 2019, p. 10 f.

levels and job profiles. Hence, the principles of HUCD constitute a useful input for drafting a procedural model for the design of an upskilling application.

2.4.2 Mechanics, Dynamics and Aesthetics

Mechanics, Dynamics and Aesthetics (MDA) is a formal approach to understanding the mechanisms of games. Conceptualized as an iterative methodology, it focuses on game design and tuning and allows to anticipate how changes to the framework of a game impact the overall game experience[143].

Hunicke et al. state that games can be basically modelled using three layers: mechanics, dynamics and aesthetics[144]. The mechanics layer consists of the various actions, behaviors and control mechanisms that the player is provided with. These are the particular components of a game, on the level of data representation and algorithms. In combination with the game's contents, the game mechanics support the overall gameplay dynamics[145]. The dynamics of a game describe the run-time behavior of the mechanics layer that results from player inputs and each other's output over time. The dynamics is responsible for the aesthetics experience of a game[146]. The third layer, the game aesthetics, describes the emotions and experiences of the player during gameplay[147].

When designing a game, it is essential to look at it from both the designer's and the player's perspective (see Figure 10). This helps to observe how small changes in one layer can affect other layers and thereby the whole UX. Using this model in iterative design and improvement, gives the design team the opportunity to control undesired outcomes and tune for desired behavior[148].

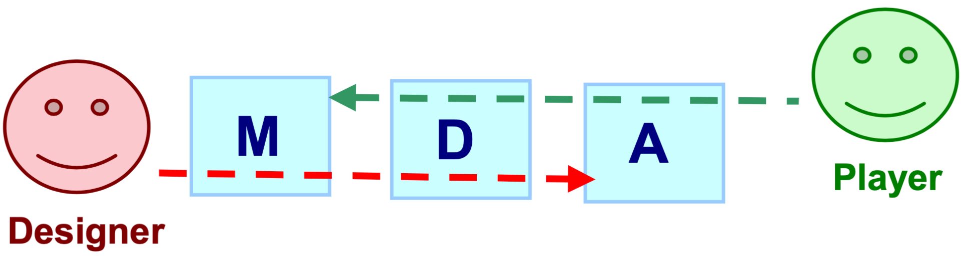


Figure 10: Designer and player perspectives in MDA[149]

Although the MDA methodology does not offer a procedural model, the MDA approach can be a useful tool in trying to understand how Gamification features work in gamified

[143] cf. Hunicke, LeBlanc, & Zubek, 2004, p. 1722 f.
[144] cf. Hunicke et al., 2004, p. 1723
[145] cf. Hunicke et al., 2004, p. 1723 f.
[146] cf. Hunicke et al., 2004, p. 1723 f.
[147] cf. Hunicke et al., 2004, p. 1723
[148] cf. Hunicke et al., 2004, p. 1723 f.
[149] cf. Hunicke et al., 2004, p. 1723

systems. MDA might prove especially beneficial in iterative design loops, when game features do not work as they are expected, and users do not show the desired behavior. In these cases, changes to the system have to be made, which need to be analyzed both from a designer's and a player's viewpoint. As MDA helps to anticipate and analyze how game features work and affect the learner, the application of this methodology should be considered in the initial decision process on game features as well.

2.4.3 Gameful Design

In order to change the user's behavior on a lasting basis, intrinsic motivation plays a more significant role than extrinsic motivation. Gamification, however, uses extrinsic rather than intrinsic rewards to motivate the user[150]. Gameful Design, on the other hand, addresses positive emotions like meaning and accomplishment. Another distinction is that Gamification adds game features and elements to an existing platform, whereas Gameful Design is integrated into the design and development process of a system from the ground up[151].

The associated term of "Gamefulness" is understood as the experiential and behavioral quality of gaming[152]. The resulting gameful experience (see Chapter 2.3) is a psychological state that is highly beneficial to user motivation. Gameful Design is the design process that provides a system with the ability to evoke gameful experience in a user[153]. Thus, effective gameful design means adding game elements or motivational affordances that are likely to increase the gameful experience, and thereby creating a gameful system[154].

Also, in Gameful Design, there are certain design principles that facilitate the successful application of the methodology[155]:

1. The design should target the satisfaction of basic needs (e.g. competence, autonomy, relatedness, curiosity, etc.).
2. The design should be based around inherent skill-based challenges (i.e. non-trivial challenges that arise from the system's goals).
3. Gameful Design should design for enjoyment, motivation and challenge as properties of a systemic whole of user-system interaction.
4. User goals and needs should be identified by formative research.
5. Formative research has to be synthesized into a form that informs that the ideation and evaluation of Gameful Design ideas.

[150] cf. Dichev et al., 2014, p. 93
[151] cf. Dichev et al., 2014, p. 94
[152] cf. Deterding et al., 2011, p. 11
[153] cf. Landers et al., 2019, p. 84
[154] cf. Landers et al., 2019, p. 87
[155] cf. Deterding, 2015, p. 305

6. The epistemic objects of game design have to be easily adoptable for interaction designers.

Deterding created a method for Gameful Design called “The Lens of Intrinsic Skill Atoms”, which is based on these design principles. This methodology depends on three concepts: design lenses, skill atoms, and intrinsic integration[156]. A design lens allows the designer to view the UX through the eyes of a single design principle. It combines a short and memorable name, a concise restatement of a design principle and a few focusing questions[157]. A design lens provides a generative and evaluative design guideline, that makes it an ideal starting point for gameful design[158].

A skill atoms describe feedback loops between the user and the game. These loops are arranged around certain central challenges or skills. Each skill atom consists of goals, actions and objects, rules, feedback, motivation, and an emergent challenge (see Figure 11)[159].

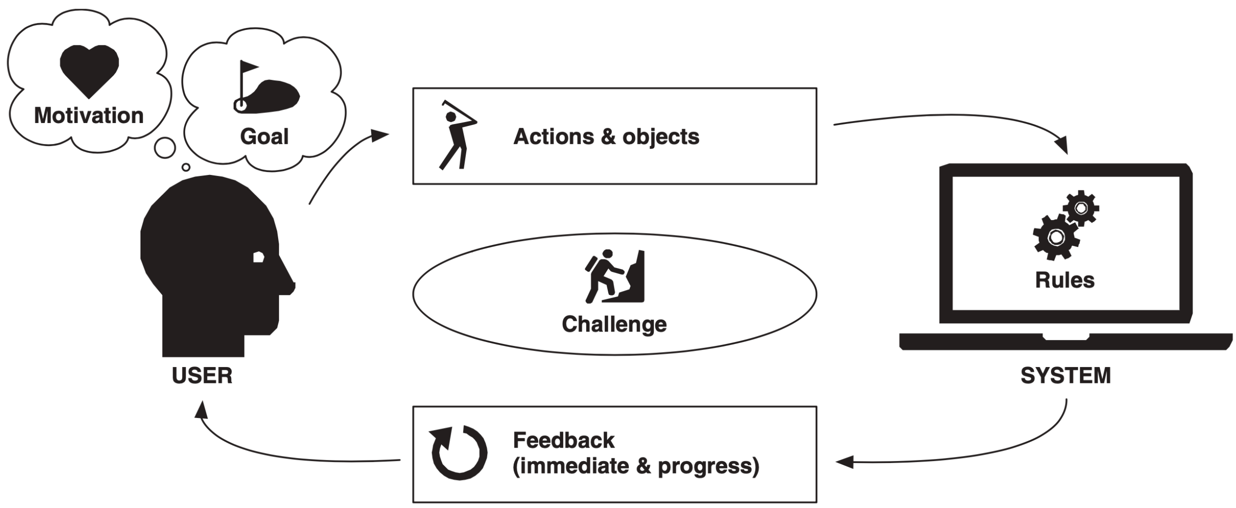


Figure 11: Schematic representation of a skill atom[160]

The combination of design lenses with skill atoms and intrinsic integration is the basic structural component of a gameful system. The user’s activity entails facing certain inherent and skill-based challenges during the pursuit of his needs. The gameful system supports the user’s needs by facilitating their attainment, removing extraneous challenges and by restructuring remaining inherent challenges into skill atoms[161]. Through repeated run-through of the atoms, the user masters the skill[162].

[156] cf. Deterding, 2015, p. 311
[157] cf. Scott, 2010
[158] cf. Deterding, 2015, p. 312
[159] cf. Deterding, 2015, p. 313
[160] cf. Deterding, 2015, p. 314
[161] cf. Deterding, 2015, p. 314 f.
[162] cf. Deterding, 2015, p. 313

It appears that Gameful Design makes sense from a didactic angle in the development of an upskilling application. If such an application evokes a user's intrinsic motivation, it should result in more sustainable learning effects compared to learning solely based on extrinsic motivation in the form of game features of classic Gamification. Yet, it is highly unlikely that a whole system for upskilling in industrial maintenance will be developed based on gameful design exclusively. This is due to the fact that machines or systems, where gamification will be implemented, already exist and are in use. So adding game features to existing platforms is the norm, when designing gamified systems in an industrial context.

The gameful design principles, however, can be used in the development of Gamification applications to ensure a gameful experience. Especially the consideration of the concept of "The Lens of Intrinsic Skill Atoms"[163] might prove useful in the development of gamified upskilling applications. Certain skills, that a maintenance engineer has to master, can be designed as skill atoms. Based on job profiles and the user's actual skill levels, individual goals can be associated with certain skill atoms. In combination with an appropriate motivational design, game mechanics and immediate feedback, the concept of skill atoms is well suited in designing courses for upskilling. The repeated run-through of the skill atom loop should lead to the mastery of the respective skill.

2.4.4 Morschheuser's Gamification Design Methodology

Morschheuser et al. developed a methodology for engineering gamified software that is based on an extensive literature research on the topic and comes along with a comprehensive list of design principles. These are reflected in different phases of the methodology. In the following is a list of the defined design principles[164]:

1. User needs, motivation and behavior, as well as the characteristics of the context should be analyzed.
2. Project objectives have to be identified and defined clearly.
3. Gamification design ideas should be tested as early as possible.
4. The design process should be iterative.
5. Profound knowledge in game-design and human psychology should be in place.
6. Gamification as the right choice to achieve the objectives should be assessed.
7. Stakeholders and organizations must understand and support gamification.

[163] cf. Deterding, 2015
[164] cf. Morschheuser, Hassan, Werder, & Hamari, 2018, p. 219 f.

8. Focus during the ideation phase should be put on user needs.

9. Metrics should be defined and used for the evaluation and monitoring of the success, as well as the psychological and behavioral effects of a gamification approach.

10. Control for cheating should be implemented.

11. Gamification design should be continuously monitored for optimization.

12. Legal and ethical constraints should be considered in the design phase.

13. Users should be involved in the ideation and design phase.

The procedural model by Morschheuser et al. is outlined in a detailed process visualization[165]. The elaborate methodology, in combination with some of the stated design principles, is a useful starting point for adapting a gamification design methodology for the specific application area of industrial maintenance.

2.4.5 Octalysis

Octalysis by Yu-kai Chou is a human-centered gamification design framework that focuses on behavioral design and the eight core drives of motivation. This methodology is based on an Octagon shape with one of the eight human core drives on each side[166] (see Figure 12).

According to Chou, every action a game user takes, is based on one of the eight core drives. These drives are[167]:

- Meaning
- Accomplishment
- Empowerment
- Ownership
- Social influence
- Scarcity
- Unpredictability
- Avoidance

The left side of the Octagon shows the right brain core drives, which function as intrinsic motivators, whereas the right side shows the left brain core drives (intrinsic motivators). The drives can also be clustered into positive motivators (top drives in the octagon) and negative motivators (bottom core drives). In order to design for these

[165] cf. Morschheuser et al., 2018, p. 232
[166] cf. Chou, 2015
[167] cf. Chou, 2015

core drives, they are linked with the respective game features that trigger them. For example, ownership can be felt by handing out virtual goods in a game. Easter Eggs are commonly used to add an unpredictable facet to a game [168].

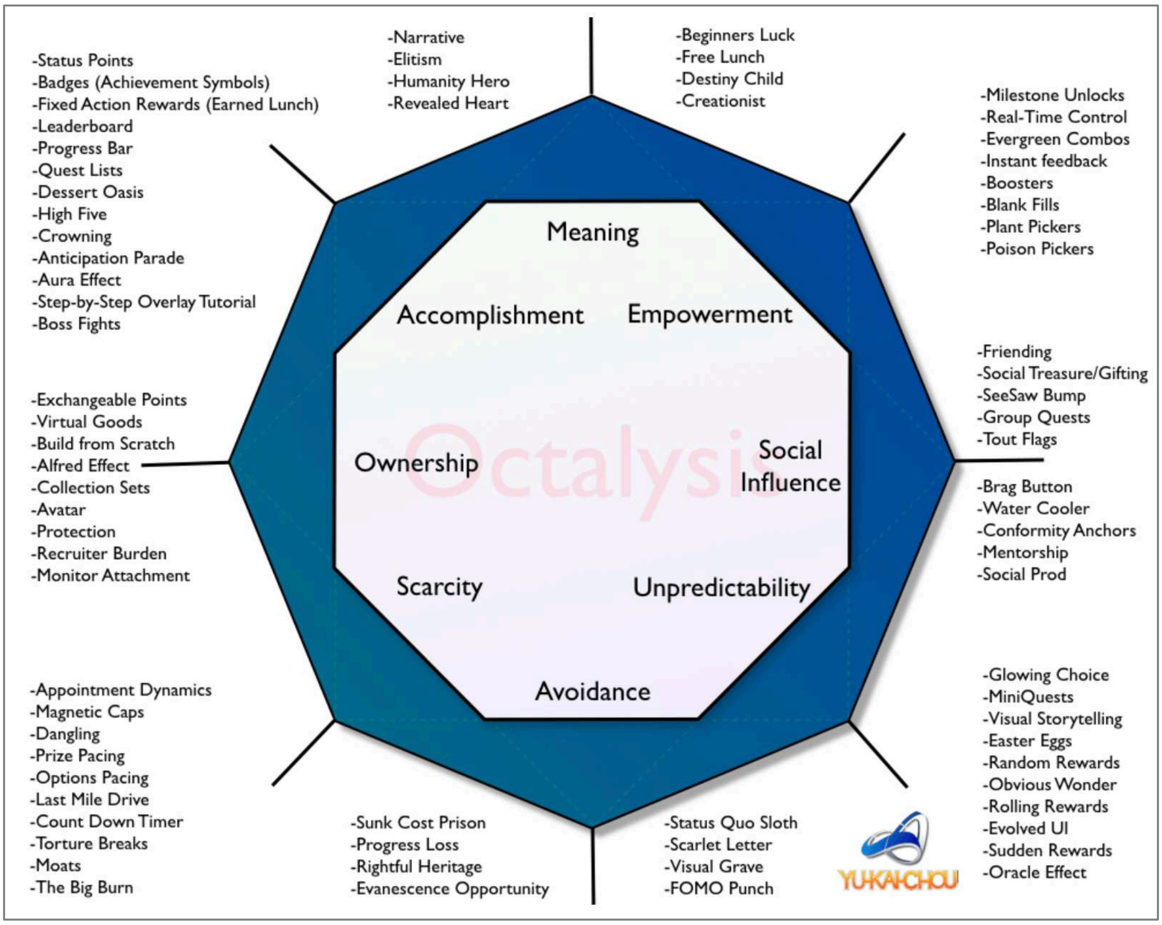


Figure 12: The Octalysis framework[169]

Hereby, the application of the Octalysis methodology provides useful assistance in designing the motivational aspects of a Gamification application. It shows an overview of motivators and the respective design features that trigger these motivators. However, Octalysis is not a complete design methodology, as it does not reference on how to implement game features. This makes the combination with other game design methodologies inevitable.

2.4.6 Comparison of the Methodologies

In the following, the previously described Gamification design and development methodologies will be compared. Table 7 presents an overview of these methodologies. Based on an analysis in selected categories, similarities and differences can be seen in the following table.

[168] cf. Chou, 2015
[169] cf. Chou, 2015

Table 7: Comparison of the Gamification design and development methodologies

	HCD/UCD	Gameful Design	MDA	Morschheuser' Design methodology	Octalysis
Description	Developing effective and efficient systems by focusing on the needs and requirements of the user	Design of gameful systems that work with intrinsic motivators; gameful design is integrated into the design of the system from ground up	Framework to analyze games based on the 3 components mechanics, dynamics and aesthetics; how they relate to each other and influence UX	Based on an extensive literature research Morschheuser et al. formulated 13 design principles. These were the basis for building a detailed design method for gamified systems along with a detailed process visualization.	Human-centered design framework that focuses on the 8 core drives of motivation.
Relates to games/gamification exclusively	No	yes	yes	yes	yes
Includes a procedural model	yes	yes	no	yes	no
Includes design principles	Yes	Yes	no	yes	no
Covered phases	Preparation – Design; Evaluation	Preparation – Design	Analysis – Design; Evaluation	Preparation - Monitoring	Analysis - Design
Method suggestions	yes	yes	no	yes	no
iterative	yes	yes	yes	yes	no
Considers motivation	No	yes	no	yes	yes
Motivational aspects (Intrinsic / extrinsic)	-	intrinsic	-	intrinsic	both
Considers User Experience	yes	yes	yes	yes	no

2.5 Software Development Lifecycles

Organizations vary by size and complexity, and their processes need to be developed in consideration of the respective business models and corporate culture[170]. This applies to the development of software as well. As a result, there are numerous different models for software development, each with its own characteristics. The choice of a particular lifecycle model should be made based on the specific requirements of the project[171]. In the following, some of the most prominent software development lifecycles will be described, as these models present the basis for the design of a procedural model for gamified training applications in industrial maintenance.

The Waterfall Model: The model, as it is known today, goes back to Winston Royce in 1970[172]. At the time, the novelty was that requirements were defined prior to any design or development steps[173]. A representation of the waterfall model is shown in Figure 13.

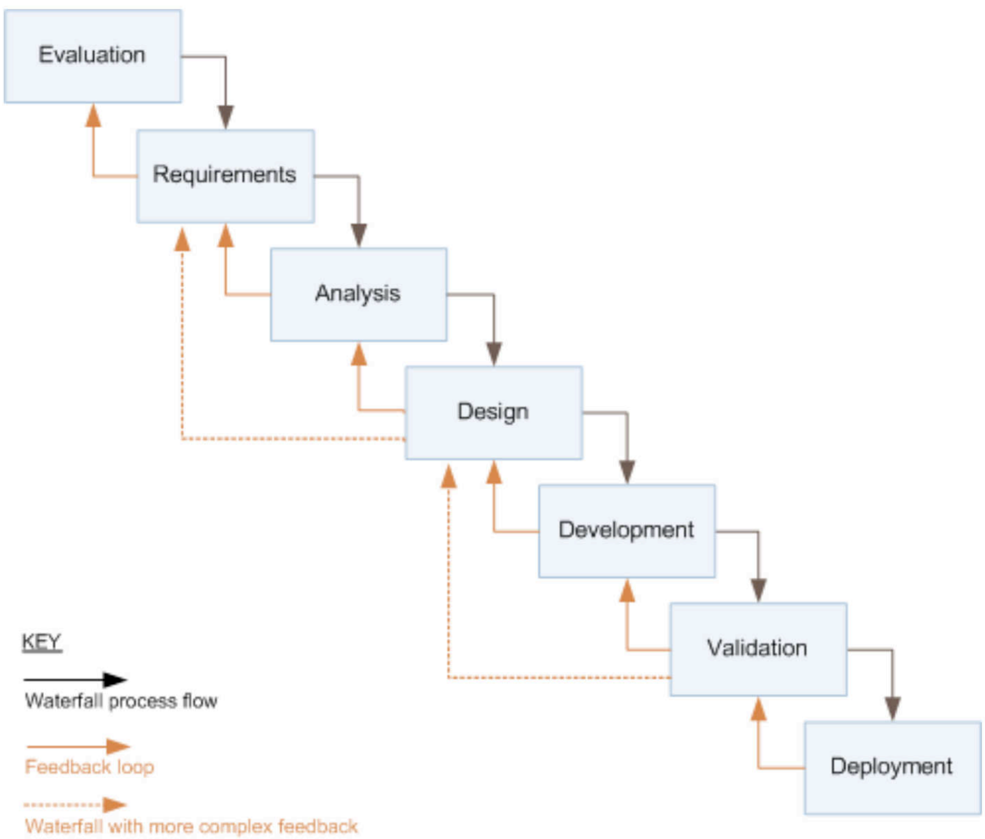


Figure 13: The waterfall model[174]

[170] cf. O'Regan, 2017, p. 8
[171] cf. O'Regan, 2017, p. 9
[172] cf. Royce, 1970
[173] cf. Ruparelia, 2010, p. 8
[174] Ruparelia, 2010, p. 9

A characteristic of this model is that there are always feedback loops to the previous stages. In this way, stages can overlap, while preceding stages are revisited. This also leads to the possibility of requirements and design being redefined, if it becomes necessary through testing[175].

V-Model: The V-model is a modification of the waterfall model, which is folded at the development stage[176]. A depiction of the V-model is shown in Figure 14.

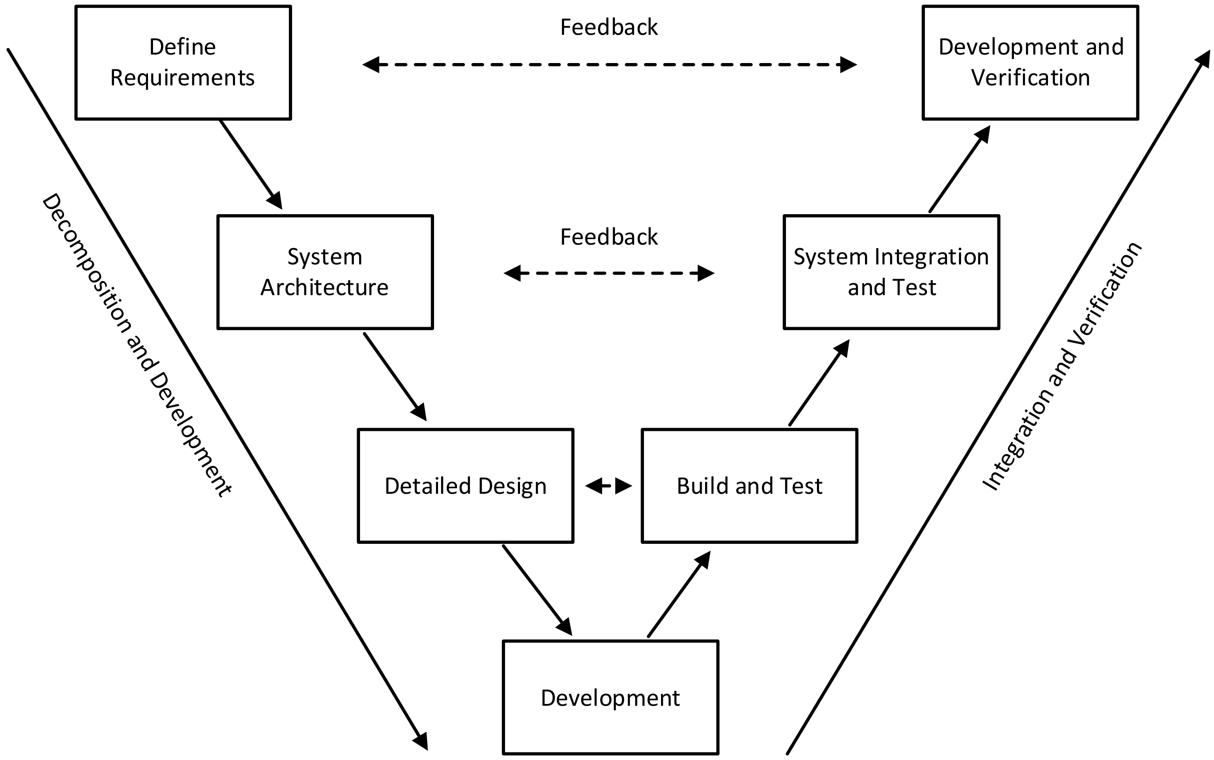


Figure 14: The V-model[177]

The left side of the V depicts the increasing decomposition and definition of requirements and design into ever smaller components. The right side shows the integration and validation of these system components. The symmetry of the model allows for feedback to be exchanged between the respective steps on the left and the right side of the V. This ensures proper verification and quality assurance processes, as well as SMART requirements and design[178].

