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# Training Of PDCA Cycle Using A Catapult In A Virtual Learning Environment

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**Abstract**

The sustainable teaching of quality methods in the sense of Lean Management and Six Sigma through assistance systems, such as Virtual Reality (VR) glasses, represents a new and growing aspect of continuing education programs. The development and usage of virtual learning environments offers the chance to deepen the theoretical prior knowledge through interactive learning possibilities. In this way, existing learning concepts are supplemented with virtual teaching content. Complex or difficult to present learning settings can be mapped virtually without high material consumption or costs. This paper presents the state of the art with respect to teaching quality methods with VR. An integration in the Assisted Reality Implementation Model is made. Subsequently, the requirements for a virtual learning environment based on a real business game are determined. The approach and implementation are explained using the example of the PDCA quality method. PDCA is an iterative design and management method used in business for the control and continual improvement of processes and products. First results of the exploration tests from the questionnaires are presented. Based on this, improvements are derived, and next steps are defined.

**Keywords**

Lean Management; Virtual Reality; Knowledge enhancement; PDCA method; Six Sigma

## 1. Introduction

Due to the Corona pandemic, face-to-face teaching had to be converted to various online formats in a short period of time. This not only had an impact on (higher) education, but workshops or training offers in learning and research factories also had to find new learning formats [1]. While the impact for theoretical knowledge transfer through video formats has been minor, the impact for practical exercises has been more severe. For the implementation of these practical exercises, different approaches are available as so-called digital laboratories, e. g. remote, digital live or full virtual laboratories [2]. In this context, Virtual Reality (VR) glasses and their versatile applications can provide great advantages for the fully virtual laboratories. Despite a high interest in this technology, also in the engineering field, the implementations in teaching are still under development [3]. At the same time, this technology is suitable for knowledge transfer [4] due to its multiple applications in diverse industries and value streams simultaneously [5, 6], location-independent experiences can be gained in different levels and user-specific difficulty levels. In addition, VR technology, through hands-on applications, supports knowledge transfer supported by the memory of "learning-by-doing" [7]. In general, positive effects can be observed from game-based teaching [8], which also can be used for the realization of the virtual learning environment (VLE) or represent a sub-goal.

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Quality methods are important basic elements in industry and science to achieve progress. The teaching of these methods is based on traditional teaching formats, such as lectures and talks. In addition, practical business games are used to illustrate the relationship between theory and practice. These business games take place in presence, hybrid or digital, rarely in the purely virtual world. For the location-independent training of these methods in interactive, virtual worlds, only a few practical applications, especially with VR glasses, are currently available [9].

## 2. State of the art of teaching quality methods with VR

Quality methods such as those taught in the fields of Lean Management and Six Sigma represent opportunities for e. g. process optimization. In practice, these methods have been successfully applied for decades and make an enormous contribution to increasing corporate efficiency and effectiveness. To apply such practice-oriented methods requires practice, for which VR applications can provide assistance [10]. The learner within VR can not only practice and try out what he/she has learned, but can also make mistakes that may lead to high costs or additional effort in problem solving in reality [2]. Despite several ongoing and already completed research projects, extensive VR applications for training purposes of quality methods have marginally found their way into practise [9]. Further research has revealed that exemplary applications exist in training first responder unit leaders (fire department), where the application of the PDCA (Plan, Do, Check, Act) method is intended to assist in decision making in complex response scenarios. However, so far only the realization of the Plan and Do phases has been reported [11]. Thus, the application potentials of the technology have not yet been exhausted. For this reason, the possibilities of conceptual application of VR in the context of Lean Management and Six Sigma will be considered in more detail.

Likewise, no standardized approach to the creation of virtual learning environments has been discernible during the extensive research work. This lack of a standardized framework for implementation leads to the fact that current VR learning environments are found in a confusing variety of isolated applications and different implementation premises, such as visual design or even teaching methodology. Systematic concepts for the integration into existing educational processes, system architectures and media concepts are missing here. Furthermore, there are no requirements for the design of VR learning environments and studies to assess its learning effects. Likewise, the organization of these teaching methods into institutional learning concepts is undeveloped [12]. For this reason, the possibilities of conceptual application of VR in the context of Lean Management and Six Sigma are considered in more detail. The development of a holistic approach to the creation and validation of VR learning environments for quality methods is necessary and considered useful. This should provide orientation for the creation of teaching units with virtual learning environments and show answers and possibilities whether and which quality methods from the field of Lean Management and Six Sigma can be implemented in VR in a meaningful way. Out of this necessity, the model of implementation for reality-based assistance systems (=Assisted Reality Implementation Model - ARIM) for the selection of Lean Management and Six Sigma quality methods was developed [9]. This represents a unified approach to create virtual learning environments as standardized and efficient as possible. ARIM is suitable for teaching quality methods interactively using augmented and virtual reality learning environments. Furthermore, ARIM enables meaningful guidance for the implementation of virtual learning environments, as well as subsequent validation. ARIM can be divided into 3 main phases, specifically 1 Potential Analysis, 2 Design and 3 Validation with respective sub-steps. Further information can be found in Figure 1.