Spiral Model: The spiral model of software development was developed by Boehm in the late eighties through various refinements of the waterfall model[179]. It is constructed

[175] cf. Ruparelia, 2010, p. 8 f.
[176] cf. Ruparelia, 2010, p. 10
[177] Ruparelia, 2010, p. 10
[178] cf. Ruparelia, 2010, p. 10
[179] cf. Boehm, 1988, p. 64

as an iterative model, with several iterations that spiral out as the project progresses[180]. Figure 15 shows a representation of the spiral model.

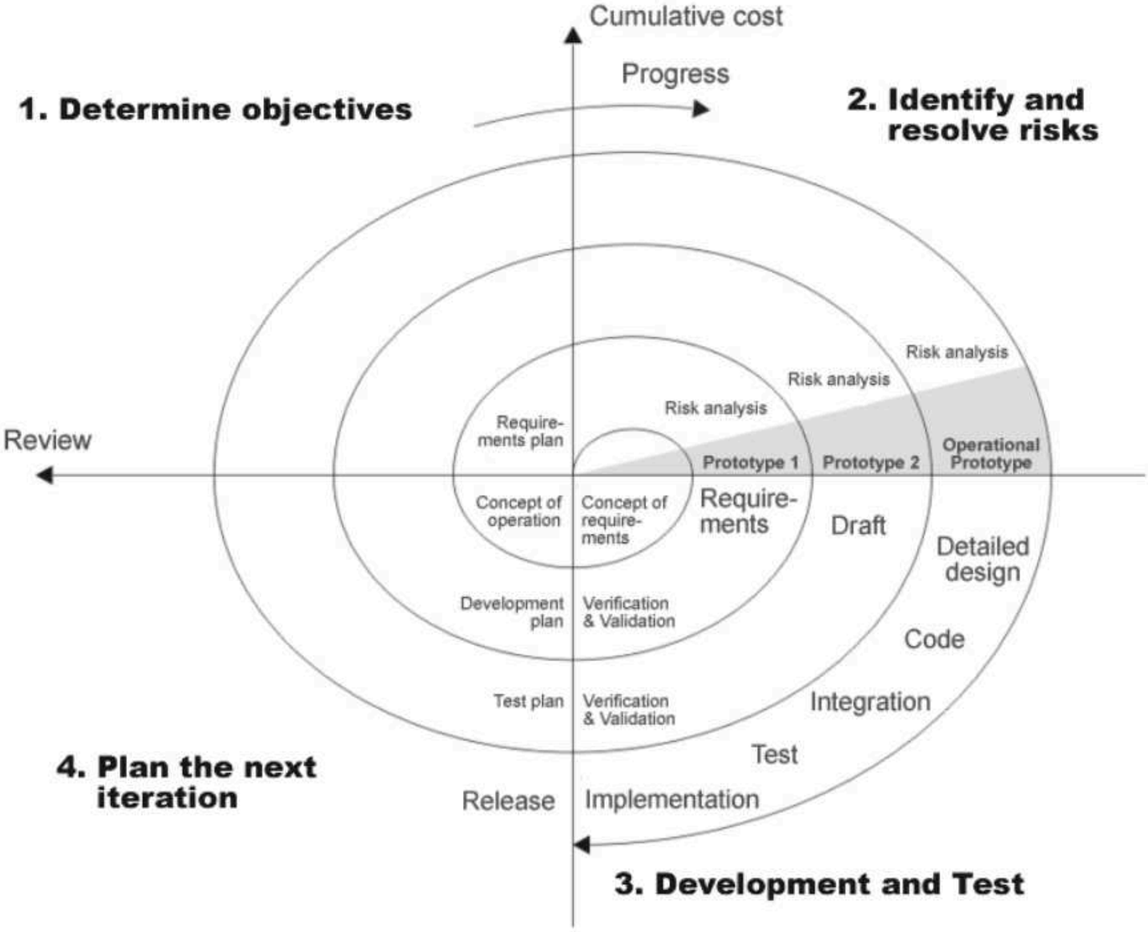


Figure 15: The spiral model[181]

This depiction shows that the spiral model is composed of four quadrants: “Determine objectives”, “Identify and resolve risks”, “Development and Test” and “Plan the next iteration”. Each iteration consists of a run-through of all four quadrants. Furthermore, a prototype is built and tested, and risks are identified and managed in each cycle[182].

Agile Software Development: The use of agile methods has massively grown in popularity. These methods tend to be more responsive to customer requirements than traditional methods (e.g. waterfall)[183]. They provide opportunities to assess the project’s direction throughout the life cycle[184].

Part of the agile mindset is that ongoing changes to requirements are considered normal. This calls for short cycle times, and iterative and incremental development[185].

[180] cf. Ruparelia, 2010, p. 10
[181] Ruparelia, 2010, p. 10
[182] cf. Ruparelia, 2010, p. 10 f.
[183] cf. O'Regan, 2017, p. 12
[184] cf. O'Regan, 2017, p. 297
[185] cf. O'Regan, 2017, p. 13

Every aspect of the development process is continuously revisited during the project. This leads to frequent delivery of partial solutions, which are evaluated and used as the basis for the following iteration. Advocates of agile software development believe that it leads to higher quality of output and increased productivity[186].

Scrum is one of the most renowned agile methods. The main development phase consists of a set of sprint cycles. Before the start of each iteration, sprint planning is performed, where user stories are assigned to the sprint. A user story usually adds a new feature or modifies an existing one. During each sprint, which has a fixed length, a new increment of the final product is developed. After an iteration, the sprint is reviewed, and feedback and new requirements are gathered. These will be taken into account for planning the next sprint[187]. The following figure shows a typical Scrum iteration.

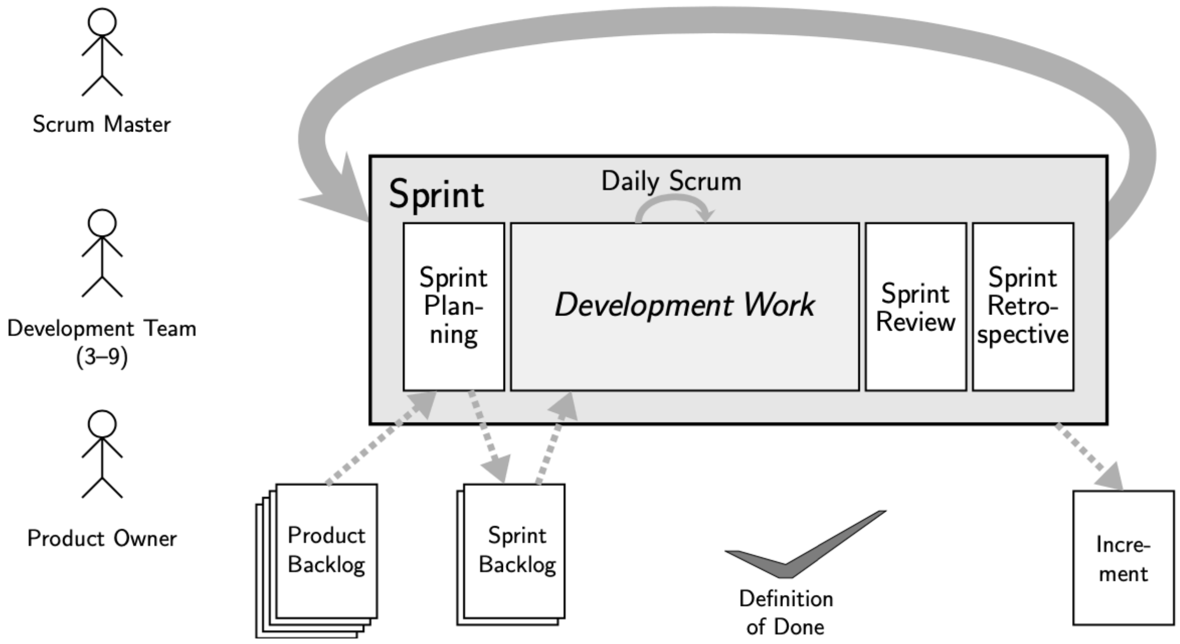


Figure 16: The Scrum methodology[188]

Game Development Software Life Cycle: When developing a game, simply adopting a software development life cycle is not enough. The different challenges and needs of this application area require a different approach[189]. Ramadan and Widyani[190] developed a life cycle model for this purpose (Figure 17).

[186] cf. O'Regan, 2017, p. 297 f.
[187] cf. O'Regan, 2017, p. 298 f.
[188] Kneuper, 2018, p. 104
[189] cf. Ramadan & Widyani, 2013, p. 95
[190] Ramadan & Widyani, 2013

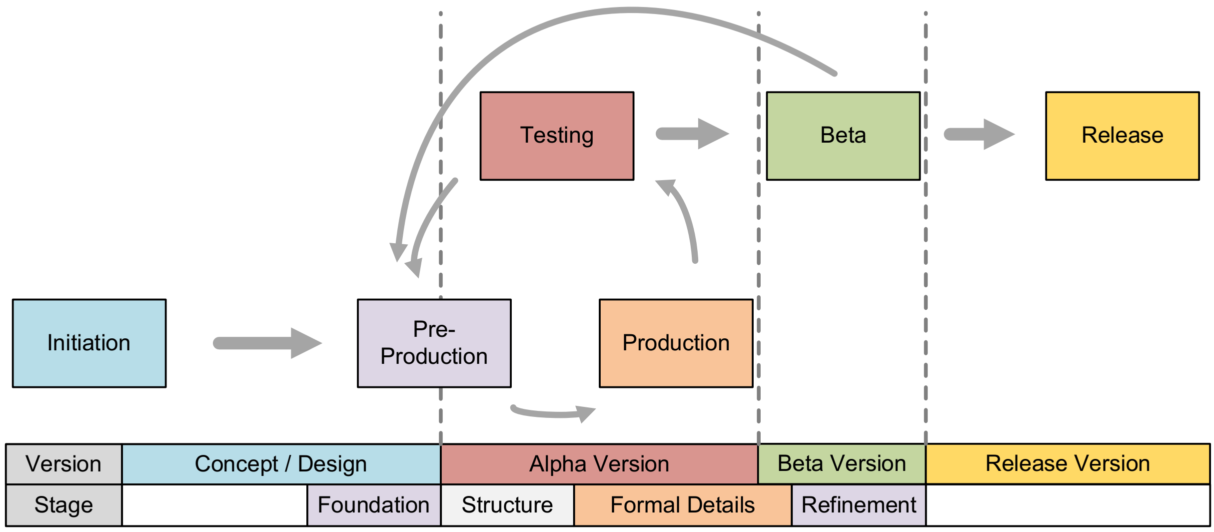


Figure 17: Game development life cycle model[191]

In the initiation phase, a rough game concept and game description are developed. In the next phase, the pre-production, the core elements of game design are created and revised, and a first prototype is built[192]. The main production phase involves assets and source code creation. The structure with refined mechanics and gameplay exists and a more complete prototype, which will only need minor changes, is built[193]. The downstream phase "Testing" requires internal testing of usability and gameplay. The output of this phase is a bug report and a potential change request. Depending on the information gathered during testing, a reiteration of the production cycle might be necessary. After that, the available version of the game is called the Alpha Version. In the Beta phase, external testing is conducted, user feedback is gathered and a bug report is written. This report either leads to another iteration of the production cycle or the release of the game. This usually involves a product launch, project documentation and planning for the maintenance of the game[194].

2.5.1 Comparison of software development lifecycles

The following table shows a comparison of the above-mentioned software development lifecycles with regard to several characteristics.

[191] Ramadan & Widyani, 2013, p. 98
[192] cf. Ramadan & Widyani, 2013, p. 98
[193] cf. Ramadan & Widyani, 2013, p. 98 f.
[194] cf. Ramadan & Widyani, 2013, p. 99

Table 8: Comparison of software development lifecycles

	Waterfall	V-model	Spiral	Agile	Game dev.
Key points	Sequential model with limited cycles; definition and analysis of requirements prior to any development	Variation of the waterfall model, ensuring SMART requirements and design; V-shape allows for verification and quality assurance	Several iterations spiraling out from small beginnings; each run-through contains all methodology steps; focus on risk containment	Rapid and frequent delivery of partial solutions, iterative development, frequent changes to requirements during project	In many aspects similar to software development; different approach needed in some aspects; focus on mechanics, gameplay and user interface
Sub-processes and activities	Evaluation, requirements, analysis, design, development, validation, deployment	Requirements, system architecture, design, development, testing, implementation, verification	Analysis, requirements, planning, risk analysis, draft, test plan, prototyping, detailed design, integration, testing, implementation	No rigid procedure; iterative and incremental development (e.g. sprint cycles)	Initiation, pre-production, production, testing, beta, release
Development type	Sequential & iterative	Sequential	Sequential & iterative	Iterative	Sequential & iterative
Requirements flexibility	Limited	Limited	Yes	Yes	Limited
Cycles / iterations	Limited	Limited	Yes	Yes (core feature)	Yes
Product delivery	End of project	End of project	End of project	Continuous incremental	End of project
Planning scale[195]	Long-term	Long-term	Long-term	Short-term	Long-term

[195] cf. Matharu, Mishra, Singh, & Upadhyay, 2015

2.6 Requirements Engineering

Requirements engineering is strongly connected to the system and (software) project management. Therefore, the initial definition of some essential terms is necessary[196]. Then, a classification for requirements is presented and selected tasks of requirements engineering are described.

When speaking of requirements, they are usually related to a system (e.g. a machine or software). A *system* is a collection of components (i.e. machine, software and human) which cooperate in an organized way to achieve some desired result, the requirements[197].

The IEEE defines a requirement as follows[198]:

> *"A requirement is a statement that identifies a product or process operational, functional, or design characteristic or constraint, which is unambiguous, testable or measurable, and necessary for product or process acceptability (by consumers or internal quality assurance guidelines)."*

As systems are created for the purpose of being used, the term "stakeholder" plays a significant role. Dick et al. define a stakeholder as follows[199]:

> *"A stakeholder is an individual, group of people, organization or other entity that has direct or indirect interest (or stake) in a system."*

With these definitions at hand, the definition of requirements engineering is possible[200]:

> *"Requirements engineering is the subset of systems engineering concerned with discovering, developing, tracing, analyzing, qualifying, communicating and managing requirements that define the system at successive levels of abstraction."*

Glinz developed a taxonomy of requirements that focuses on system requirements[201]. This taxonomy is decpicted in Figure 18.

[196] cf. Dick, Hull, & Jackson, 2017, p. 7
[197] Dick et al., 2017, p. 5
[198] IEEE, 2005, p. 9
[199] Dick et al., 2017, p. 8
[200] Dick et al., 2017, p. 9
[201] Glinz, 2007

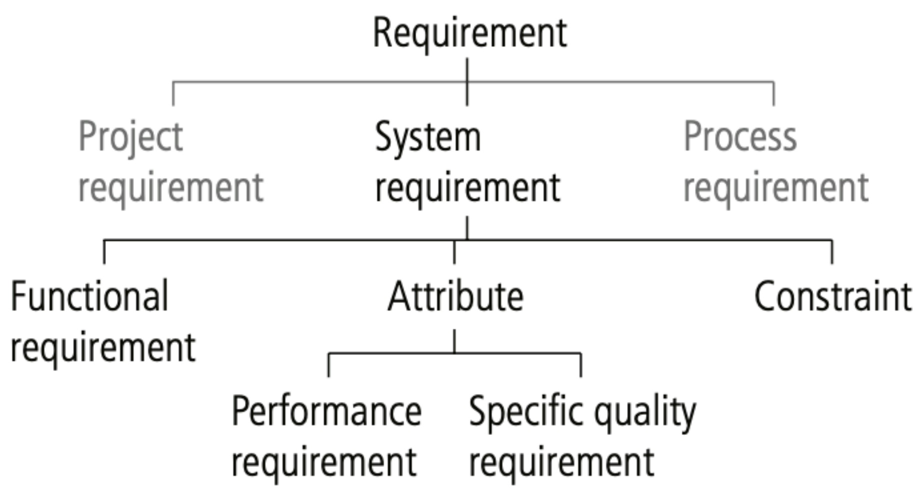


Figure 18: Taxonomy of requirements by Glinz[202]

Project and process requirements are conceptually different from system requirements and will therefore not be considered in this thesis. The taxonomy by Glinz is based on concerns, which are matters of interest within a system[203].

The set of all system requirements are divided into functional requirements, attributes and constraints[204]. In the following, these are described in detail.

Functional requirements specify the functions a system must be able to perform. It therefore pertains to a functional concern. These requirements specifically relate to the system's behavior, data, input, reactions, and so on[205].

Performance requirements pertain to performance concerns (i.e. timing, speed, volume, throughput, etc.). Specific quality requirements pertain to quality concerns other than the quality of meeting functional requirements. These relate to the reliability the reliability, usability, security, maintainability, etc. of the system. The combination of performance and specific quality requirements are the attributes of a system[206].

Constraints are requirements that constrain the solution space beyond what is necessary for meeting the given functional, performance and specific quality requirements[207]. A non-functional requirement is an attribute of or a constraint to a system[208].

[202] Glinz, 2007, p. 25
[203] cf. Glinz, 2007, p. 24
[204] cf. Glinz, 2007, p. 24
[205] cf. Glinz, 2007, p. 24 f.
[206] cf. Glinz, 2007, p. 24 f.
[207] cf. Glinz, 2007, p. 24 f.
[208] Glinz, 2007, p. 25

Furthermore, selected tasks of requirements engineering should be taken into consideration, where the focus will be on tasks that are of particular relevance for designing a Gamification application.

System modelling: A model is an abstraction of a system, that focuses on essential aspects of a system and deliberately excludes other aspects. Usually these models are visualized and the data is prepared using diagrams. This offers significant benefits when communicating within the development team as well as with stakeholders. By modelling a system, a certain degree of formality is introduced, the vocabulary can be precisely defined, the system can be analyzed and the communication within the whole organization is simplified. Thereby, system modelling supports the analysis and design process as a whole[209].

There are numerous techniques for the modelling of a system. Some of the most prominent are data flow diagrams, entity-relationship diagrams and state charts[210]. These techniques are applied in various methods for requirements engineering. Viewpoint methods, object-oriented methods, the UML (Unified Modelling Language) notation and SysML (System Modelling Language) are among the most commonly used methods[211].

Elicitation and gathering of requirements: The elicitation and gathering is one of the first steps in the management of requirements. Elicitation means the collection of information from primary resources. For this purpose, individuals are consulted first hand who are directly concerned with the project[212]. Table 9 shows techniques that are commonly used for the elicitation of requirements.

Gathering requirements describes the indirect collection of information from secondary sources, which are sources other than human beings. This information is already available and just needs to be retrieved[213]. Table 10 shows documents that can be used for gathering requirements.

The identification of requirements is not bound by any order. In some cases, elicitation might precede gathering and, in some cases, it might be the other way around. In a few cases, only one of the techniques may be used[214].

[209] cf. Dick et al., 2017, p. 57 f.
[210] cf. Dick et al., 2017, p. 58 f.
[211] cf. Dick et al., 2017, p. 69 f.
[212] cf. Chemuturi, 2012, p. 33 f.
[213] cf. Chemuturi, 2012, p. 33
[214] cf. Chemuturi, 2012, p. 33

Table 9: Methods for elicitating requirements[215]

Methods for eliciting requirements	
Method	Description
Personal interviews	Primary means of capturing project requirements in the case of in-house software development projects; a set of question is asked to aid in the structured elicitation of requirements
Customer/Market surveys	Especially for capturing requirements for a product; collecting information from a wide audience; objective is to obtain information from targeted users or to prove/disprove a hypothesis; methods: face-to-face, postal, web-based
Questionnaires	Design of a suitable questionnaire; often in combination with some sort of incentive for response
Observation	Analyst observes the operations while they are taking place and collects information; allows to observe ”a different version” of the story, other than the one told by the organization or the employee
Demonstration of product prototypes	More often used to finalize requirements than to obtain original requirements; organization builds prototype based on their stated requirements and end-users look at/use the prototype and provide feedback
Product demonstrations	COTS (commercial off-the-shelf) products are available with comprehensive functionality with built in best practices à requirements for customization through demonstrations
Brainstorming	Used mainly in generating initial requirements

Table 10: Methods for gathering requirements[216]

Methods for gathering requirements	
Document	Description
Organizational records	Logs of activities carried out in the organization
Process documentation	Consisting of processes, procedures, standards, guidelines, SOPs (Standard Operating Procedures)
Customer satisfaction surveys	Bring out inefficiencies inherent in the process
Customer complaints	Give information about possible improvements in the system
Publications / reports / case studies	… produced by experts / industry associations / consultancy organizations

Documentation of requirements: In the requirement documentation process, two aspects have to be carefully considered. The requirements need to be readable and processable[217]. To achieve this, there are a few guidelines for writing and reviewing requirements.

Many organizations use the concept of “key requirements” for prioritization. These requirements are a subset of all requirements that are absolutely mandatory. This can be particularly helpful to capture the essence of the system, especially when communicating with stakeholders. Performance attributes should be used to quantify these key requirements. This allows them to be used as KPIs (Key Performance Indicators) later on[218].

For the ease of processing the requirement, additional information should be attached to the requirement[219]. This leads to the introduction of the term “attribute”. An attribute is additional information that is attached to the requirement and aids in managing that requirement[220]. A typical requirement expression should therefore consist of a

215 Own representation based on Chemuturi, 2012, p. 34 f.
216 Own representation based on Chemuturi, 2012, p. 44 f.
217 cf. Dick et al., 2017, p. 93
218 cf. Dick et al., 2017, p. 96
219 cf. Dick et al., 2017, p. 97
220 cf. Wheatcraft, Ryan, & Dick, 2016, p. 452

requirement statement and attributes[221]. Wheatcraft et al. list 44 types of attributes that can be used when writing requirements[222].

The careful use of language is a useful tool in writing requirements. Consistent language makes it easier to identify and manage all kinds of requirements. Verbs like “shall”, “should” and “may” can be used to indicate requirements and their respective prioritization[223].

Analysis and assessment of requirements: Before analyzing, it is important that all possible requirements are collected from all available sources. After the elicitation and gathering, the information is in the raw form. During the analysis phase, information gaps or missing requirements may be found, which may require going back to the sources[224]. The typical activities in the analysis and assessment of requirements are listed and described in Table 11.

Table 11: Activities in analyzing requirements[225]

Activities in analyzing requirements	
Activity	Description
1.Enumerate all the requirements	-
2. Verify each requirement for completeness	Definition and specification of all information
3. Evaluate each requirement for its feasibility	Technical / Financial / Timeline
4. Bifurcate requirements into a.Core functionality requirements b.Ancillary functionality requirements	Allows better grouping of the requirements à helps in setting priorities
5. Group core functionality requirements together into logical groups	Workstations / departments
6. Group ancillary functionality requirements into their logical groups	-
7. Identify requirements that are duplicated	-
8. Identify requirements that are contradictory to each other	-
9. Identify system interfaces	-
10. Identify stakeholders for each requirement	Primary / secondary stakeholders
11. Prioritize the requirements by the logical group and within every logical group	By timeline / technical feasibility / financial feasibility
12. Identify gaps (in the case of COTS product implementation)	a.Between the product and the organizational needs b.The needs that can be met by re-engineering the organizational processes c.The needs that necessitate product customization
13. Determine the schedule of implementation for the requirements	Assigning calendar dates to planned activites
14. Resolve the issues / inconsistencies uncovered in the above activities	Requirement feasibility / shortfall of information / contradictory or duplicate requirements / logical grouping / prioritizing

Establishment of requirements: After documenting and analyzing, the final requirements have to be written down in a document. For this purpose, the

[221] cf. Wheatcraft et al., 2016, p. 451
[222] cf. Wheatcraft et al., 2016, p. 452 f.
[223] cf. Dick et al., 2017, p. 101
[224] cf. Chemuturi, 2012, p. 55 f.
[225] Own representation based on Chemuturi, 2012, p. 57 f.

requirements are recorded in a structured manner in a requirements specification document. This document can be used by the development team and stakeholders of the product for reasons of support during the development process and for controlling the outcome[226].

2.7 Interim Conclusion

Obviously, human learning plays an important role in professional life. However, only intrinsically motivated learning is sustainable. New technologies are enablers for new forms of learning, with Gamification being one of them. Gamification has proven successful for increasing intrinsic motivation. Design teams have a variety of game features at hand that trigger different kinds of intrinsic motivation.

The implementation into mobile apps (e.g. Duolingo) brought Gamification to the smartphones of a wide audience. As Gamification is gradually being put to use for motivational reasons in different areas of everyday life (e.g. sports, learning languages, etc.), it is only logical that companies are trying to adapt this strategy for skilling their employees (see Chapter 2.3.3).

As pointed out in Chapter 2.2, it is more important than ever that employees can quickly adapt to new situations. Rapidly changing qualifications and learning requirements have left a gap in professional training that Gamification is able to fill. As learning becomes a steady part of work life, it is a good idea to facilitate learning with high user experience. Implementing Gamification into a learning setting perfectly meets this demand. It connects the potential for high intrinsic motivation with a gameful experience and fun. These are the ingredients for a great learning experience.

The conducted literature research brought to light an extensive amount of scientific work regarding Gamification and procedural models on its design and implementation. There are successful examples of implementing Gamification in education, business and health. The density of findings decreases, however, when looking into industrial settings. Some work has been done on Gamification in assembly, manufacturing and logistics, but nothing could be found regarding industrial maintenance. Obviously, that is a field that has not got much attention in this context.

Nevertheless, this was the assumption going into this thesis and the main reason for starting it. This assumption has been proven through the extensive literature research that was conducted at the beginning of the thesis. The existing literature on this topic was described and analyzed in Chapter 2 of this work.

The remaining chapters of this thesis will cover the practical part of the work. In Chapter 3, the developed morphology for implementing a Gamification application for training

[226] cf. Chemuturi, 2012, p. 67 f.

purposes will be described. Chapter 4 covers the associated procedural model. In Chapter 5, the results of the survey on the content of Chapters 3 and 4 will be presented. In Chapter 6 the main findings are summarized in a conclusion and an outlook is presented.

3 A Morphology for Gamification

As already described in Chapter 1.2, a morphology can be used for describing complex systems in a clearly arranged form. It gathers all significant attributes of a system and ascribes all conceivable features and characteristics to them[227]. There are many existing morphologies, that were developed in industrial settings. Yet, no specific morphology could be found for the implementation of gamification. In this chapter, this method will be applied for preparing the data concerning all possible configurations of a Gamification application for training in industrial maintenance. The different attributes and the associated characteristics that have to be taken into account have been listed in such a format.

Notably, the categories have been chosen following the morphology by Ranz et al.[228]. The morphology by Abele et al.[229] also provided useful input for the morphology developed in this work. Therefore, these two morphologies are briefly described before focusing on the morphology for Gamification.

Morphology on Human Robot Collaboration Systems: For the design of human robot collaboration systems various design and technology decisions have to be made. Ranz et al. proposed a morphological framework that considers qualitative, quantitative, conceptual and technical aspects of these systems. Their morphology is split into five dimensions: “Objectives & Economics”, “Product”, “Process”, “System” and “Safety”[230]. As an example, the following table shows section 4 (“System”) of this morphology.

Table 12: Detail of the morphology by Ranz et al.[231]

#		#	Attribute	Characteristic				
4	System	4.1	Kinematics	*Gantry robot*	*SCARA*	*Articulated robot*	*Parallel robot*	
		4.2	Robot workspace	$R \leq 500$ *mm*	$500 < R \leq 1.000$ *mm*	$R > 1.000$ *mm*		
		4.3	Space requirements	$A \leq 1\ m^2$	$1 < A \leq 5\ m^2$	$A > 5\ m^2$		
		4.4	Installation	*upright*	*pendent (horizontaly)*	*pendent (vertically)*		
		4.5	Spatial flexibility	*stationary*	*relocatable*	*linearly travelling*	*track-guided*	*autonomously guided*
		4.6	Tool flexibility	*none*	*configurable tool*	*multi-purpose tool*	*tool changing system*	*adaptive tool*
		4.7	Power supply	*wired*	*autonomous*			
		4.8	Interface to human	*mechanical*	*acoustical*	*optical*		
		4.9	Interface to robot	*electronical*	*mechanical*	*acoustical*	*optical*	
		4.10	Design	*functional*	*caricaturized*	*zoo-morph*	*humanoid*	
		4.11	Programming	*code based*	*intuitive*	*hand-guided*	*gesture based*	*automatic programming*

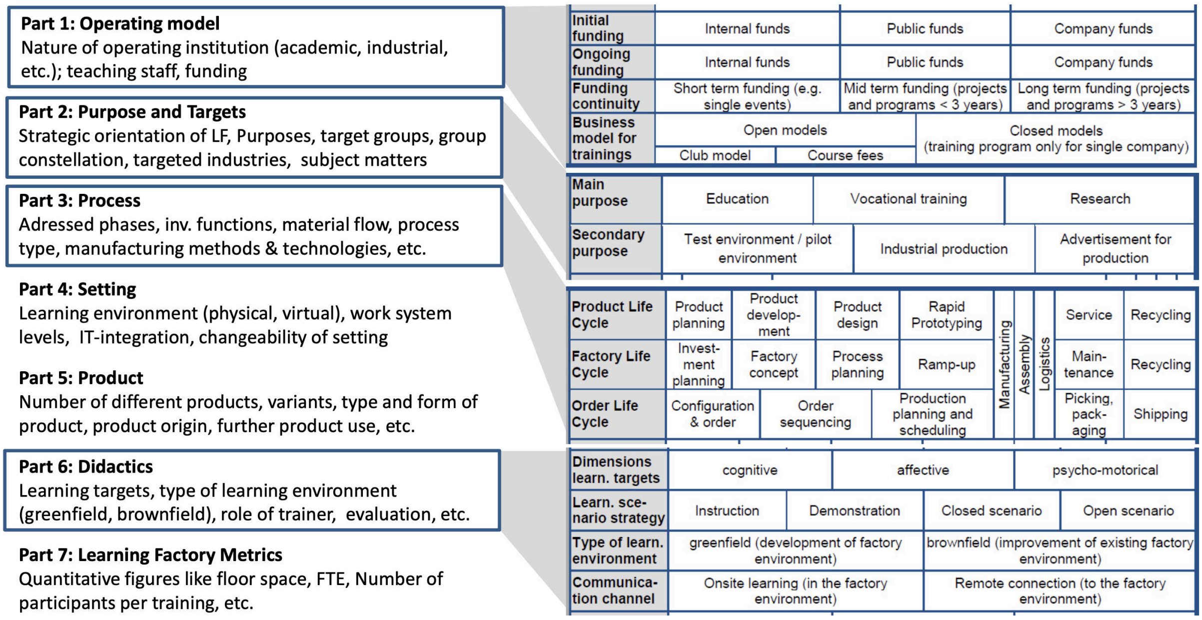
Deciding on at least one characteristic within every attribute results in a specification of the physical human robot collaboration system. This is usually an iterative process.

[227] cf. Ranz et al., 2018, p. 100
[228] cf. Ranz et al., 2018
[229] cf. Abele et al., 2015
[230] cf. Ranz et al., 2018, p. 99 f.
[231] Ranz et al., 2018, p. 102

If qualitative and quantitative objectives are not met, the developed scenarios have to be revised[232].

Morphology on Learning factories: The morphology by Abele et al. covers the most relevant characteristics and features of learning factories in seven dimensions[233]. Figure 19 shows a selection of features of this morphology.

Figure 19: Detail of the morphology by Abele et al.[234]



In this work, this method for data preparation has been applied to the application area of Gamification in industrial maintenance. The different attributes and characteristics that have to be taken into account when developing such an application have been gathered using a morphology. In the following, this morphology for a Gamification application for upskilling in industrial maintenance will be described category by category. Going through this morphology and choosing one or more appropriate characteristics within every attribute leads to a determination of the specifications of the Gamification application.

[232] cf. Ranz et al., 2018, p. 101
[233] cf. Abele et al., 2015, p. 1
[234] Abele et al., 2015, p. 3

Category 1: Objectives and Economics comprises general and economic objectives of the application. This detail of the morphology is shown in Table 13.

Table 13: Detail of the morphology - category 1[235]

#	Category	#	Attribute	Characteristic			Reference
1	Objectives & Economics	1.1	Superior objective	Learning outcome	Productivity increase	Flexibility increase	Ranz et al., 2018
				Learning experience	other		
		1.2	Investment	I <= EUR 50.000	EUR 50k < I <= EUR 100k	I > EUR 100k	Ranz et al., 2018
		1.3	Productive hours/week	h <= 40	40 < h <= 80	80 < h <= 100	Ranz et al., 2018
				h > 100			
		1.4	Availability	V <= 80%	80% < V <= 90%	V > 90%	Ranz et al., 2018
		1.5	Lifespan	< 1 yr	1-3 yrs	3-5 yrs	Ranz et al., 2018
				> 5yrs			
		1.6	Development	Own development	External assisted development	External development	Tisch et al., 2015
		1.7	Initial funding	Department funds	Internal funds	Company funds	Tisch et al., 2015
		1.8	Ongoing funding	Department funds	Internal funds	Company funds	Tisch et al., 2015
		1.9	Funding continuity	Short term funding	Mid term funding	Long term funding	Tisch et al., 2015

One of the first steps in a development project is deciding on a superior objective of the product. This is the primary target of the organization when adopting, developing or designing a Gamification application. An improved learning outcome, increased productivity (through enhanced learning opportunities), flexibility (e.g. location-independent learning) and an improved learning experience are likely targets[236].

In addition to that, every organization has to meet certain economic and business-related objectives. The available budget determines the possible investment costs and general decisions on the performance of the application have to be made (e.g. availability, lifespan, productive hours)[237].

A development decision (insourcing vs. outsourcing) has to be made and the development needs to be financed. For this purpose, a variety of possibilities for initial and ongoing funding is conceivable[238].

Category 2: Setting covers the setting in which the Gamification application is going to be implemented. The respective detail of the morphology can be seen in Table 14.

One of the most consequential decisions in the development of a Gamification application for training has to be made regarding its purpose (i.e. skilling, upskilling or reskilling) and the type of training (on-the-job training or off-the-job-training). This specification has an influence on the design of the learning content in particular.

[235] Own representation based on Ranz et al., 2018; Tisch, Ranz, Abele, Metternich, & Hummel, 2015
[236] cf. Ranz et al., 2018, p. 101
[237] cf. Ranz et al., 2018, p. 101
[238] cf. Tisch et al., 2015, p. 358

Table 14: Detail of the morphology - category 2[239]

#	Category	#	Attribute	Characteristic			Reference
2	Setting	2.1	Main purpose	Skilling	Upskilling	Reskilling	Tisch et al., 2015
		2.2	Type of training	On-the-job training	Off-the-job training		
		2.3	Target group	Apprentice	Working student	Worker	
				Engineer	Manager		
		2.4	User knowledge	Novice	Advanced Beginner	Competent professional	
				Proficient professional	Expert		
		2.5	Target industry	Mechanical & plant eng.	Automotive	Logistics	
				Transportation	FMCG	Aerospace	
				Chemical industry	Electronics	Construction	
				Insurance / banking	Textile industry	other	
		2.6	Subject-rel. learning content	Maintenance work	Troubleshooting	Instruction of beginners	Bundesagentur für Arbeit, 2011
				Documentation	Maintenance concept development	Technical consulting	
				Initial operation	Data processing	Inspection	
				Functional reliability and eco-friendliness of machines	Retrofit	Optimization	
				Online maintenance	R & D	other	
		2.7	Implementation setting	Integration into workplace	Standalone training software		

Target groups and user knowledge are essential objects of consideration in the definition of the setting as well. As the regarded Gamification application will operate in an industrial maintenance setting, the maintenance tasks that will be trained have to be decided on. There are a broad variety of tasks that a training application could address, such as troubleshooting or documentation[240]. The implementation setting indicates whether the application is going to be integrated into an existing workplace (e.g. a machine that is frequently maintained by a maintenance engineer) or is going to be a standalone training software on a laptop, handheld device etc.

Category 3: Process covers the process that the training application will relate to. The detail of category 3 is shown in Table 15.

This category links the process and the subject related learning content. It indicates the process area and type, the machine variance the maintenance engineer has to deal with and the degree of automation with which the process is carried out.

Especially when integrating an application into an existing workplace, the process has to be analyzed carefully in order to reach the targeted learning outcome using Gamification.

239 Own representation based on Bundesagentur für Arbeit, 2011; Tisch et al., 2015
240 cf. Bundesagentur für Arbeit, 2011, p. 304 f.

Table 15: Detail of the morphology - category 3[241]

#	Category	#	Attribute	Characteristic			Reference
3	**Process**	3.1	Process area	Manufacturing	Assembly	Logistics	Ranz et al., 2018
				Quality control	other		
		3.2	Machine variance	non	low variation	high variation	Ranz et al., 2018
				individualized machines			
		3.3	Process type	Mass production	Serial production	Small series production	Tisch et al., 2015
				One-off production			
		3.4	Degree of automation	Manual	Partly automated / hybrid automation	Fully automated	Tisch et al., 2015

Category 4: Learning design covers all attributes of the application which relate to the design of the learning content. The detail of category 4 is shown in Table 16.

In the course of the learning design category decisions on the learning objective, instructional strategy and the preferred instructional materials of the application have to be made. The addressed competence classes and previous knowledge of the users can be narrowed down to reduce the complexity of the gamified application. In addition to that, the learning design includes attributes that concern the tracking and evaluation of the user's progress.

Category 5: System covers the technical attributes of a Gamification application (see Table 17).

For a gamified learning application, based on the implementation setting, both onsite and offsite access is conceivable. Furthermore, the decision on the platform of the application is an essential one. The different possibilities of data collection and interfaces need to be carefully considered. Decisions on the average duration of a training and the number of offered trainings limit the size of the Gamification application.

Applicability of the morphology: This morphology can be used for describing a Gamification application as a complex system. All significant attributes of Gamification applications for training purposes are clustered into categories and ascribed all conceivable characteristics. Hence, the proposed morphology is not only a tool for describing a system, but also one that is useful in the design process. Especially in combination with the developed procedural model (see Chapter 4), this morphology helps to gather all necessary requirements to the application. The intertwined application of the morphology and the procedural model (references to the morphology are made in certain steps of the procedural model) therefore creates the basis for designing and developing a Gamification application for trainings purposes in industrial maintenance.

It should be noted, though, that the morphology in this form is applicable specifically to Gamification applications used for skilling, upskilling or reskilling employees in

[241] Own representation based on Ranz et al., 2018; Tisch et al., 2015

industrial maintenance. It satisfies the requirement of characterizing conceptual and technical as well as quantitative and qualitative aspects of Gamification applications. Nevertheless, the use of a generally valid categorization of attributes, as proposed by Ranz et al.[242], makes this morphology easy to adopt to other industries and application fields.

Table 16: Detail of the morphology - category 4[243]

#	Category	#	Attribute	Characteristic			Reference
4	Learning design	4.1	Learning objectives	Acquisition of knowledge	Acquisition of skills	Attitude change	Northern College
		4.2	Instructional strategy	Direct instruction	Indirect instruction	Experiental learning	
				Independent study	Interactive instruction		
		4.3	Instructional material	Readings	Instructional videos	Podcasts	
				Forums	Graphics	Animations	
				Interactive worksheets	Case studies	Simulations	
				Games	Quizzes	Other	
		4.4	Competence classes	Technical and methodological competencies	Social & communication competencies	Personal competencies	Tisch et al., 2015
				Activity- and implementation-oriented competencies			
		4.5	Learning scenario strategy	Instruction	Demonstration	Closed scenario	Tisch et al., 2015
				Open scenario			
		4.6	Degree of autonomy	Instructed	Self-guided / self-regulated	Self-determined / Self-organized	Tisch et al., 2015
		4.7	Standardization of trainings	Standardized trainings	Customized trainings		Tisch et al., 2015
		4.8	Theoretical foundation	Prerequisite	In advance (en bloc)	Alternating with practical parts	Tisch et al., 2015
				Based on demand	Afterwards		
		4.9	Learning success evaluation	Based on progression in application	Knowledge test	Practical example	Tisch et al., 2015
				None			
		4.10	Complexity of learning modules	Address technical and process knowledge	Address conceptual knowledge		Enke et al., 2015
		4.11	Use of user specific learning profiles	yes	no		Ansari et al., 2018
		4.12	Learning goals	Short-term: process optimization and steeper learning curves	Mid-term: optimal division of labor	Long-term: process & product innovations by mutual learning	Ansari et al., 2018
		4.13	Learning curve of user is tracked & can be displayed	yes	no		

[242] Ranz et al., 2018
[243] Own representation based on Ansari et al., 2018; Enke et al., 2015; Northern College; Tisch et al., 2015

Table 17: Detail of the morphology - category 5

#	Category	#	Attribute	Characteristic			Reference
5	System	5.1	Communication channel	Onsite learning	Remote connection		Tisch et al., 2015
		5.2	Platform / System integration	Smartphone/Tablet application	Browser application	Computer program	
				Additional system to a common machine	Digitalized machine / Assistance system	Smart Factory	
		5.3	Reciprocal learning	Yes	No		
		5.4	Data collection	Sensors	Monitoring systems	Feedback	
				Manual input			
		5.5	Interface to human	mechanical	acoustical	optical	Ranz et al., 2018
				haptic			
		5.6	Average duration of a training	< 1 day	1 - 2 days	3- 5 days	
				5 - 10 days	> 10 days		
		5.7	Number of different trainings	1	2 - 4	5 - 10	
				> 10			
		5.8	Evaluation	Feedback of users	Learning output of users	Transfer to everyday work	Tisch et al., 2015
				Economic impact of trainings	Return on trainings / ROI		

4 Design of a Procedural Model for Gamified Applications

In this chapter, the procedural model for the design of a gamified application for skilling, upskilling or reskilling employees in industrial maintenance will be described. The model consists of 6 phases: project preparation, analysis, requirements engineering, design, testing and use phase. Figure 20 shows the model on a high level of abstraction.

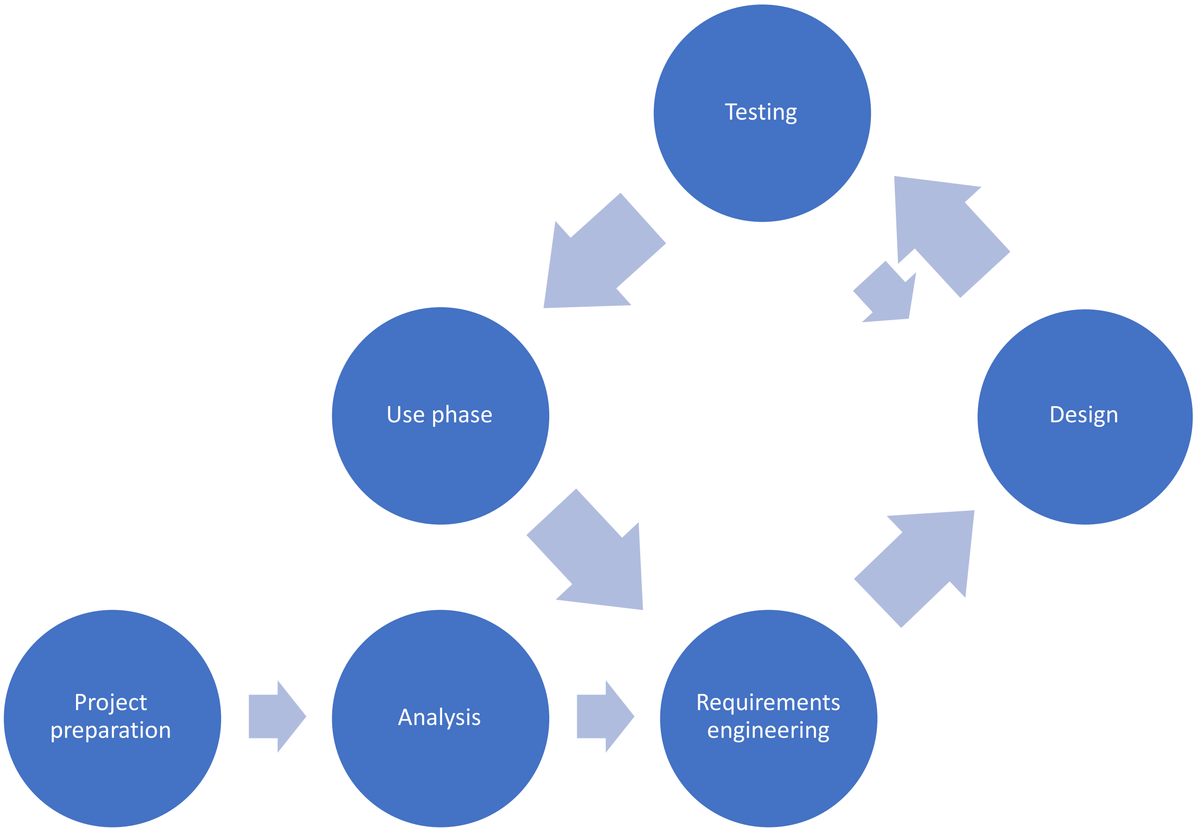


Figure 20: The procedural model

In that way, the abstracted procedural model resembles the CRISP-DM (Cross Industry Standard Process for Data Mining) process model, as both are circular life cycle flow diagrams with similar process steps[244].

As this depiction already suggests, there are interdependencies between the phases of the model. Especially the design and testing phase are strongly linked due to the various testing cycles that entail adaptions of the code and design of the application. Once the application is put into operation, new requirements emerge and after a while there is a need for a new version of the system. As with data mining, a solution for a gamified training application is not finished once it is deployed, but it is a constant life

[244] cf. Wirth & Hipp, 2000, p. 4 f.

cycle process with continuous updates and patches to fix errors and meet new requirements[245]. This is when the cycle closes and a new iteration of the development process starts. In the following, the procedural model will be described phase by phase.

Phase 1 - Project Preparation: In the initial phase of the project (see Figure 21), the system has to be delimited to determine which aspects will be considered during the development of the application and which will be deliberately omitted.

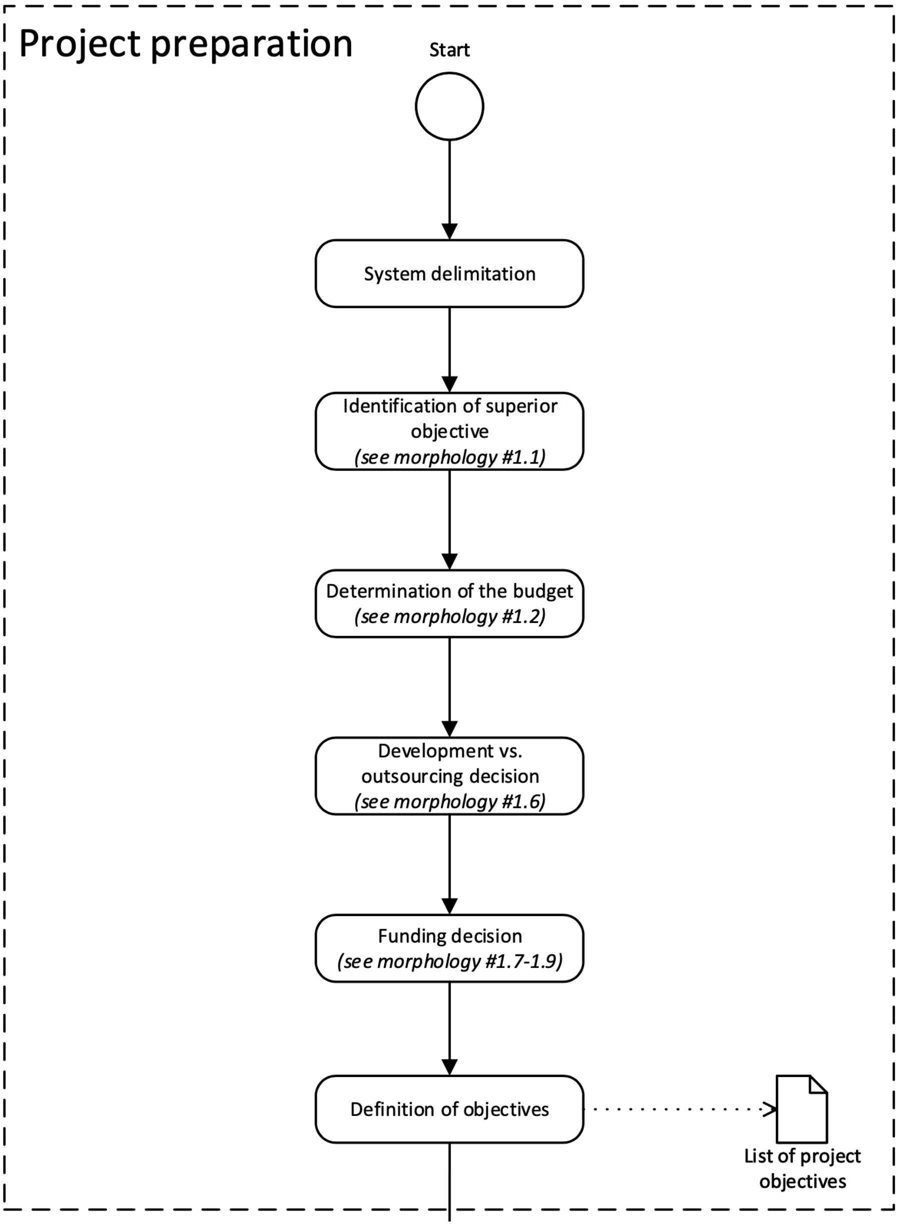


Figure 21: Phase 1 - Project preparation

In this early project stage it is important to identify and define objectives[246] that set the framework for the development process. In addition to that, consulting the morphology

[245] cf. Wirth & Hipp, 2000, p. 4 f.
[246] cf. Deterding, 2015, p. 316; DIN ISO/FDIS 9241-210:2019, 2019, p. 13; Morschheuser et al., 2018, p. 225; Wirth & Hipp, 2000, p. 5

for gamified upskilling applications is strongly suggested in this phase. By this, an overview of the system to be developed can be gained.

Phase 2 - Analysis: The analysis phase of the development process (see Figure 22) consists of two essential elements: the context analysis and the user analysis[247]. Gaining a profound understanding of the contextual characteristics is of significant importance[248].

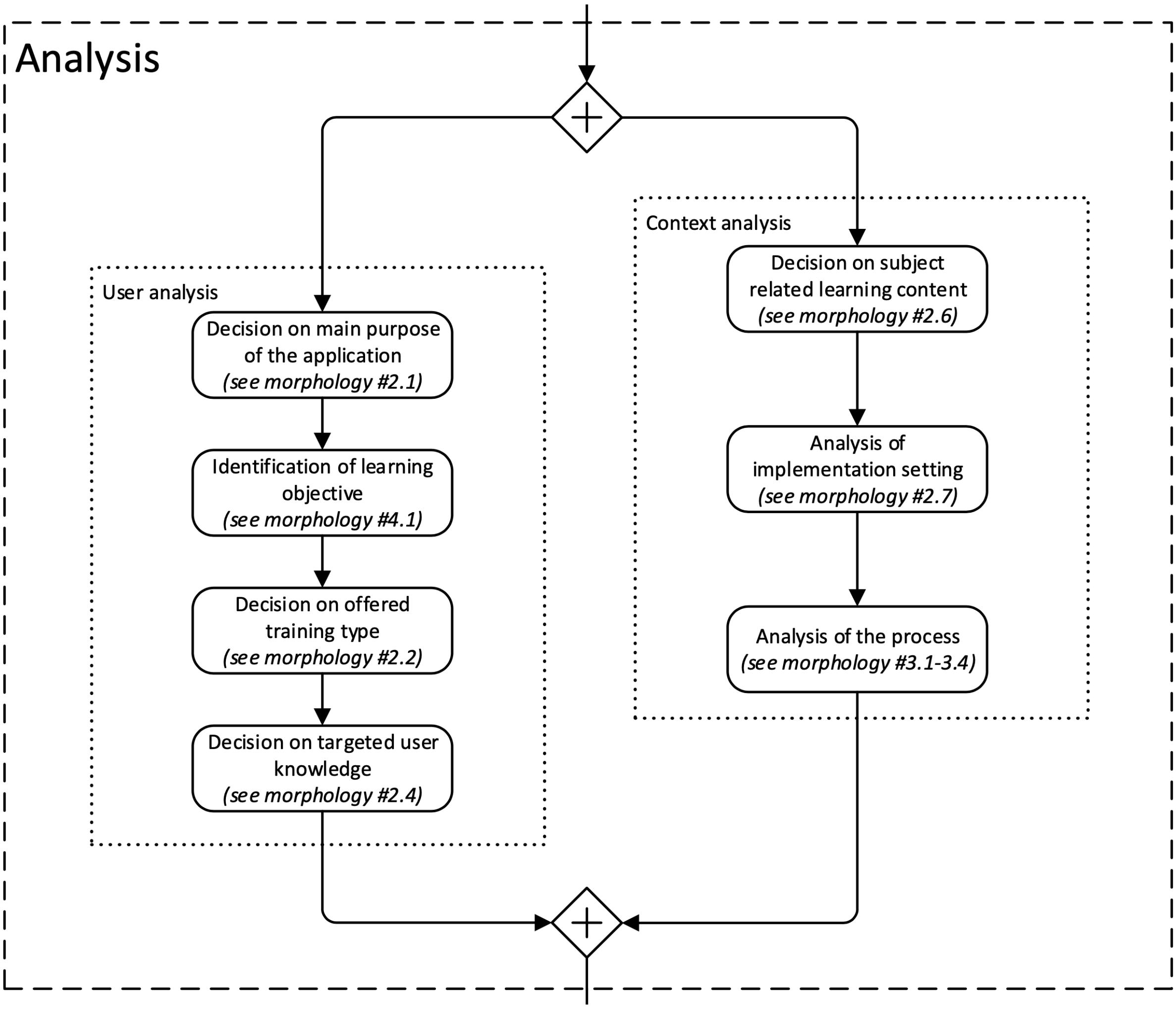


Figure 22: Phase 2 - Analysis

During this analysis phase, the morphology is used for determining certain characteristics of the system is suggested. For both user and context analysis, a few decision-making steps have been chosen. In the user analysis, the first essential step is deciding on the targeted training purpose (skilling, upskilling or reskilling) of the system. The identification of learning objectives, offered training types and the targeted

[247] cf. Deterding, 2015, p. 316; DIN ISO/FDIS 9241-210:2019, 2019, p. 12 f.; Morschheuser et al., 2018, p. 225; Wirth & Hipp, 2000, p. 5
[248] cf. Morschheuser et al., 2018, p. 225

user knowledge of the learners are the remaining objects that should definitely be considered during user analysis.

In the context analysis, the first and most significant step is deciding on the learning content that application should offer. With maintenance being the targeted application area, this can be anything from documentation activities of every day work to more complex matters of predictive maintenance. The examination of the implementation setting provides information whether the application is going to be integrated into an existing workplace or will be used on a separate platform (e.g. browser application or smartphone app). Analyzing the process rounds off the context analysis by gaining insights into the activities that need to be mastered by the user of the application in order to reach the learning objectives.

Phase 3 - Requirements Engineering: The third phase of the procedural model (see Figure 23) covers key activities of requirements engineering. Starting off with a model of the system[249], the preliminary requirements, gathered during project preparation and analysis, can be summarized.

After the design team has listed the initial requirements resulting from the user and context analysis, the next step is building a low-fi prototype of the system. This is a visualization of the design ideas at an early stage without investing too much time. A prominent method for low-fi prototyping is building a paper-based prototype with easily accessible tools like paper, pen and other handicraft materials[250].

In the process of requirements elicitation and gathering information are collected from primary and secondary recourses. For this purpose, there are a number of techniques that can be applied (see Table 9). Especially interviewing the users and their executives, handing out questionnaires and observing operations can be a helpful source of information. During this part of the project it is again strongly suggested to consult the morphology for support in the requirements elicitation and gathering process.

There certain system-related and didactic requirements that need to be derived: the communication channel used by the application (onsite or offsite) has to be chosen, one or more suitable platforms for the application (e.g. smartphone app, browser application, assistance system, etc.) have to be found. Based on these decisions, means of data collection (e.g. sensors or manual input) and adequate user interfaces (e.g. optical or acoustical) have to be determined.

[249] cf. Dick et al., 2017, p. 57 f.
[250] cf. Sefelin, Tscheligi, & Giller, 2003, p. 778

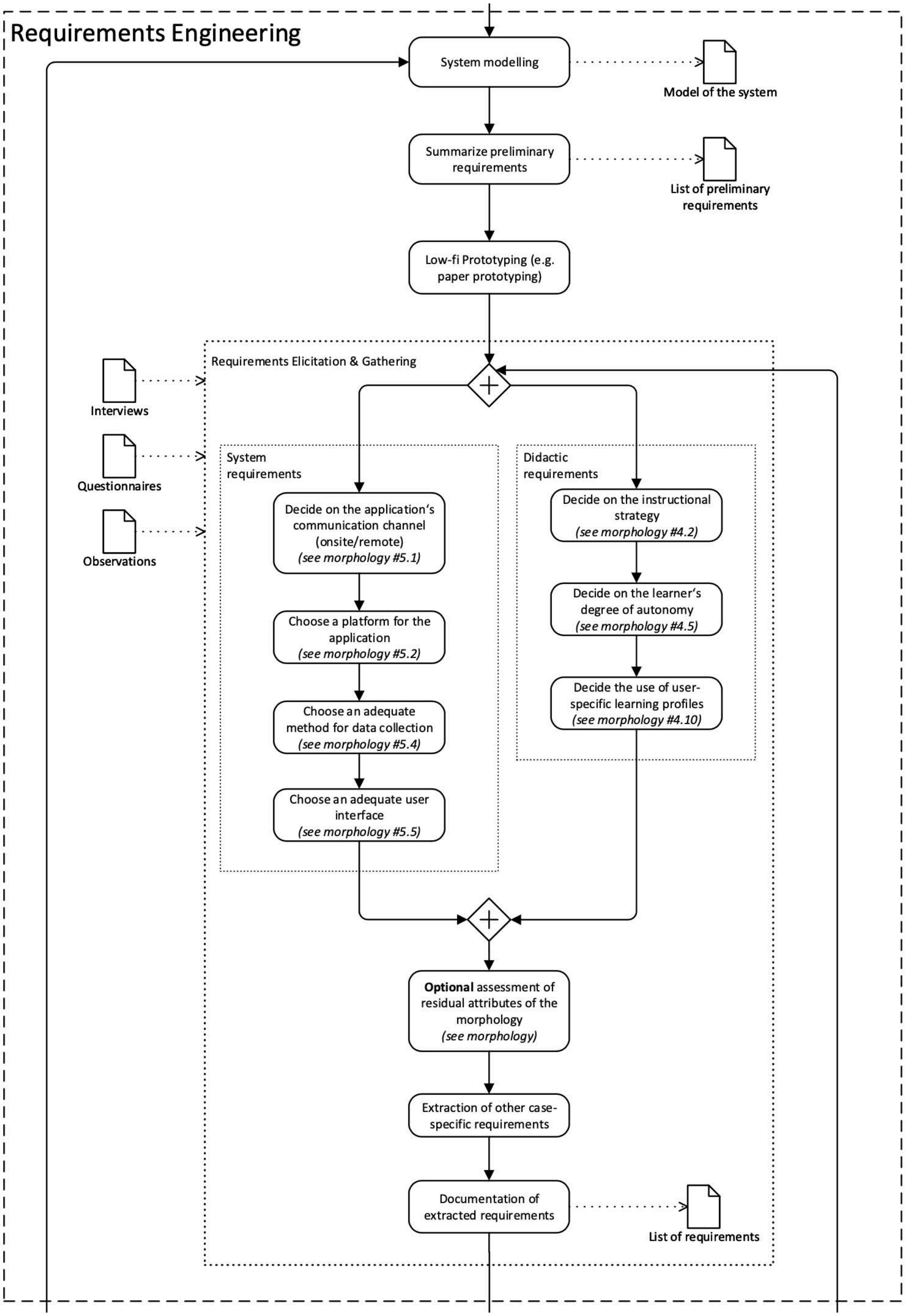


Figure 23: Phase 3 - Requirements Engineering

On the other side, the didactic requirements include, among others (see morphology category 4) the offered instructional strategies (e.g. direct or indirect instruction), the preferred instructional materials (e.g. e-books, instructional videos or case studies) and the learner's degree of autonomy when using the application. On top of that, the decision on the use of user-specific learning profiles is a decision that needs to be made before the design phase.

After going through these suggested attributes of the morphology in the course of the elicitation and gathering of system-related and didactic requirements, the optional assessment of the residual attributes of the morphology can be performed. At the end of this process, the case-specific requirements are extracted and documented, resulting in a list of requirements.

Phase 4 - Design: The fourth phase of the procedural model is the design phase, in which the core of the application is developed. The detail of this phase can be seen in Figures 24 & 25.

The design team begins this phase with brainstorming design ideas. The advantage of brainstorming at early development stages is that it quickly generates many ideas. There are various techniques for brainstorming like brainwriting, affinity diagrams and visual brainstorming[251]. The use of brainwriting and affinity diagrams can be helpful for drafting content-related ideas, while visual brainstorming ideas should be used for first design ideas concerning the user interface.

In order to identify gaps and misunderstandings in the definition of requirements, a prototype of the application will be built before finalizing the requirements. A prototype is an early working version of the system, which gives a realistic impression of how the final product may look like. For this purpose, the prototype's objectives and functional requirements have to be defined. After that, a prototype is built and evaluated[252].

The next step is the analysis and assessment of the requirements. The key activities in analyzing requirements have been listed in Table 11 in Chapter 2.6. In the following, the decision on pursuing or discarding the concept should be made. If the project is pursued, a final requirements loop is possible. Another iteration of the requirements engineering process is conducted and, possibly, another prototype is built. After this iteration, the application's final requirements are defined, specified and frozen[253]. The output of this step is a requirements specification document, as described in Chapter 2.6. The above-mentioned requirement loop helps moving the product from concept to validated product specifications and allows for highly iterative design[254].

[251] cf. Wilson, 2013, p. 2 f.
[252] cf. O'Regan, 2017, p. 52
[253] cf. Carmel & Becker, 1995, p. 57
[254] cf. Carmel & Becker, 1995, p. 56

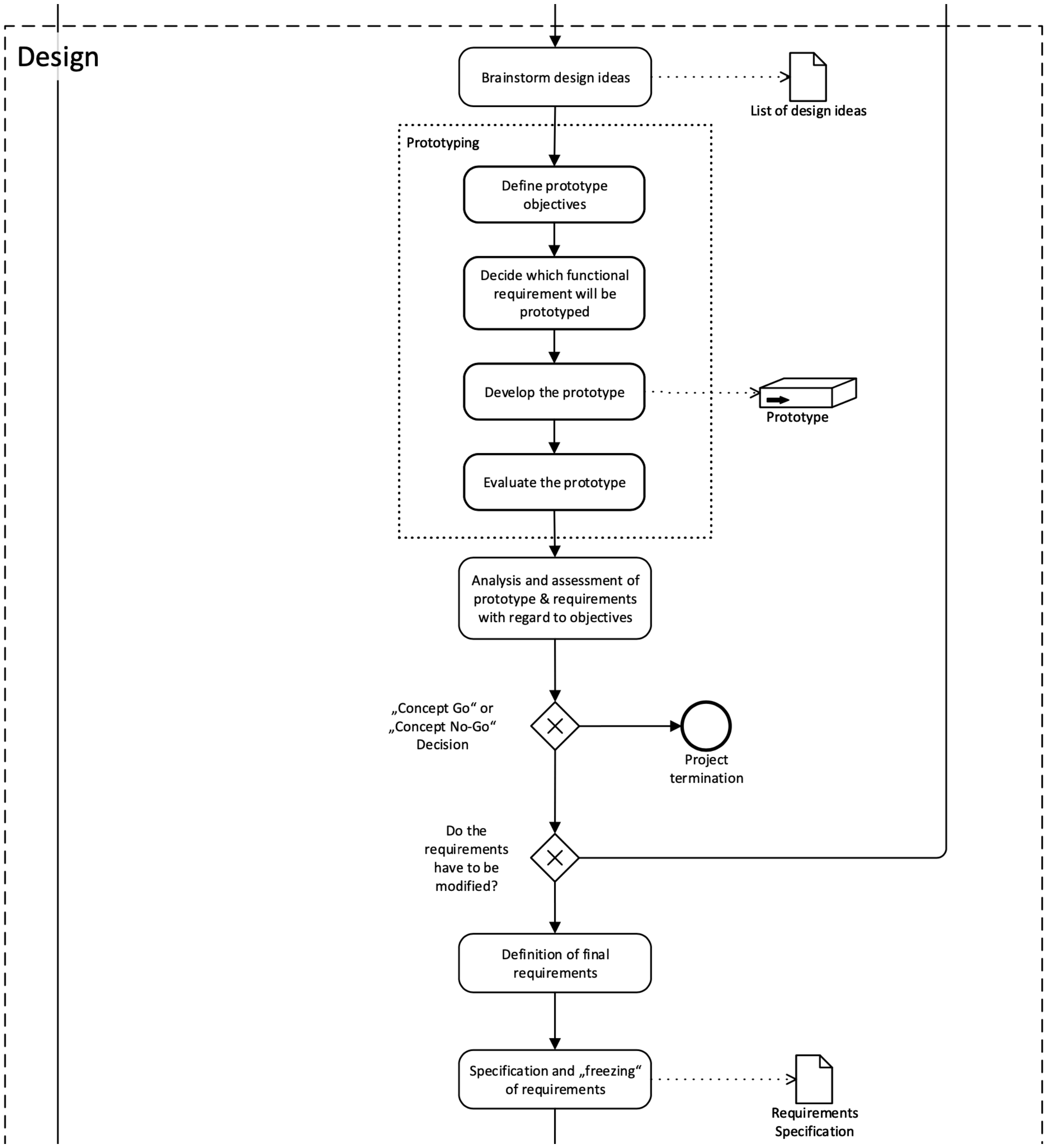


Figure 24: Phase 4 – Design (Part 1)

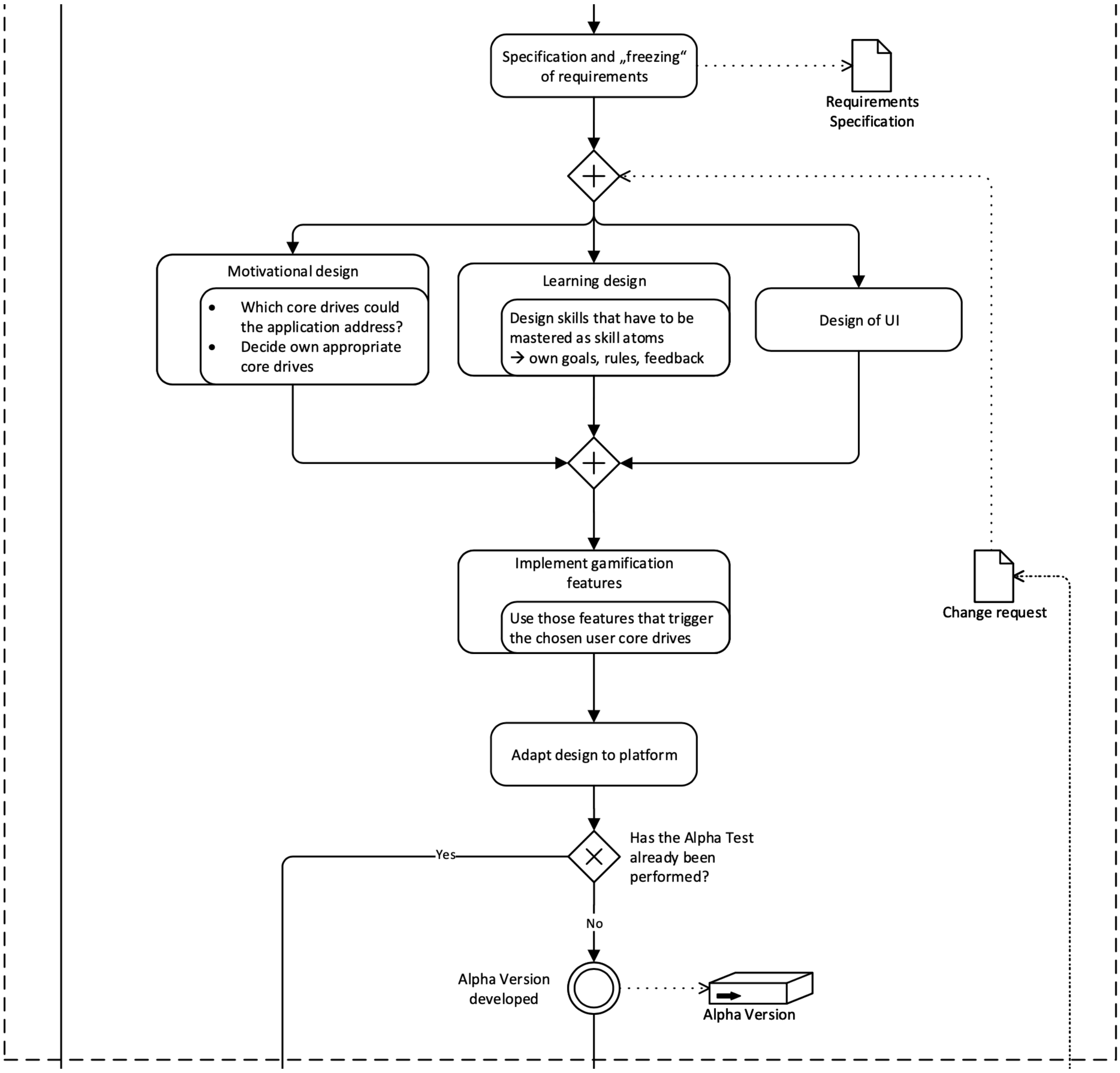


Figure 25: Phase 4 – Design (Part 2)

With specified and frozen requirements at hand, the main design steps can start. The identified learning contents (see morphology in Chapter 3) have to be prepared in a didactically useful way. For this purpose, gameful design[255] offers a method for designing skills and competencies that have to be mastered as skill atoms (see Chapter 2.4.3). The technique "Lenses of intrinsic skill atoms" should be used as the main design tool for designing learning tasks in the gamification application. Every skill (e.g. documentation of maintenance activities) the maintenance staff has to learn can be designed as a skill atom with its own goals, rules and feedback. Motivational design is another key aspect in designing a gamified training application. Psychological aspects of learning and human motivation should be carefully considered (see Chapter 2.1). Octalysis[256] is the preferred model for motivational design in this procedural model. It provides the techniques for stimulating the human core drives and already

[255] cf. Deterding, 2015
[256] cf. Chou, 2015

offers suggestions of corresponding game features (see Chapter 2.4.5). In addition to learning and motivational design, the application itself, of course, has to be molded into an appealing user interface.

After the main design steps, the application's content will be equipped with adequate game design features (see Chapter 2.3.2). The final design then has to be implemented on whatever platform (see morphology in Chapter 3) has been chosen for the application. After the implementation, the alpha version of the application is ready for testing.

Phase 5 - Testing: The fifth phase of the development process covers all testing activities. Phase 5 is shown in Figures 26 & 27.

With the last step of the design phase, the alpha version of the application has been developed. The first step of phase 5, therefore, is alpha testing. Depending on the size and structure of the organization applying this procedural model, the development team responsible for the application, a quality assurance team or any other in-house user performs internal testing in order to identify bugs of the system. For this purpose, specifications of the requirements and the design are reviewed, and a test plan with test cases is developed[257]. The output of these internal tests is a bug report. Depending on the severity of the design errors, another iteration of the design phase may be necessary. If alpha testing only brings minor bugs to light, a "bug removal" step may be sufficient. After executing all test cases, removing the identified bugs with potentially reiterating the design phase, and applying the finishing touches on game design, code and user interface, the criteria for exiting the alpha testing phase are fulfilled. As a result, the beta testing phase of the application is allowed to start[258].

This beta version of the gamified training application is released to a limited number of users working in maintenance (i.e. users outside the development team) and already used for on- or off-the-job training. In addition to another bug report, user feedback can be obtained and the quality of the system can be evaluated[259]. Based on this data, a decision on reiterating the design phase has to be made. After all bugs are removed from the system, the code is frozen and tests are rerun to make sure no errors can be reproduced[260]. Although it should not be the case, the reproduction of an error may require unfreezing the code and going through the design again. After all bugs are removed from the system and a beta test summary report is delivered, the criteria for the release version of the system are fulfilled[261].

[257] cf. https://www.guru99.com/alpha-testing.html (accessed 12 September 2020)
[258] cf. Carmel & Becker, 1995, p. 57; Ramadan & Widyani, 2013, p. 99; https://www.guru99.com/alpha-beta-testing-demystified.html (accessed 12 September 2020)
[259] cf. Ramadan & Widyani, 2013, p. 99
[260] cf. O'Regan, 2019, p. 46;
[261] cf. Ramadan & Widyani, 2013, p. 99; https://www.guru99.com/alpha-beta-testing-demystified.html (accessed 12 September 2020)

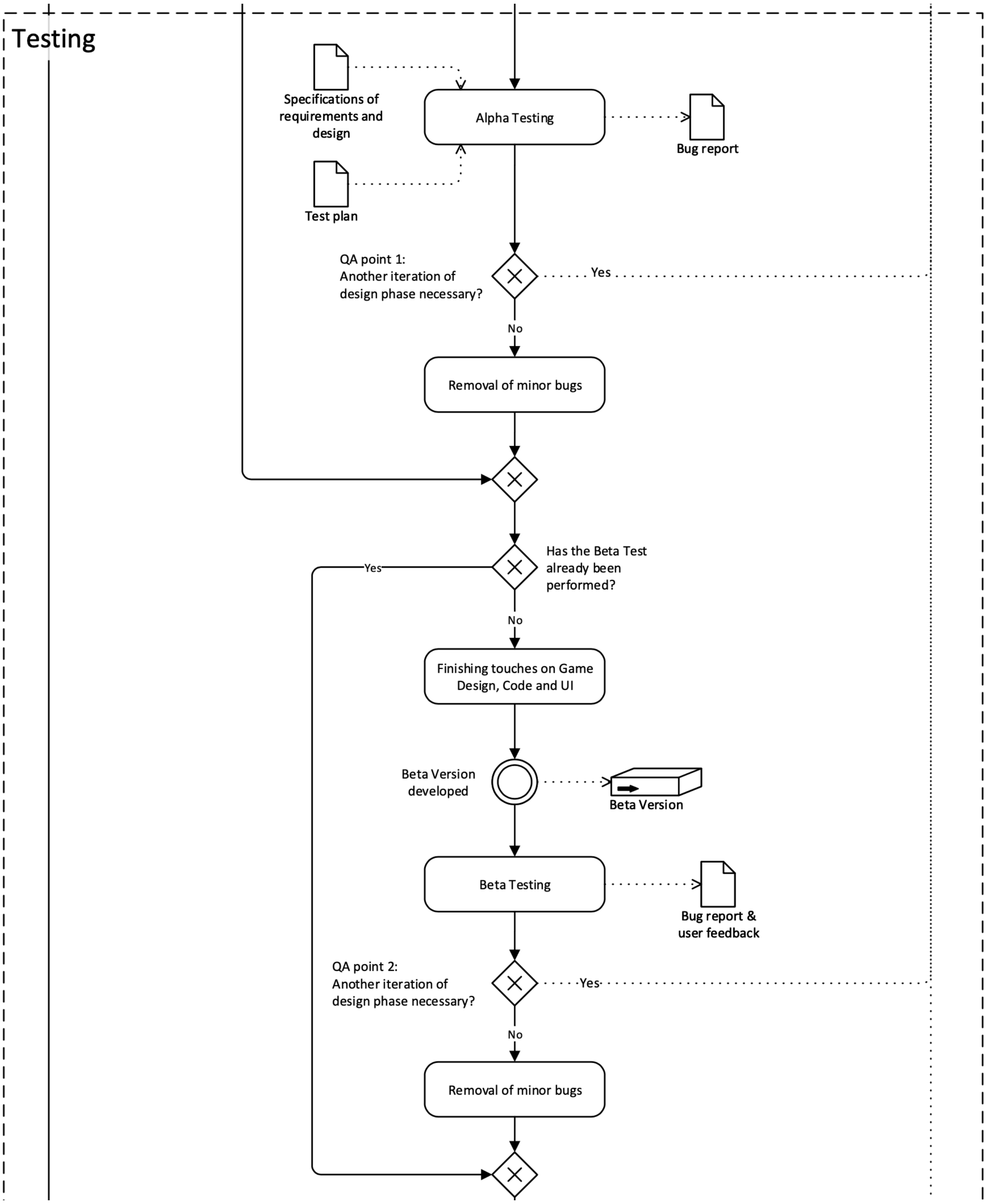


Figure 26: Phase 5 – Testing (Part 1)

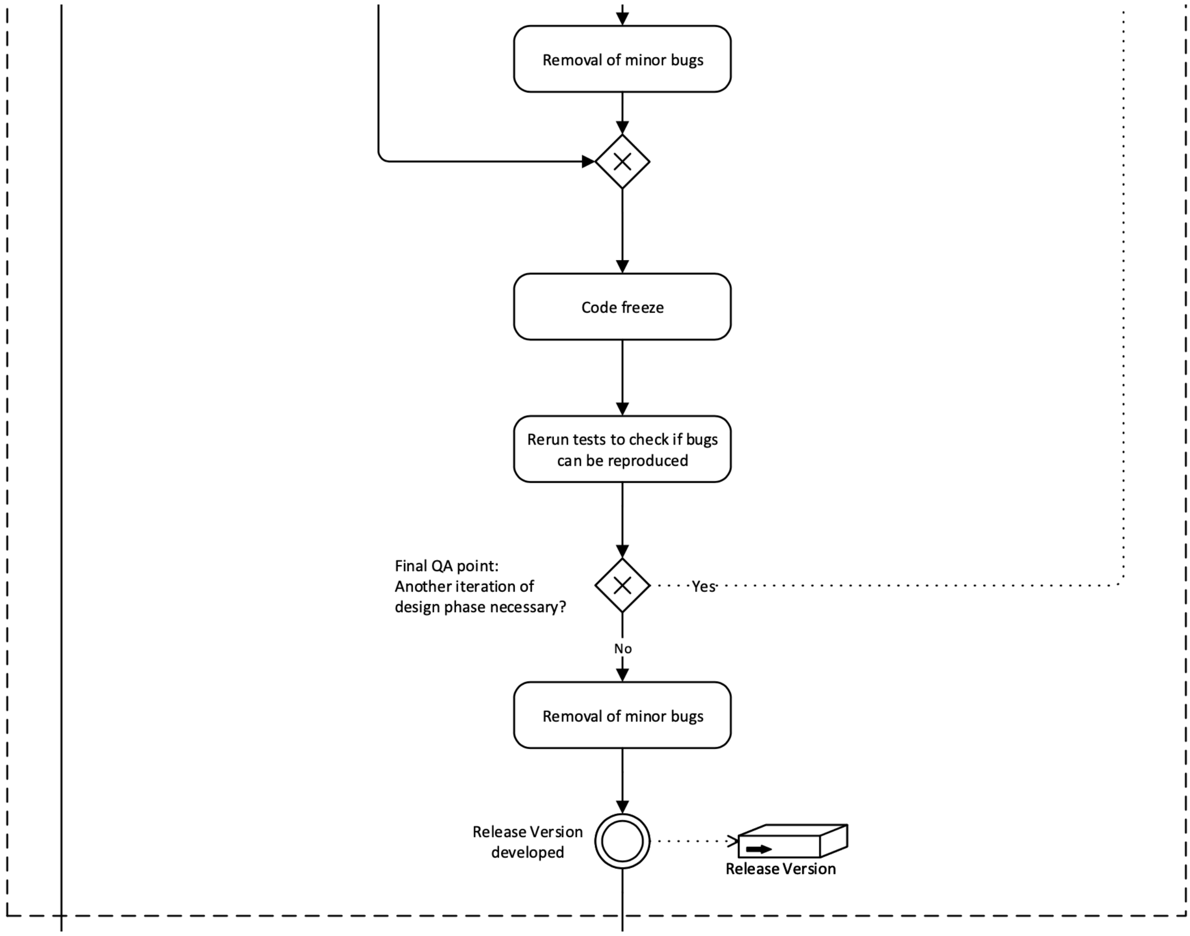


Figure 27: Phase 5 – Testing (Part 2)

In short, the described quality loop consists of design and build stages resulting in gradual release stages of the application. If threshold defect standards are not met, the code and design have to be improved until an acceptable quality level is reached[262].

Phase 6 - Use phase: The sixth phase of the procedural model covers all activities that happen in the operating stage of the system. The detail including the use phase is shown in Figure 28.

After the release version was developed in the final step of phase 5, the application is ready to launch. During the operation, the usage of the application is monitored, user feedback is constantly evaluated and occurring bugs are documented. The responsibility for supporting the use phase of the system is dependent on the resources of the organization implementing it. This can be a sub-group of the development team or an IT department. The analysis of this data is the basis for servicing the current version of the application. Defects are removed and new patches are developed, which are then released. Meanwhile, user needs are constantly observed. At some point, a general overhaul of the application is necessary, resulting in a completely new version. This event initiates a loop back to requirements engineering in phase 3, starting a new

[262] cf. Carmel & Becker, 1995, p. 57

iteration of the whole development process. After the new version of the application is developed, the current version enters the phaseout stage, which results in the closedown[263].

Applicability of the procedural model: The procedural model, that has been described in this chapter, is specifically applicable to the design and implementation of Gamification applications in the field of industrial maintenance. The phases “project preparation”, “analysis”, “requirements engineering” and “design” are based heavily on the literature research on Gamification. In combination with the morphology, the core of which is the design of gamified learning content, the procedural model is well suited for being used as a guideline in developing a gamified training application.

The later phases of the procedural model, “testing” and “use phase”, as well as the mentioned requirement loop and quality loop are more based on software development methodologies and principles. As depicted in Chapter 2.5, software development generally is a highly iterative process. The underlying procedural model is designed after the same iterative process. The main cycles are surrounded around the requirements loop and the quality loop. Depending on the mindset and approach of the organization and the development team, the procedural model can be interpreted and applied differently.

Development teams working with traditional software development methodologies can adopt their sequential way of working to this procedural model. In this case, these cycles are run through once or twice, with only minor requirements flexibility and less changes to the design after the initial development. The gamified application is delivered at the end of the project and planning has to happen long-term.

On the other hand, these cycles can be seen as the core elements of a highly iterative process. Development teams working with an agile mindset can easily adopt the requirements loop and quality loop to a series of sprint cycles. In this case, the application is not delivered at the very end of the project, but every cycle provides an increment of the final product.

Although there is no clear right or wrong in interpreting the procedural model with regard to iterations, the recommendation is to use this model with an agile mindset. The nature of a gamified application for training purposes being a human-centered product may require changes to requirements along the way, which makes an agile approach very advisable.

[263] cf. Rajlich & Bennett, 2000, p. 66 f.

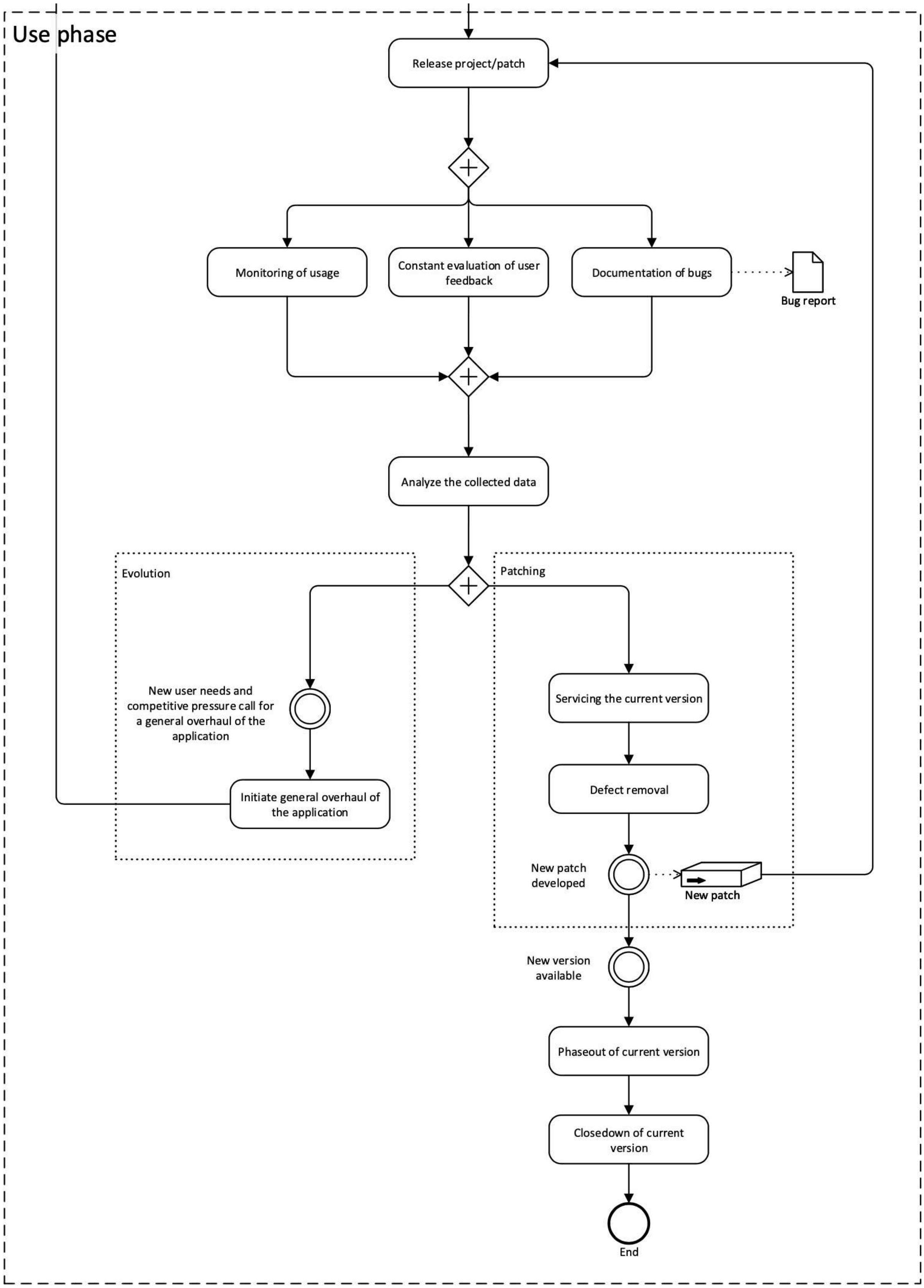


Figure 28: Phase 6 - Use phase

5 Questionnaire-based Evaluation: Structure and Results

To validate the morphology and procedural model created in this thesis, a survey has been conducted via the platform Lamapoll[264]. For this purpose, a set of questions has been created to acquire feedback on the work. The participants of the survey have been clustered according to their respective professional fields Based on their field of expertise, the participants have been asked questions associated to their respective expert knowledge in order to increase the quality of the feedback.

In particular, the main goal of the questionnaire based online survey has been set to receive feedback on the morphology and the procedural model.

- Regarding the morphology, the questions concern some selected attributes and their respective characteristics which are based on own work and cannot be found in literature in this form.
- Regarding the procedural model, feedback was generated through questions on carefully selected phases, which, again, are based on own work and cannot be found in literature in this form. The questions were created using depictions of excerpts of the procedural model. Well documented procedures in requirements engineering and software development need no further validation (e.g. the process of Alpha and Beta testing in a software development project).

Other goals of the survey were to receive feedback on the proposed interplay of procedural model and morphology, on potentially missing process steps in the procedural model and on potentially missing categories, attributes, and/or characteristics in the morphology. Also, gaining new perspectives and input for the improvement of the procedural model and the morphology were defined objectives of the survey.

In the following the structure of the survey is briefly outlined:

1. Description of the purpose of the thesis and the survey
2. Brief introduction to Gamification
3. Introductory questions: in order to cluster responses for further evaluation; (question-piping)
4. Question-pipes:
    I. Industrial Maintenance

[264] cf. https://app.lamapoll.de/ (accessed 6 September 2020)

II. Developer (IT, software development, etc.)

III. User (teaching, learning, etc.)

Based on the above-listed structure of the survey, the results will be discussed in the followings. Positive feedback on the evaluated parts of the morphology and procedural model has been regarded as a proof of concept. Negative feedback has been analyzed and interpreted, and a conclusion has been drawn on whether changes to the respective parts are necessary or not. These changes and implications have been outlined in Chapter 5.2.

Overall, 48 people started the survey, resulting in 32 returns. This means 16 participants aborted the survey, which is equivalent to a return quota of 67% (see Figure 29). That implies that 16 people dropped out at some point during the survey. Hence, and due to the fact that question-pipes were installed, not all 12 questions have the same amount of responses. Some questions have more than 32 answers, some have less.

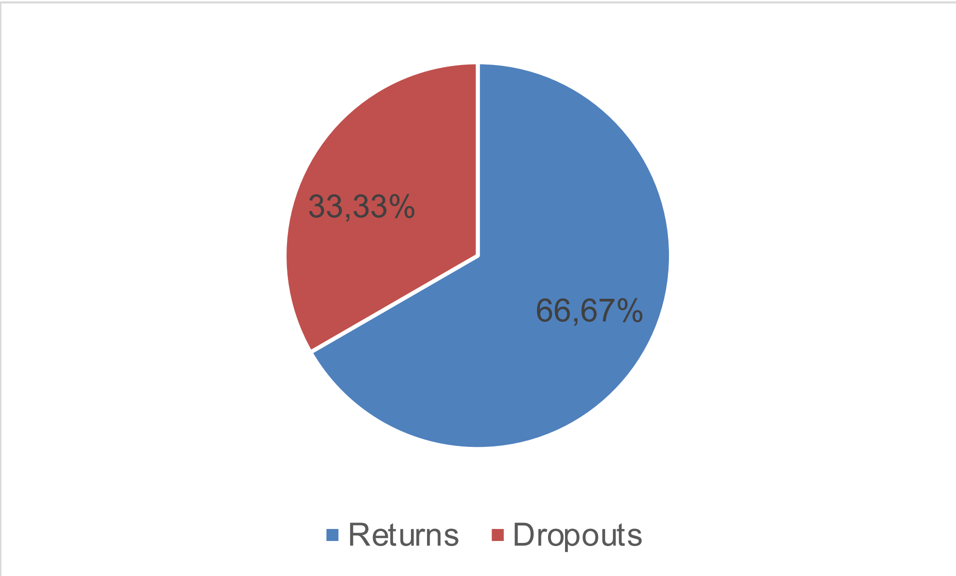


Figure 29: Returns & dropouts of the survey

5.1 Introductory Questions

The first four questions of the survey were introductory questions with the purpose of gaining insights into the participant's professional fields and assigning those questions to the participants that best fit their field of expertise or their interest (question-pipes). This should ensure high quality feedback.

Question 1: Are you familiar with the concept of Gamification?

The possible answers were:

- Yes
- No

Results: Out of 41 answers, 29 people stated that they are familiar with the concept of Gamification. Hence, 71% at least know what Gamification is (see Figure 30).

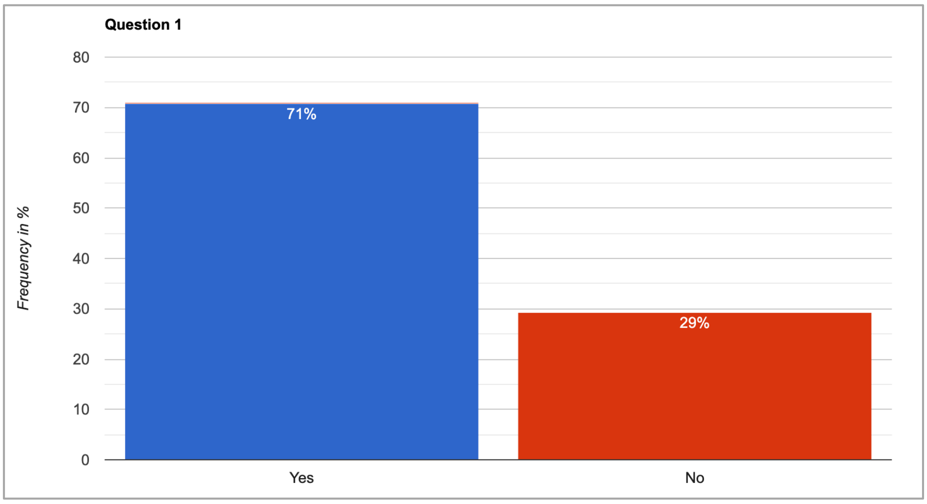


Figure 30: Results of question 1

Interpretation: The fact that more than 70% were familiar with Gamification, highlights the validity of the feedback gathered through this survey.

Question 2: Do you already have experience with Gamification?

For this question, multiple answers were possible. The answers choices were:

- Yes, in a private context
- Yes, in a professional context
- No

Results: 46 answers were given in total. 20 indicated that they have had experience with Gamification in a private context, 16 have experienced Gamification in their profession, and 10 have had no experience at all. Figure 31 shows the frequencies of each possible answer, based on the number of respondents.

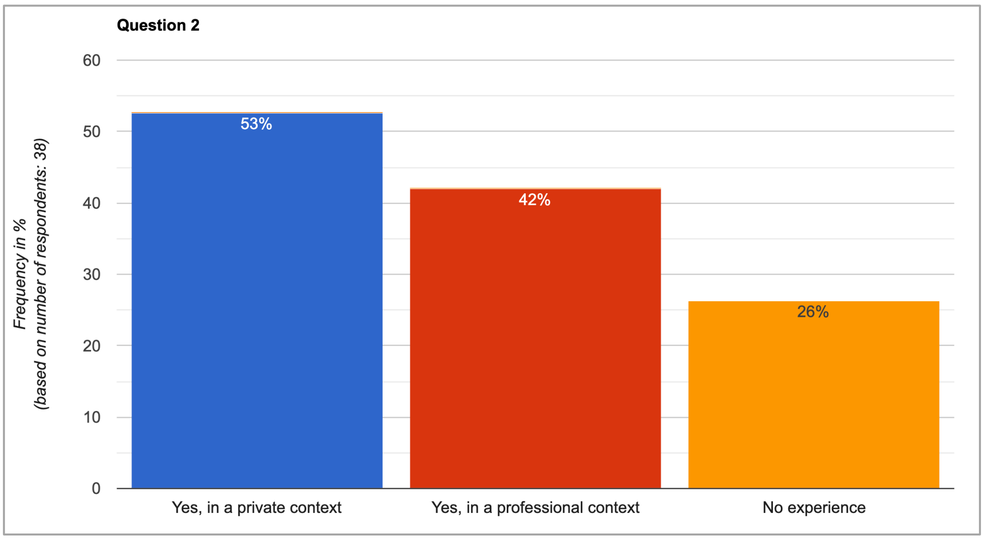


Figure 31: Results of question 2

Interpretation: This, again, shows a high number of participants that actually have experienced Gamification in some form. This result was expected and shows that the participants were correctly chosen in order to give high quality feedback.

Question 3: In what industry do you work?

The possible answers were clustered into three groups. Within each group there was one blank field, where participants could manually enter their respective industry, if it was not among the provided answers:

- Science
  - ICT
  - Industrial Engineering
  - Education
  - Other: _____
- Industry
  - Manufacturing company
  - Logistics company
  - Provider of training programs
  - Other: _____
- Currently in education
  - Student
  - Other: _____

Results: The results show that the majority of the participants has a background in education or industrial engineering. The exact results are shown in Table 18.

Table 18: Results of question 3

Results

Options	Count	Frequency
Science		
ICT	2	5,26%
Industrial Engineering	13	34,21%
Education	4	10,53%
Other:	3	7,89%
Industry		
Manufacturing company	0	0,00%
Logistics company	0	0,00%
Provider of training programs	2	5,26%
Other:	0	0,00%
Currently in education		
Student	3	7,89%
Other:	11	28,95%
Total	38 Answers	38 Respondents

Result details for Input field "Other"

Value/Answer	Count	Frequency
Science		
Consulting	1	7,14%
Mechanical Engineering - Robotics	1	7,14%
Socioeconomic research	1	7,14%
Currenty in education		
Researcher / Research Assistant	3	21,43%
Teacher	3	21,43%
Dean	1	7,14%
Faculty	1	7,14%
PhD	1	7,14%
Management	1	7,14%
Project manager	1	7,14%
Total	**14**	**100%**

Interpretation: People working in industrial engineering or education make up a vast majority of the participants of the survey. As the “Industrial maintenance”- and “User”-question-pipes specifically target those two groups, the participants seem to have the appropriate expertise for the survey.

The field of ICT, however, is remarkably underrepresented. This correlates with the low number of participants choosing the question pipe “Developer” (see question 4).

Question 4: Please choose the answer that best fits your interests / professional field / etc. (You will be assigned the remaining questions based on your answer.)

The possible answers, which correspond to the following question pipes, were:

- Industrial maintenance
- Developer (IT / Software development / etc.)
- User (Teaching / Learners [e.g. students/apprentices] / etc.)

Results: Of the 38 participants who answered this question, 23 chose “User”, 9 chose “Industrial maintenance”, and 6 chose “Developer” as their respective question pipes. This distribution resulted in the frequencies that can be seen in Figure 32.

Interpretation: Obviously, the participants preferred the user-viewpoint on this matter. This makes sense, considering that a large group of the participants can be associated to education. The small number of participants choosing the “Developer” question pipe results from the few ICT experts taking part in this survey.

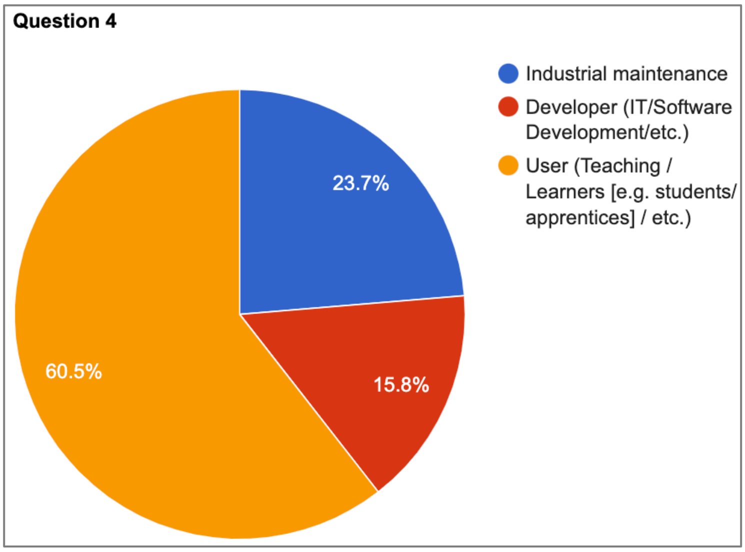


Figure 32: Results of question 4

5.2 Questions on the Morphology

Question 5: A Gamification application is being developed for training purposes in industrial maintenance. Prior to development, a user analysis is conducted. The following target groups are identified:

- **Apprentice**
- **Working student**
- **Employee**
- **Engineer**
- **Manager**

Do you believe that this distinction of target groups is sufficient? Please mark your answer and explain your decision.

The participant was provided with six selection fields, ranging from "Very sufficient" to "Very insufficient".

Results: In total, 8 participants answered this question. The exact results are shown in Table 19. An average of 3.75 suggests that the participants leaned towards thinking that the target groups were chosen insufficiently.

Table 19: Results of question 5

	Very sufficient				Very insufficient			
Value	**1**	**2**	**3**	**4**	**5**	**6**	**Total**	**Average**
Frequency in %	12,50%	25,00%	0,00%	25,00%	12,50%	25,00%	100,00%	**3,75**
Frequency Count	1	2	0	2	1	2	8	

The participants were provided with the opportunity to comment their decision, which two participants did. One participant stated that the given target groups do not match the usual functional structure of industrial maintenance. He or she would suggest to use apprentice, technician (both experienced and unexperienced), foreman, and department manager as the target groups for the Gamification application. The second comment was about rather focusing on competence classes and professional job titles.

Interpretation: The results of this questions show that this part of the morphology needs some improvement. While competence classes are considered in the “Learning design” category of the morphology, the phrasing of the target groups needs to be improved to match the actual professional job titles and functional structures in industrial maintenance. The resulting changes to the morphology are described in Chapter 5.2.

Question 6: Is a Gamification application a well-suited format for upskilling workers in usual activities of industrial maintenance?

Please choose the respective suitability for every activity. (At the end of the question you have the chance to add and assess three additional activities.)

A total of 15 maintenance activities were listed: Maintenance work, troubleshooting, instruction of beginners, documentation, maintenance concept development, technical consulting, initial operation, data processing, inspection, functional reliability and eco-friendliness of machines, retrofit, optimization, software maintenance, online maintenance and R & D. In addition to the given activities, the participants had the chance to add and assess missing activities.

The scale included 5 answer choices: very good / good / medium / bad / very bad.

Results: Six participants answered this question. The frequencies of each selection can be seen in Figure 33.

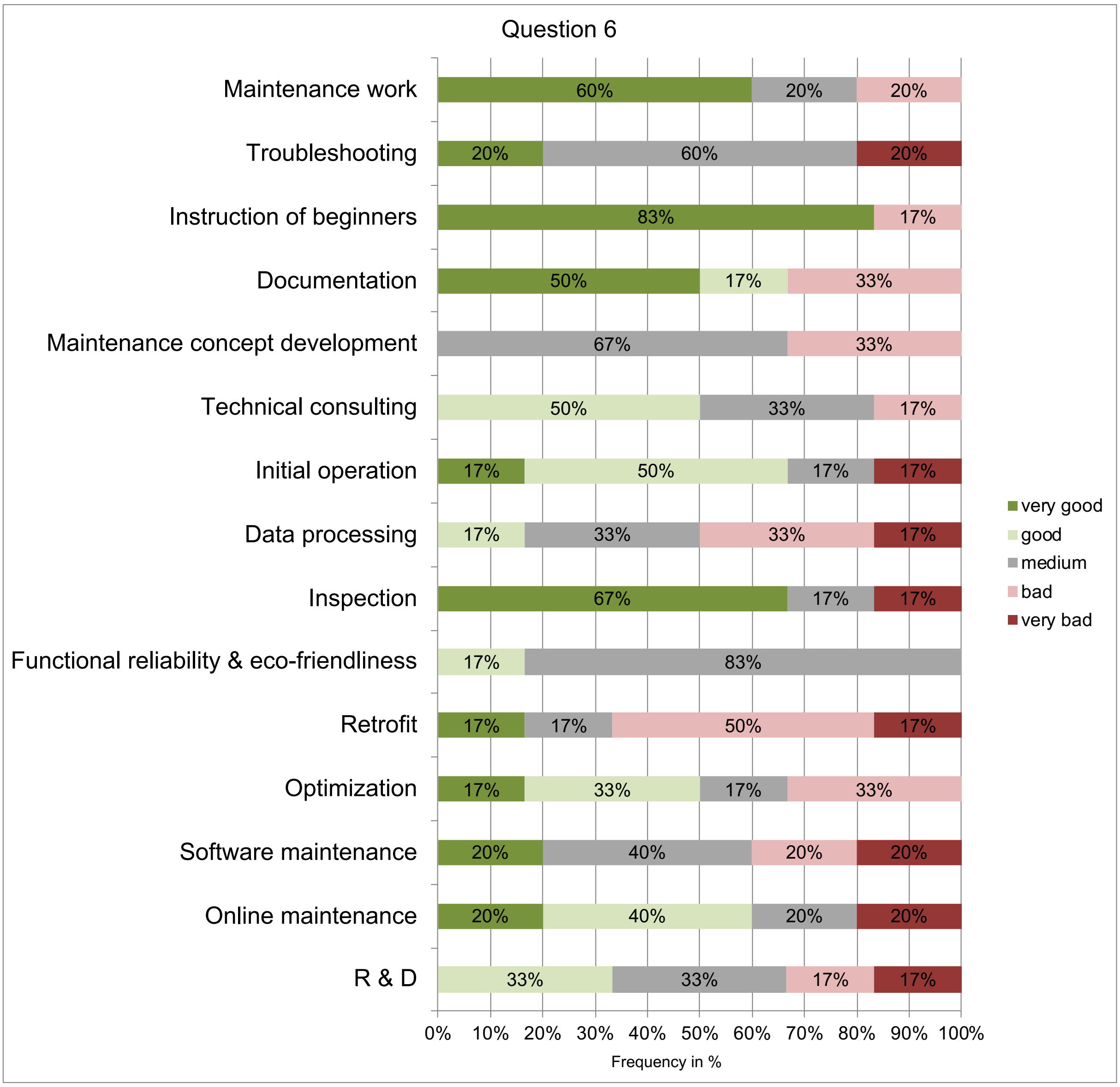


Figure 33: Results of question 6

Five participants added activities in the field "Other" that they thought were missing in the original selection. The given answers and their respective assessment are shown in Table 20.

Table 20: Answers to "Other"

Number of answers	very good	good	medium	bad	very bad	Total
Maintenance planning / Shift scheduling	1	0	0	0	0	1
On the job training / VET + Professional training	1	0	0	0	0	1
Condition Monitoring	0	1	0	0	0	1
Off the job training / VET	1	0	0	0	0	1
Predictive maintenance	0	1	0	0	0	1

Interpretation: The participants considered four activities to be well-suited for upskilling using a Gamification application: instruction of beginners, inspection, maintenance work and documentation. Initial operation, online maintenance and optimization were still regarded as suitable training content for a Gamification application.

Other activities, like retrofit, data processing, maintenance concept development, troubleshooting, software maintenance and R & D, were regarded as less suitable for being trained with the use of Gamification.

Furthermore, the feedback of the participants revealed that activities like maintenance planning & shift scheduling, condition monitoring and predictive maintenance were missing. The participants also mentioned on- and off-the-job-training. These, however, cannot be regarded as maintenance activities and are already taken into account in the “Setting”-category of the morphology.

As a consequence of the feedback, the maintenance activities in the morphology will be sorted by their suitability for gamified upskilling. Thereby, the most suitable activities are listed before less suitable activities. Those activities that were considered as unsuitable will be removed from the morphology. In addition to that, the missing activities will be added to the morphology. The resulting changes to the morphology are described in Chapter 5.2.

Question 7: A Gamification application is being developed for training purposes in industrial maintenance. There are different instructional strategies for conveying learning content. Please choose the strategies that you think are well-suited for the use in a Gamification application.

This question had six answer choices, with multiple answers being allowed:

- *Direct instruction (e.g. lectures, demonstrations)*
- *Indirect instruction (e.g. case studies, problem solving)*
- *Experiential learning (e.g. games, experiments)*
- *Independent study (e.g. reads, exercises)*
- *Interactive instruction (e.g. discussions, group projects)*

Results: This question was answered by 22 participants. The results of question 7 are shown in Figure 34. The shown values are the frequencies in percent based on the number of respondents (22 answers).

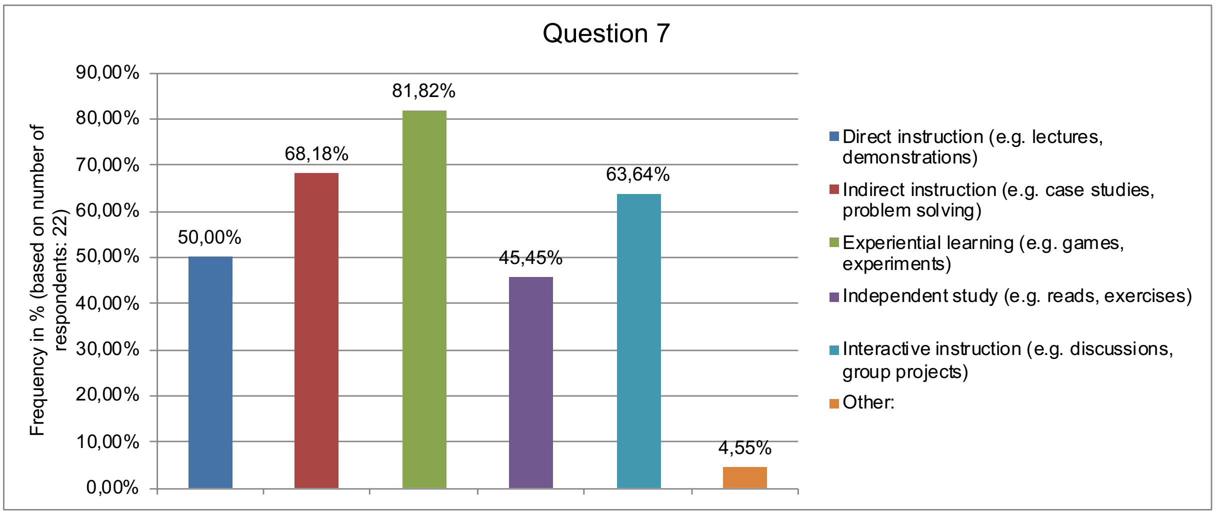


Figure 34: Results of question 7

Interpretation: The results show that none of the presented instructional strategies was considered as unsuitable for Gamification. Some strategies, however, performed better than others. Especially experiential learning received the most responses, as over 80% of the respondents regard experiential learning as a suitable strategy for Gamification. This was highly expected, as it involves learning using games and experiments. The participants also imagined indirect and interactive instruction to be well-suited for Gamification. Both strategies can be considered as hands-on learning approaches where the user has to actively participate. This makes these strategies well-suited for Gamification.

The two remaining strategies received slightly worse feedback. Direct instruction and independent study were considered as suitable by only about 50% percent of the respondents. These strategies, however, can be efficient gamified learning strategies as well. Many gamified learning applications that I used (e.g. Duolingo or Codecademy) usually chose an approach, where different strategies were mixed. For example, badges were given out for completing reads on the theoretical foundations of a concept, followed by gamified learning exercises or problem solving. Likewise, pre-recorded lectures, for example, could also be a part of a Gamification application, where any sort of rewards is handed out for running through the content. In my opinion, all of the listed strategies can be justified as a suitable Gamification approach.

One respondent gave extensive feedback on this question in the field “Other”. He or she stated that the selection of a suitable learning strategy is highly dependent on the learning objectives, target group characteristics and context, and that the consideration of these aspects resolves the question whether Gamification is a suitable concept for learning in each specific case or not. This, of course, is true and has been taken into account in the development of the morphology. By using the morphology, the objectives, the setting and the process are extensively studied before deciding on an instructional strategy in category 4 of the morphology.

To sum up, the answers to this question revealed a hierarchy, from well-suited to medium-suited instructional strategies. No strategy, however, has been disqualified as a gamified learning strategy by the respondents.

Question 8: There are different possibilities for evaluating learning success. For the use in a gamified upskilling application in industrial maintenance, the following formats for evaluating learning success have been identified:

- **Progression in the learning modules of the application**
- **Knowledge test**
- **Practical example**
- **No evaluation of learning success**

Do you believe that this list covers all possible formats for evaluating learning success in this specific use case? Please mark your answer.

The participants were given two answer choices: *Yes* or *No*.

If the participants chose "No" as an answer, they were posed an additional question: *"Which additional format(s) for evaluating learning success should be considered?"*

Results: In total, 22 participants answered this question. 13 respondents stated that the given formats for evaluating learning success cover all plausible formats, resulting in a 59% approval rating. 9 respondents (41%) thought that this list was not complete. The result can be seen in Figure 35.

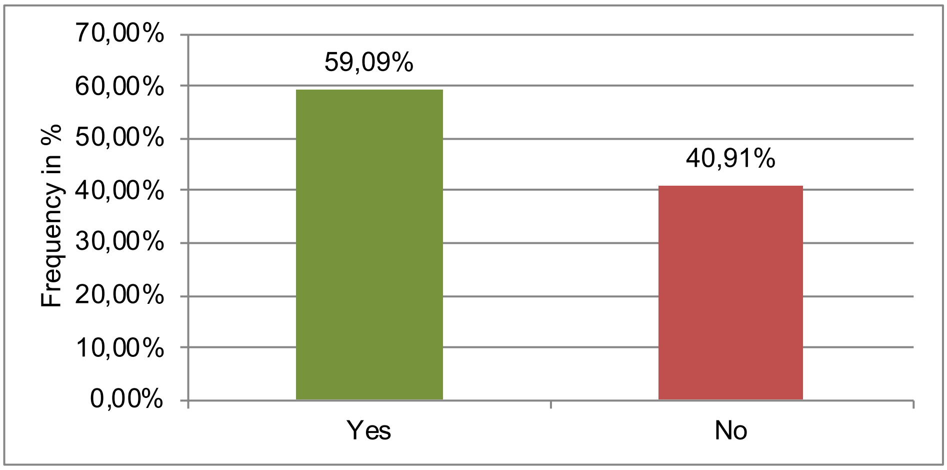


Figure 35: Results of question 8

Those 9 respondents who answered with "No" gave the following responses to the follow-up question:

- "Analysis of a case-study / simulation"
- "Formative evaluation by application and implementation"

- “Participation in a group-project and peer-assessment”
- “Competition between teams”
- “Continuous assessment and feedback to the learner is very important.”
- “Feedback from the learners as their auto-evaluation after a period of time, with reference to their working practices”
- “Formative assessment through reflectivity or reflexivity”
- “The question is how learning success is defined. Based on the definition, different formats for evaluating learning success are possible.”
- ““Knowledge tests” are conducted but, at the same time, there is “no evaluation of learning success”. How does that fit together?”

Interpretation: A majority of the respondents regarded the list of formats as complete, which shows that the presented list of formats received positive reception overall. The feedback given by those 9 respondents, however, is valuable and needs discussion.

A subgroup of the respondents focused on the evaluation of the learning success by practical application of the knowledge, which was not made explicit enough in the original list. Although “Practical example” is part of the original list, this term can be split up into more precisely defined terms. The “Analysis of a case-study or simulation” and “Group-project and peer-assessment” is valuable input for redefining the practical evaluation format of the morphology.

“Continuous assessment and feedback to the learner” is another input that needs consideration in the final selection. Although a “Knowledge test” was originally considered, this term may not be precise enough. A format called “Continuous knowledge assessment & feedback” is a more precise definition of the originally implied evaluation format for the learning success.

As mentioned in Chapter 2, competition is an essential facet of gamified learning. Using the competition between users and user groups as an indicator for learning success makes it a relevant evaluation format. This input will be considered in the adapted morphology.

Auto-evaluation and reflection are the remaining terms that were mentioned among the answers to the follow-up question. Using “Self-assessment” as an evaluation format in a learning process is an obvious possibility that has not been considered in the original list and will be included in the adaption.

In addition to the input on new evaluation formats, two respondents questioned the general plausibility of the question. One respondent legitimately stated that the definition of learning success is the decisive factor for choosing appropriate evaluation formats. Of course, the definition of learning objectives and the subsequent evaluation of goal attainment go hand in hand. This was taken into account during the development of the morphology. When applying the morphology, learning objectives are defined prior to the decision on evaluation formats.

Another respondent questioned the simultaneous existence of knowledge tests and the possibility of conducting no evaluation in the original list. This list, however, can just be seen as a listing of possible evaluation formats in the described context. Based on different learning objectives, target group characteristics and contexts the appropriate evaluation formats have to be chosen for each specific use case separately. While it may be reasonable for some use cases to apply more than one evaluation format in the course of a training, other use cases may just use one or no evaluation format.

The subsequent changes to the morphology will be described in Chapter 5.2.

Question 9: A Gamification application is being developed for training purposes in industrial maintenance. The possible use cases are as diverse as the possibilities for data collection. These are:

- **Sensors**
- **Monitoring systems**
- **Feedback**
- **Manual input**

Do you believe that this distinction of possibilities for data collection is sufficient? Please mark your answer and explain your decision.

The participant was provided with six selection fields, ranging from “Very sufficient” to “Very insufficient”.

Results: In total, 12 participants answered this question. The exact results are shown in Table 21. At first glance, an average of 3.08 allows no clear conclusion on whether the distinction of possibilities for data collection is sufficient or not.

Table 21: Results of question 9

	Very sufficient					Very insufficient		
Value	**1**	**2**	**3**	**4**	**5**	**6**	**Total**	**Average**
Frequency in %	0,00%	25,00%	50,00%	16,67%	8,33%	0,00%	100,00%	**3,08**
Frequency Count	0	3	6	2	1	0	12	

The participants were provided with the opportunity to comment their decision, which 7 participants did. Their comments are presented in the following:

- “Machine control, portable data terminal, PPS and QS are missing”
- “What about AR tools? Conversational AI?”
- “Maybe additional, old data (e.g. list of errors, time tracking) are relevant.”

- "If manual input is explicitly mentioned, why not voice or visual input?"
- "The difference between feedback and manual input is not clear to me."
- "Do monitoring systems include data from machine control?"
- "The distinction between sensors and monitoring systems is unclear. If technical monitoring systems are meant (e.g. condition monitoring of machines), these systems usually rely on sensor data."

Interpretation: As an average of 3.08 yields no distinctive result, a detailed discussion of the comments is necessary.

Augmented Reality is a tool that could very well be used in the course of gamified trainings in industrial maintenance. Through the user's interaction with the virtual and real world on a device, a Gamification application can generate user specific data. Therefore, a consideration in the morphology for possibilities of data collection makes sense.

The original list includes manual input as a form of data collection. Acoustical, conversational and visual input are also thinkable forms of data collection. When thinking of acoustical input, voice recognition as a form of data collection comes to mind. Communicating with the application in the form of chat bots are a good source of conversational input to the system. Visual recognition using motion recognition, for example, could track the workers movements during the learning process and generate useful data. As all these examples are possible forms of collecting data for a Gamification application, these technologies will be considered in the morphology.

From the comments can be taken that the existence of both sensors and monitoring systems was the cause of some confusion among the participants. Monitoring systems, of course, make use of sensors but are more complex systems and can oversee more aspects of a process than a single sensor. Sensors of all kind are the data source for modern monitoring systems, production control and quality surveillance. In order to minimize confusion and to not overload this attribute of the morphology, sensors and monitoring systems will be merged into a single characteristic.

Also, the difference between feedback and manual input seemed to be unclear. Feedback, in the way as it was perceived when creating the list, meant actively asking the user for individual feedback on certain exercises or learning content. This feedback could then be used as a data source for individualizing the user's learning experience. Manual input, on the other hand, was meant as a sole source of data input. For example, when using Duolingo for learning a language, the user always has to type in text or press certain buttons on the screen in order for the application to get data. Still, both techniques are forms of manual input and will therefore be merged in the final version of the morphology.

The subsequent changes to the morphology will be described in Chapter 5.2.

5.3 Questions on the Procedural Model

Question 10: In the course of this master thesis a procedural model for the launch of a Gamification application for upskilling purposes in industrial maintenance has been developed. The following figure shows the procedural model's general structure.

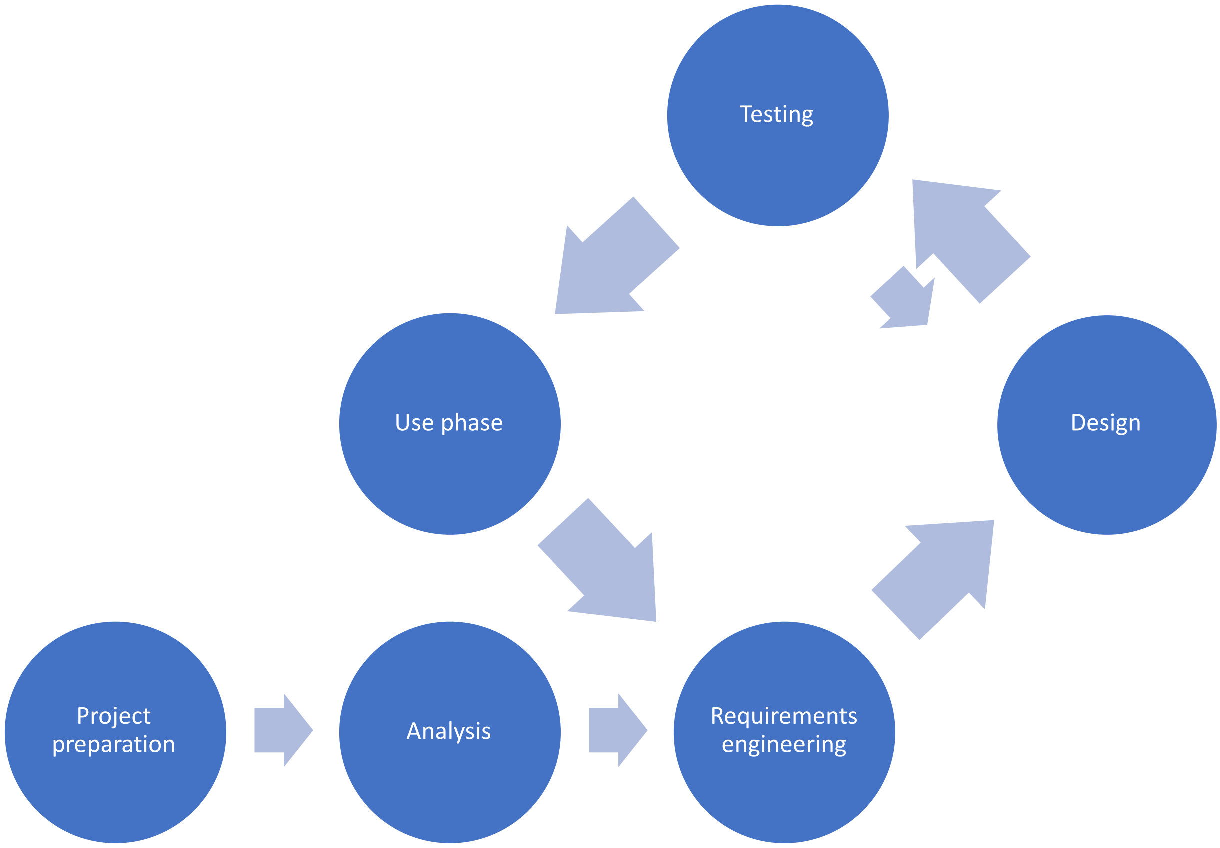


Figure 36: General structure of the procedural model

Do you think that the procedural model is well-suited for the specific use case?

The participant was provided with six selection fields, ranging from "Very suitable" to "Very unsuitable".

Results: In total, 5 participants answered this question. The average answer had the value of 2.00, which can be seen as a great approval rate. The results of question 10 can be seen in Figure 37.

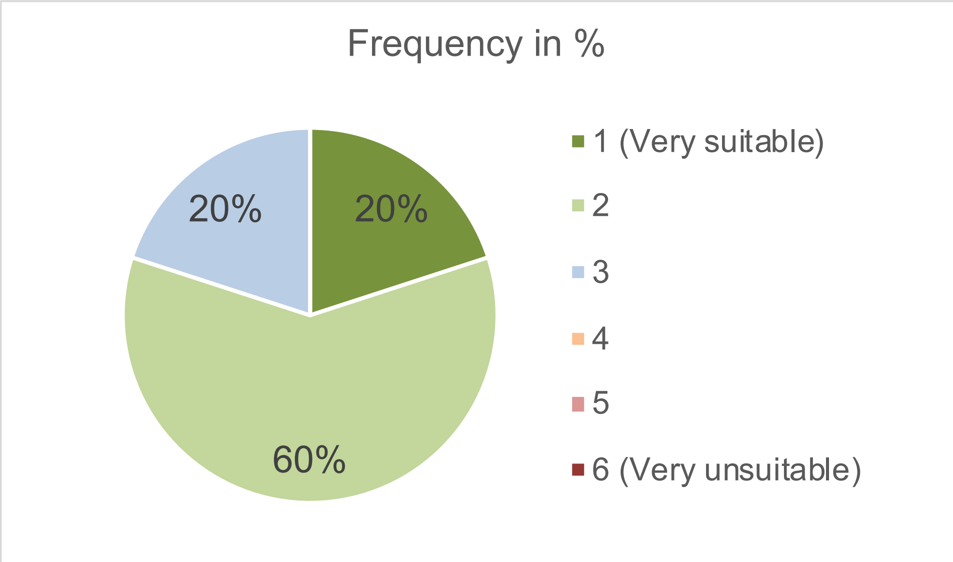


Figure 37: Results of question 10

One respondent took the possibility and wrote a statement in the comment section of the question:

- "It is suitable because it is quite general. This procedure is also suitable for building a ship – it is unspecific and therefore not very helpful. The phase "Analysis" could be included in the loop."

Interpretation: Overall, the respondents rated the general structure of the procedural model as suitable, resulting in an average of 2.00. This can be regarded as a high approval rate. No respondent answered with a value of 4 or worse.

Regarding the comment made by one participant, the structure shown in Figure 36 does explicitly show the structure of the procedural model on a very abstract level. This structure, however, is not the detailed procedural model that is used for the development of a gamified upskilling application. Still, the procedural model has been designed as a generic model, in order to provide applicability for a variety of use cases for training in maintenance.

The inclusion of the "Analysis"-phase in the requirements loop is an option that was considered during the development of the procedural model. While in the "Analysis"-phase a general user and context analysis is conducted, the "Requirements engineering"-phase yields the detailed requirements about the system and the learning design. Unless the target group or the context change substantially, which is unlikely over the lifespan of a gamified training application, no reiteration of the "Analysis"-phase is considered necessary.

Question 11: During the design phase of a Gamification application for upskilling purposes suitable learning content has to be created, motivating incentives have to be added and an attractive user interface (UI) has to be designed. Finally, appropriate game features (e.g. levels, points and rankings) have to be implemented.

The following figure shows the central activities of the procedural model's design phase.

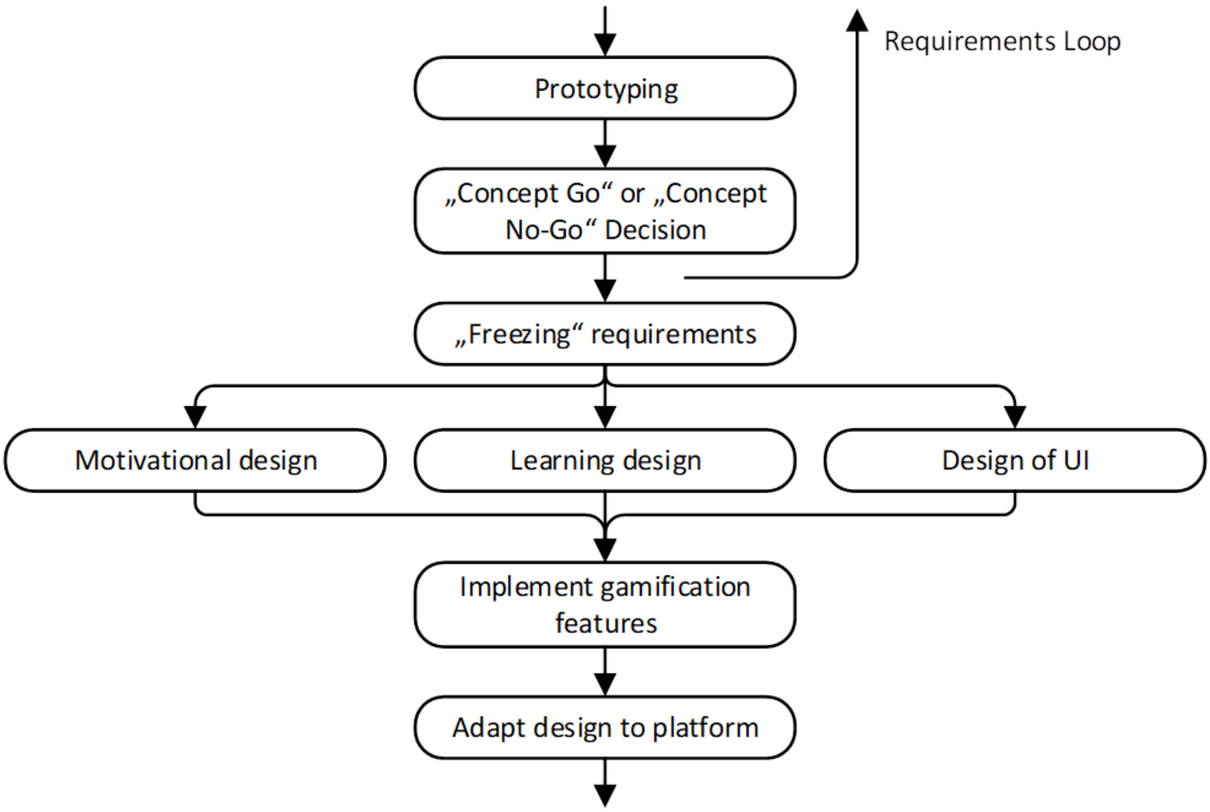


Figure 38: Central activities of the procedural model's design phase

The "Requirements Loop" indicates that requirements are collected iteratively and can be adapted after prototyping and the go or no-go decision.

Do you think that a design phase in this form is well-suited for this specific use case?

The participant was provided with six selection fields, ranging from "Very suitable" to "Very unsuitable".

Results: Overall, 26 participants answered this questions, resulting in an average value of 2.81. The exact results of the question can be seen in Figure 39.

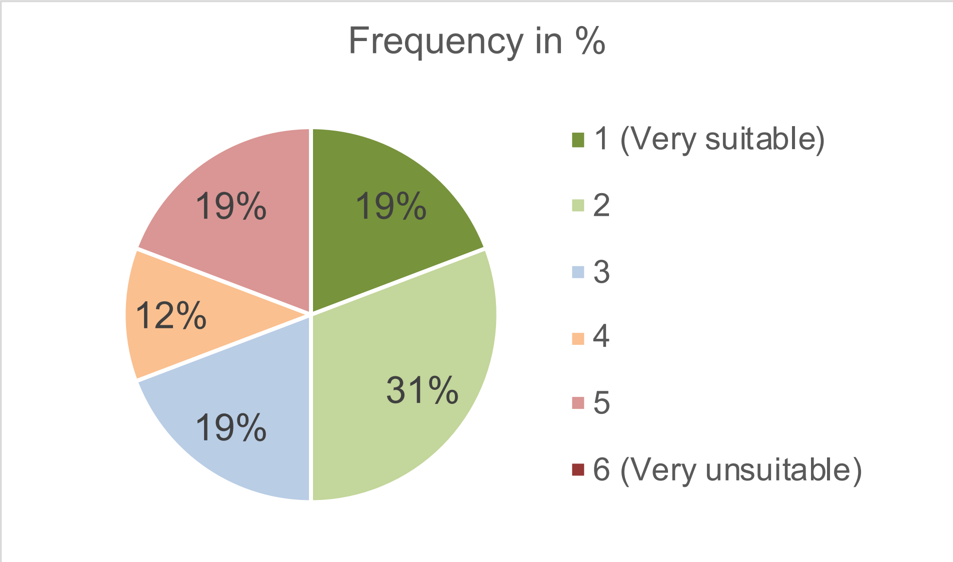


Figure 39: Results of question 11

8 participants took the possibility of explaining their decision in the comment section of the question:

- "The model is good. The use case, the domain and the learning objectives are not described, which makes the question hard to answer."
- "It makes sense."
- "This question cannot be answered by an industrial maintenance technician."
- "Here, as well, the model is on a very generic level. Without knowing the phases in detail, one cannot say if the model is suitable."
- "Before implementing, there should be a loop, as well as after the implementation."
- "An "experience loop" could be included that takes into account learning effects for improving the design."
- "Shouldn't the requirements loop also be applied between "Implement gamification tasks" and "Adapt design to platform"? It might, thus, provide for reflection-upon-pilot-application."
- "Evaluation/reflection of the prototype and re-design process?"
- "The weak element is the one about motivation. From the cultural-historical activity theory, motives to participate are connected to the features of the whole industrial activity. Incentives are not enough."

Interpretation: The average answer had a value of 2.81, which shows a tendency towards the design phase of the model being suitable for the purpose. To better understand the participant's decisions, the discussion of the comments is necessary.

One respondent stated that the use case and the objectives of the application were unclear. This is because the context and the overall purpose as well as the learning objectives are examined in different phases prior to the design phase of the model.

The excerpt shown in Figure 38 just shows the activities required for designing a gamified application with the requirements already being in place.

Another comment addresses the generic structure of the design phase. On the one hand, this section of the model was abstracted to a certain degree in order to pose a simple to understand question. On the other hand, the design phase of the procedural model was deliberately kept at a relatively generic level, as the main focus of the thesis explicitly is the extraction of requirements, which resulted in the less generic phases “Analysis” and “Requirements engineering”.

A few comments are focused on the selection of loops in the model. As described in Chapter 4, the loops of the use phase result in new patches and new versions of the application. Within these loops, bugs are repaired, and the design is adapted respectively. The experiences of the design team flow into these iterations, which, in my opinion, makes a separate “experience loop” within the design phase unnecessary.

Another suggestion mentioned an additional requirements loop after the implementation of the gamification features and before the adaption to the platform in order to account for necessary changes before the pilot application. This, however, is covered by a comprehensive testing phase, which includes several quality assurance points that may trigger change requests.

Also, the prototype is evaluated immediately after it’s development, which is not shown in this depiction (Figure 38) due to reasons of better clarity. Necessary changes to the prototype flow into the go or no-go decision. An go-decision may then result in a requirements loop to improve the initial prototype. Likewise, the final product is monitored over the use phase. Insights on user feedback, usage and bugs flow into the re-design process.

While the comment on motivational theory is somewhat unclear to me, incentives actually make up the fundamental nature of Gamification. Incentives are the driving force behind all gamification features and are the reason for increased user motivation. This was described in detail in Chapter 2.

To sum up, the results of question 11 resulted in a proof of the design phase concept. Through discussion the participant’s comments could be resolved and no further changes to the procedural model are necessary.

5.4 Follow-up Question

Question 12: On a scale of 1 to 5, how useful, do you think, is the application of Gamification for upskilling employees in corporate practice?

The participant was provided with five selection fields, ranging from “Very useful” to “Very unuseful”.

Results: Overall, 33 participants answered this question. The average answer value was 1.82. The exact results of question 12 are shown in Table 22 and Figure 40.

Table 22: Results of question 12

	Very useful				Very unuseful		
Value	**1**	**2**	**3**	**4**	**5**	**Total**	**Average**
Frequency in %	48,48%	30,30%	15,15%	3,03%	3,03%	100%	**1,82**
Frequency Count	16	10	5	1	1	33	

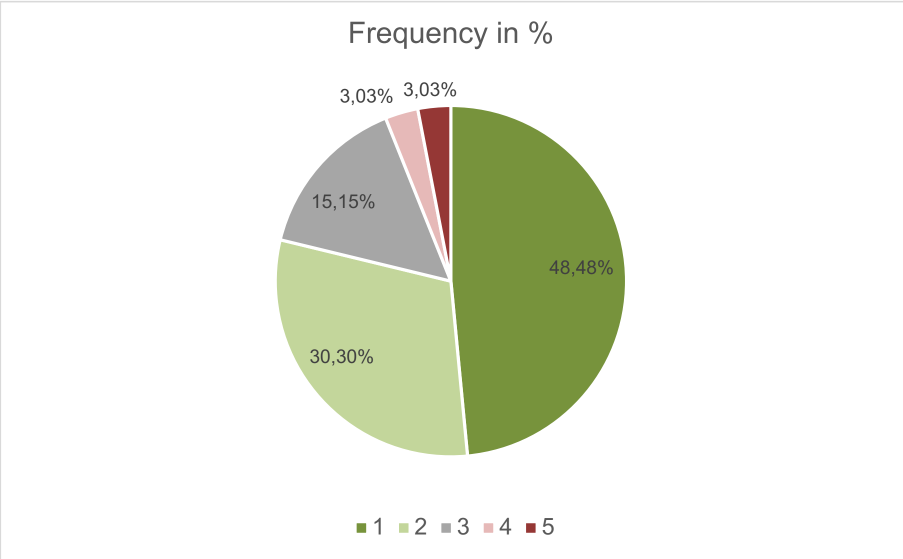


Figure 40: Pie chart of the results of question 12

Interpretation: Almost 80% of the respondents think that Gamification is a useful tool for skilling employees in corporate practice. While 15% of the respondents were unsure about the benefits of Gamification, only 6% regard Gamification as not useful for the application in corporate practice. This proofs the already expected high confidence in the concept of Gamification from experts in industrial maintenance and education.

5.5 Implications of the Survey

Through the survey, a lot of useful feedback has been gathered for both the morphology and the procedural model. The results of the survey and the feedback from the experts have been described and interpreted in detail. While the concept of the procedural model could be proven through the survey, the morphology underwent some minor changes to meet the expert's feedback. These changes to the morphology are briefly described in this chapter (changes in bold letters).

Based on the respondent's feedback both the listed target groups and the subject-related learning content of category 2 of the morphology were changed. The target groups now match the suggested functional structure of industrial maintenance. The typical activities of industrial maintenance that can be used for gamified trainings were updated based on the feedback. The list is now sorted by suitability and missing activities were added. The final form of category 2 of the morphology can be seen in Table 23.

Table 23: Updated category 2 of the morphology

#	Category	#	Attribute	Characteristic			Reference
2	Setting	2.1	Main purpose	Skilling	Upskilling	Reskilling	
		2.2	Type of training	On-the-job training	Off-the-job training		
		2.3	**Target group**	**Apprentice**	**Technician (experienced)**	**Technician (unexperienced)**	
				Foreman	**Department manager**		
		2.4	User knowledge	Novice	Advanced Beginner	Competent professional	
				Proficient professional	Expert		
		2.5	Target industry	Mechanical & plant eng.	Automotive	Logistics	Tisch et al., 2015
				Transportation	FMCG	Aerospace	
				Chemical industry	Electronics	Construction	
				Insurance / banking	Textile industry	other	
		2.6	**Subject-rel. learning content**	**Instruction of beginners**	**Inspection**	**Documentation**	Bundesagentur für Arbeit, 2011
				Maintenance work	**Initial operation**	**Technical consulting**	
				Optimization	**Online maintenance**	**Maintenance planning & shift scheduling**	
				Functional reliability and eco-friendliness of machines	**Predictive maintenance**	**Condition monitoring**	
				Troubleshooting	**Data processing**	**other**	
		2.7	Implementation setting	Integration into workplace	Standalone training software		

Through the feedback, no instructional strategy was disqualified as unsuitable for Gamification. The strategies, however, were sorted by suitability based on the respondent's feedback. Whereas, the attribute "learning success evaluation" underwent comprehensive changes. Based on the received feedback, "Continuous knowledge assessment & feedback", "Analysis of a case-study / simulation", "Group project & peer assessment" and "Competition between user / user groups" could be added. These changes to category 4 of the morphology can be seen in Table 24.

Table 24: Updated category 4 of the morphology

#	Category	#	Attribute	Characteristic			Reference
4	Learning design	4.1	Learning objectives	Acquisition of knowledge	Acquisition of skills	Attitude change	Northern College
		4.2	**Instructional strategy**	**Experiential learning**	**Indirect instruction**	**Interactive instruction**	
				Direct instruction	**Independent study**		
		4.3	Instructional material	Readings	Instructional videos	Podcasts	
				Forums	Graphics	Animations	
				Interactive worksheets	Case studies	Simulations	
				Games	Quizzes	Other	
		4.4	Competence classes	Technical and methodological competencies	Social & communication competencies	Personal competencies	Tisch et al., 2015
				Activity- and implementation-oriented competencies			
		4.5	Learning scenario strategy	Instruction	Demonstration	Closed scenario	Tisch et al., 2015
				Open scenario			
		4.6	Degree of autonomy	Instructed	Self-guided / self-regulated	Self-determined / Self-organized	Tisch et al., 2015
		4.7	Standardization of trainings	Standardized trainings	Customized trainings		Tisch et al., 2015
		4.8	Theoretical foundation	Prerequisite	In advance (en bloc)	Alternating with practical parts	Tisch et al., 2015
				Based on demand	Afterwards		
		4.9	**Learning success evaluation**	**Based on progression in application**	**Continuous knowledge assessment & feedback**	**Analysis of a case-study / simulation**	Tisch et al., 2015
				Group-project & peer assessment	**Self-assessment**	**Competition between user / user groups**	
				None			
		4.10	Complexity of learning modules	Address technical and process knowledge	Address conceptual knowledge		Enke et al., 2015
		4.11	Use of user specific learning profiles	yes	no		Ansari et al., 2018
		4.12	Learning goals	Short-term: process optimization and steeper learning curves	Mid-term: optimal division of labor	Long-term: process & product innovations by mutual learning	Ansari et al., 2018
		4.13	Learning curve of user is tracked & can be displayed	yes	no		

Question 9 of the survey produced useful feedback on the possibilities for data collection for Gamification. Sensors and monitoring systems were merged into one characteristic "Monitoring sensors/systems", and "Voice recognition", "Visual recognition" and "Augmented Reality" were added. The final form of category 5 of the morphology can be seen in Table 25.

Table 25: Updated category 5 of the morphology

#	Category	#	Attribute	Characteristic			Reference
5	System	5.1	Communication channel	Onsite learning	Remote connection		Tisch et al., 2015
		5.2	Platform / System integration	Smartphone/Tablet application	Browser application	Computer program	
				Additional system to a common machine	Digitalized machine / Assistance system	Smart Factory	
		5.3	Reciprocal learning	Yes	No		
		5.4	**Data collection**	**Monitoring sensors/systems**	**Voice recognition**	**Visual recognition**	
				Augmented Reality	**Manual input**		
		5.5	Interface to human	mechanical	acoustical	optical	Ranz et al., 2018
				haptic			
		5.6	Average duration of a training	< 1 day	1 - 2 days	3- 5 days	
				5 - 10 days	> 10 days		
		5.7	Number of different trainings	1	2 - 4	5 - 10	
				> 10			
		5.8	Evaluation	Feedback of users	Learning output of users	Transfer to everyday work	Tisch et al., 2015
				Economic impact of trainings	Return on trainings / ROI		

6 Conclusion and Outlook

At the beginning of this work, Gamification was defined and delimitated from other forms of applied gaming. For Gamification, unlike Game-based Learning and Serious Games, game design elements are deployed in a value creation process for increasing user activity and motivation. The most prominent Gamification tools and features (e.g levels, points and leaderboards) were identified and the application of Gamification in educational, industrial, health- and customer-related contexts were described. Both Gamification and software development methodologies were analyzed and their applicability for the design of a gamified application for training in industrial maintenance was evaluated. Together with the analysis of relevant methods and procedures in Requirements Engineering the basis for the development of the procedural model was established.

Based on the analysis of the literature research, this thesis produced two considerable outcomes: a morphology that is able to assist in determining the specifications of a gamified training application and a procedural model that covers the necessary activities of the development process. The linkage of these two elements and the joint application during development offer an appropriate step-by-step approach to extract and specify requirements of a gamification tool and its features with regard to on- and off-the-job upskilling in industrial maintenance.

Both elements were evaluated through a survey in which a group of experts was asked for feedback on certain parts of the morphology and the procedural model. This feedback was analyzed in detail and was subsequently used for improvements. In addition to that, the survey showed that the interest for and the potential of Gamification is high. The majority of the experts considered Gamification as a highly useful tool for future practical training. While the concept of the procedural model could be proven through the survey, the morphology underwent some minor changes to meet the expert's feedback. Thereby, the appropriateness and the practicality of the outcomes could be ensured. The main research question of this thesis (see Chapter 1.1) has been answered as a result.

The morphology gathers all significant attributes of a gamified training application and ascribes all conceivable features and characteristics to them. Therefore, the data concerning all possible configurations of a Gamification application for training in industrial maintenance is gathered in this morphology. The categories have been chosen following the morphology by Ranz et al.[265]. Going through this morphology and choosing one or more appropriate characteristics within every attribute leads to a determination of the specifications of the Gamification application. This constitutes a

[265] cf. Ranz et al., 2018

considerable addition to the literature on Gamification in the context of training in industrial maintenance.

Especially at a time when learning and qualification requirements for future jobs in industrial maintenance are changing constantly (P1), Gamification presents an approach that is able to motivate the user to achieve high learning outcomes while offering a high user experience. Especially with regard to troubleshooting, opportunities for experiential learning are decreasing due to improved machine performance (P2), which makes knowledge transfer more and more difficult. A Gamification application, in combination with modern technology, is able to provide the user with additional informal learning opportunities. A gamified application offers the platform and the incentive system for increasing the motivation for learning to a higher level. Combining Gamification features with state-of-the-art technologies like AR can generate environments in which the learner can experience learning beyond traditional learning strategies.

The initial literature research, however, showed the non-existence of a procedural model for designing and developing a gamified application for upskilling maintenance staff (P3). The procedural model that was developed in the course of this thesis is specifically applicable to the design and implementation of a gamified application for skilling, upskilling or reskilling employees in the field of industrial maintenance. The model consists of 6 phases: project preparation, analysis, requirements engineering, design, testing and use phase. In combination with the morphology, the core of which is the design of gamified learning content, the procedural model is well suited for being used as a guideline in developing a gamified training application.

The main iterative cycles are surrounded around the requirements loop and the quality loop. The chosen visualization allows both development teams working with traditional software development mindsets and teams working with an agile mindset to adapt the procedural model to their working style. While traditional software development teams run through the model only once during the development process, agile teams can easily adopt the model to a series of sprint cycles.

To sum up, both the developed morphology and procedural model are in state that they are ready for pilot application and testing in a practical setting. Future work on this topic could focus on a pilot application of morphology and procedural model. The insights gathered through this initial application could be the source for further improvements. In addition to that, the procedural model was designed as generic model in order to ensure the applicability for a variety of specific maintenance use cases. Still, this is a limitation of the current state of the procedural model. Only in combination with the morphology, the procedural model is provided with a specific maintenance context. As a next step, future research could therefore use this generic procedural model as the basis for refining the model with regard to specific application areas and use cases within industrial maintenance.

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List of Abbreviations

Abbreviation	Description
AR	Augmented Reality
Cedefop	European Centre for the Development of Vocational Training
CRISP-DM	Cross Industry Standard Process for Data Mining
ECVET	European Credit System for Vocational Education and Training
EQF	European Qualifications Framework
et al.	and others
f.	following
HCD	Human-centered design
HEP	Human error probability
HRP	Human reliability probability
HUCD	Human-User centered design
ICT	Information and communications technology
IEEE	Institute of Electrical and Electronics Engineers
ISCO	International Standard Classification of Occupations
IT	Information technology
KldB	Klassifikation der Berufe
MDA	Mechanics, dynmacis and aesthetics
p.	page
Px	Problem No. x
R & D	Research and development
SMART	Specific, measurable, achievable, relevant and timely
SysML	System Modelling Language
UCD	User-centered design
UML	Unified Modelling Language
UX	User experience
VDI	Verein Deutscher Ingenieure e.V.
VET	Vocational Education and Training

Appendix

On the following pages, a copy of the survey, which was conducted with the use of the online platform LamaPoll, is attached.

TECHNISCHE UNIVERSITÄT WIEN

INSTITUTE OF MANAGEMENT SCIENCE
Research Group of
Smart and Knowledge-Based Maintenance

Survey - Master Thesis on Gamification in Industrial Maintenance

Dear participants!

The purpose of this survey is to **gather feedback on the current master thesis** at the Institute of Management Science. We would greatly appreciate your taking **5 minutes** time to participate in this survey.

This master thesis is supervised by the Research Group of Smart and Knowledge-Based Maintenance.

No personal data will be collected in the following questionnaire.
Thank you!

By clicking on "Next", you agree on this and you will start the survey.

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Description of the thesis

Gamification is a new instrument in support of learning. So far, there is no procedural model and no morphology for the application in corporate practice, especially in the field of industrial maintenance.

In the course of this thesis, both a procedural model and morphology have been developed for the elicitation of requirements for the specific application in industrial maintenance.

By taking part in this survey, you can contribute to evaluating the results of the master thesis and closing the respective gap in scientific literature.

Introductory questions (1/2)

★ Question 1

Are you familiar with the concept of Gamification?

- ◯ Yes
- ◯ No

Gamification - Overview

Gamification describes the use of game design elements (e.g. points, rankings, badges, etc.) in non-game contexts.

The goal is to increase user motivation for usually monotonuous and/or challenging tasks through the integration of these game elements.

Especially in learning situations, Gamification is applied more and more frequently (e.g. "Duolingo" for learning foreign languages, or "Codecademy" for acquiring programming skills). In particular, Gamification supports work-based trainings in Industry 4.0.

Introductory questions (2/2)

Question 2

Do you already have experience with Gamification?

(Multipe answers allowed)

- [ ] Yes, in a private context
- [ ] Yes, in a professional context
- [ ] No experience

Question 3

In what industry do you work?

Science

- ◯ ICT
- ◯ Industrial Engineering
- ◯ Education
- ◯ Other: ________

Industry

- ◯ Manufacturing company
- ◯ Logistics company
- ◯ Provider of training programs
- ◯ Other: ________

Currently in education

- ◯ Student
- ◯ Other: ________

Question 4

Please choose the answer that best fits your interests / professional field / etc.

(You will be assigned the remaining questions based on your answer.)

- ◯ **Industrial maintenance**
- ◯ **Developer** (IT/Software Development/etc.)
- ◯ **User** (Teaching / Learners [e.g. students/apprentices] / etc.)

Question Pipe - Industrial Maintenance (1/3)

Question 5a

A Gamification application is being developed for training purposes in industrial maintenance. Prior to development, a user analysis is conducted. The following **target groups** are identified:

- Apprentice
- Working student
- Employee
- Engineer
- Manager

Do you believe that this distinction of target groups is sufficient? Please mark your answer and explain your decision.

Very sufficient ○ ○ ○ ○ ○ ○ Very insufficient

Comment

Question Pipe - Industrial Maintenance (2/3)

Question 6a

A Gamification application is being developed for training purposes in industrial maintenance. The possible use cases are as diverse as the possibilites for data collection. These are:

- Sensors
- Monitoring systems
- Feedback
- Manual Input

Do you believe that this distinction of **possibilites for data collection** is sufficient? Please mark your answer and explain your decision.

Very sufficient ○ ○ ○ ○ ○ ○ Very insufficient

Comment

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Question Pipe - Industrial Maintenance (3/3)

Question 7a

Great, only two more questions left 😉

Is a Gamification application a well-suited format for upskilling workers in usual activities of industrial maintenance?

Please choose the respective suitability for every activity.
(At the end of the question you have the chance to add and assess three additional activities.)

	Suitability				
	very good	good	medium	bad	very bad
Maintenance work	◯	◯	◯	◯	◯
Troubleshooting	◯	◯	◯	◯	◯
Instruction of beginners	◯	◯	◯	◯	◯
Documentation	◯	◯	◯	◯	◯
Maintenance concept development	◯	◯	◯	◯	◯
Technical consulting	◯	◯	◯	◯	◯
Initial operation	◯	◯	◯	◯	◯
Data processing	◯	◯	◯	◯	◯
Inspection	◯	◯	◯	◯	◯
Functional reliability and eco-friendliness of machines	◯	◯	◯	◯	◯
Retrofit	◯	◯	◯	◯	◯
Optimization	◯	◯	◯	◯	◯
Software maintenance	◯	◯	◯	◯	◯
Online maintenance	◯	◯	◯	◯	◯

R & D

Other

Other

Other

Question Pipe - User (1/3)

Question 5b

A gamification application is being developed for training purposes in industrial maintenance. There are different **instructional strategies** for conveying learning content. Please choose the strategies that you think are well-suited for the use in a Gamification application.

(Multiple answers allowed)

- [ ] Direct instruction (e.g. lectures, demonstrations)
- [ ] Indirect instruction (e.g. case studies, problem solving)
- [ ] Experiential learning (e.g. games, experiments)
- [ ] Independent study (e.g. reads, exercises)
- [ ] Interactive instruction (e.g. discussions, group projects)
- [ ] Other: __________

Question Pipe - User (2/3)

Question 6b

There are different possibilites for evaluating learning success. For the use in a gamified upskilling-application in industrial maintenance, the following formats for evaluating learning success have been identified:

- Progession in the learning modules of the application
- Knowledge test
- Practical example
- No evaluation of learning success

Do you believe that this list covers all possible formats for evaluating learning success in this specific use case? Please mark your answer.

○ Yes ○ No

Follow-up question

Which additional format(s) for evaluating learning success should be considered?

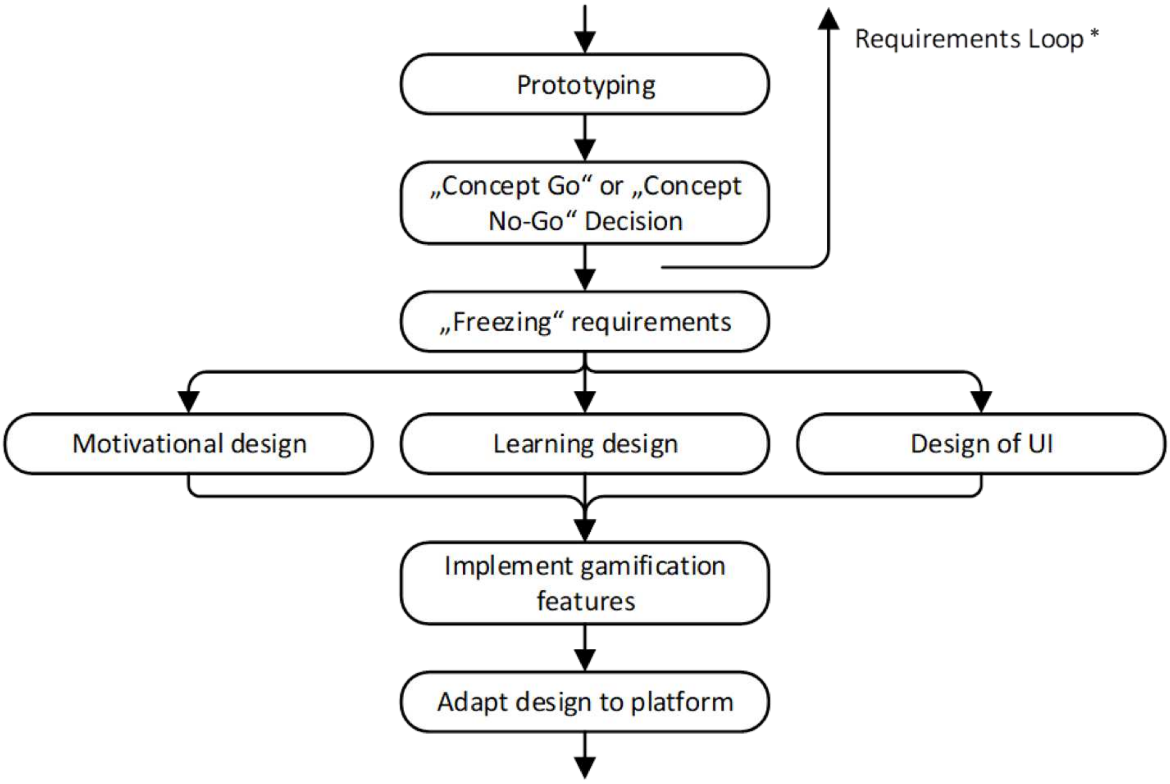
Question Pipe - User (3/3)

Question 7b

Great, only two more questions left 😉

During the design phase of a Gamification application for upskilling purposes suitable learning content has to be created, motivating incentives have to be added and an attractive user interface (UI) has to be designed. Finally, appropriate game features (e.g. leves, points and rankings) have to be implemented.

The following figure shows the central activities of the procedural model's design phase.



** The "Requirements Loop" indicates that requirements are collected iteratively and can be adapted after prototyping and the go or no-go decision.*

Do you think that a design phase in this form is well-suited for this specific use case?

Very suitable ○ ○ ○ ○ ○ ○ Very unsuitable

Comment

Question Pipe - Developer (1/3)

Question 5c

A Gamification application is being developed for training purposes in industrial maintenance. The possible use cases are as diverse as the possibilites for data collection. These are:

• Sensors
• Monitoring systems
• Feedback
• Manual Input

Do you believe that this distinction of **possibilites for data collection** is sufficient? Please mark your answer and explain your decision.

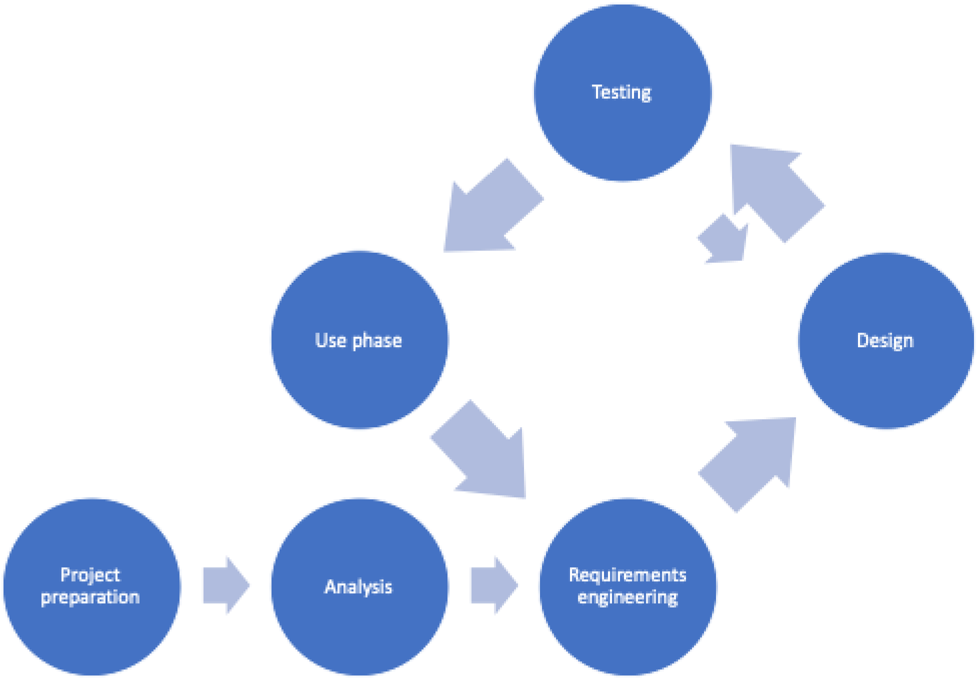
Very sufficient ○ ○ ○ ○ ○ ○ Very insufficient

Comment

Question Pipe - Developer (2/3)

Question 6c

In the course of this master thesis a procedural model for the launch of a Gamification application for upskilling purposes in industrial maintenance has been developed. The following figure shows the **procedural model's general structure**.



Do you think that this procedural model is well-suited for the specific use case?

Very suitable ◯ ◯ ◯ ◯ ◯ ◯ Very unsuitable

Comment

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Question Pipe - Developer (3/3)

Question 7c

Great, only two more questions left 😉

During the design phase of a Gamification application for upskilling purposes suitable learning content has to be created, motivating incentives have to be added and an attractive user interface (UI) has to be designed. Finally, appropriate game features (e.g. leves, points and rankings) have to be implemented.

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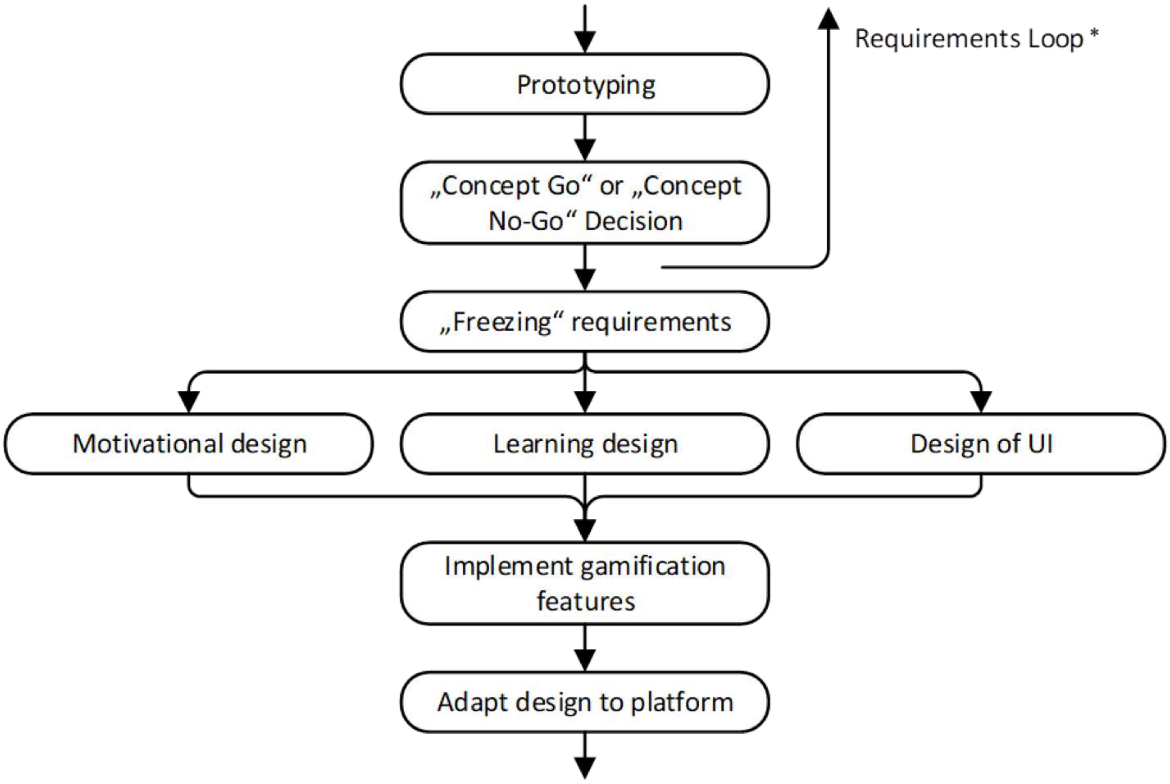

** The "Requirements Loop" indicates that requirements are collected iteratively and can be adapted after prototyping and the go or no-go decision.*

Do you think that a design phase in this form is well-suited for this specific use case?

Very suitable ◯ ◯ ◯ ◯ ◯ ◯ Very unsuitable

Comment

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Follow-up question

★ Question 8

On a scale of 1 to 5, how useful do you think is the **application of Gamification** for upskilling employees in corporate practice?

	1	2	3	4	5	
Very useful	◯	◯	◯	◯	◯	Very unuseful

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Thank you and Good-Bye!

Thank you for taking part in this survey.

Do you want to be informed on the results of this survey?

Then please leave your e-mail address here.