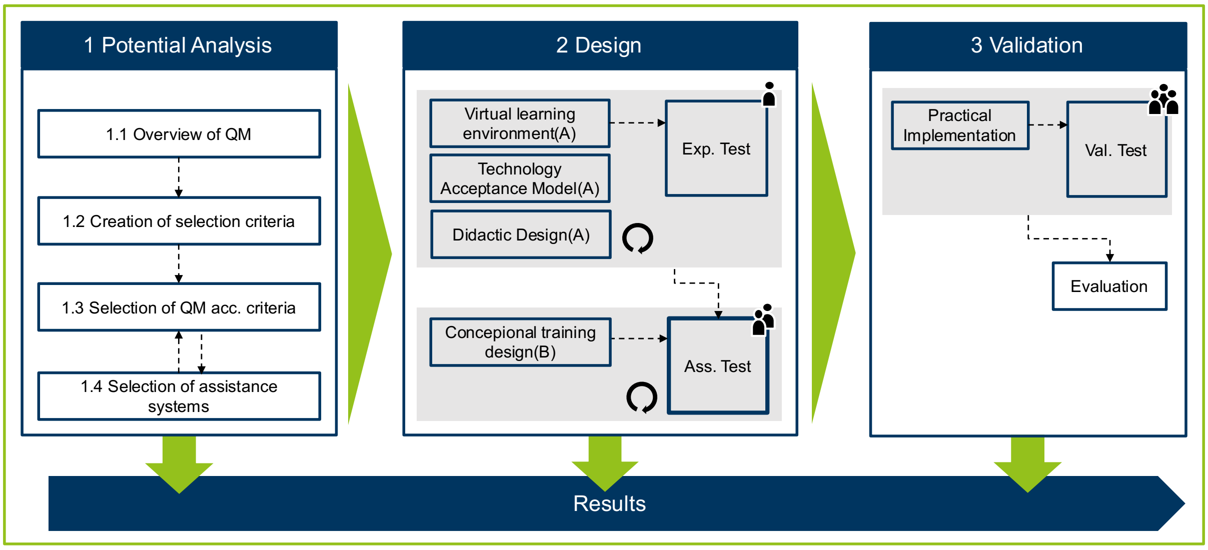


Figure 1: ARIM- Assisted Reality Implementation Model

This paper focuses on phase 2, the ARIM Design phase and the practical realization of the PDCA method. Section (A in 2 Design) includes the aspect of the VLE. For this, it deals with the instructional principles as well as the requirements for hardware, software, context of use, degree of realism, and interaction and navigation modes [13,14]. Another specific feature in content creation is the application of the evolutionary prototyping process [15], which will be validated by the exploration test.

Through these special interaction possibilities, the goal is to create a high recall value, concomitantly to increase the knowledge transfer and to stimulate the knowledge deepening. For this purpose, the development of a holistic VLE for the deepening of knowledge of the PDCA method is considered useful. Thus, this learning environment can be used in the field of further education to train employees of a production company and to provide appropriate qualification measures regarding process improvements.

## 3. From the real to the virtual PDCA – Catapult

One opportunity for teaching statistical methods but also for training the PDCA method in presence is a wooden catapult simulation [16]. This is also the case in the research project WILLEN (see Acknowledgements), which is the starting point for the virtual realization. The effort to realize a virtual PDCA catapult creates the possibility to offer a flexible use of VLE, so that online and face-to-face teaching can be intelligently combined in the training program. This will be tested in the research project WILLEN for its applicability, completeness, and acceptance. The background to the creation of VR and AR training units is to combine, as far as possible, compressed face-to-face phases in a further education institute with teaching units that can be attended flexibly online from home. This should make it easier to reconcile further training, and thus also the qualification of individuals, with company and, for example, family circumstances. In concrete terms, the first two ARIM Analysis and Design phases are currently being applied. The goal is to test individual methods that support action-oriented learning and, if successful, to embed them in a holistic training program. For a first learning application with VR assistance systems, the research project will implement the PDCA method in conjunction with a virtual catapult, since this method shows an overlap between the areas of Six Sigma and Lean Management [9]. The implementation is aimed with the help of standalone VR glasses, so that a self-sufficient use is guaranteed, which is also a result from phase 1 of the ARIM. This primarily realizes learning at one's own pace as well as learning by doing.

For the concrete realization of the virtual catapult further assumptions were made: For the implementation of the prototype, the necessary theoretical input for the VLE is assumed. This prior theoretical knowledge is made available to the participants through the platform moodle. Moodle is a learning management system that supports both blended learning and 100% online courses [17]. Due to the already existing theoretical input, an intensified examination of the VR technology is possible in the actual application. During the implementation of a virtual learning application, the aim is to design an intuitive interaction, so that it can be used by participants in everyday life without much additional effort. Questionnaires and interviews will then be used to determine whether this aspect is also perceived accordingly by the participants. This type of implementation is referred to as exploration testing. Due to the deliberate lack of theoretical input within the VLE, the element of an initial learning check is integrated, as the scenario cannot be solved without this prior knowledge.

### 3.1 Virtual PDCA application in design

For the intended implementation of the virtual PDCA method in the use of further education, the analogous business game is analysed in reality, i. e. here a deepening of the ARIM Design phase took place. To this end, the context of use is first understood and defined to determine the usage requirements for the PDCA method in the context of the catapult game. In the subsequent step, the requirements are determined taking into account the context of use. This is done with the help of the classical approach of the product development process [18]. The requirements are numbered with item number (Pos.) and are distinguished between demands (D), which are mandatory criteria, and wishes (W), which are optional criteria. With wishes, the effort to benefit must always be evaluated. As a result, a catalogue of requirements has been created, subdivided according to various aspects. A detailed explanation of the individual criteria is not provided here. An excerpt of the requirements for the implementation of the intended virtual PDCA method can be found in Table 1.

Table 1: Requirement List

| Requirement List | | |
|---|---|---|
| **Pos.** | **D/W** | **Requirement - Name** |
| 1 | | **Catapult** |
| 1.1 | D | At least: four deflection positions<br>two fixing points<br>two ball cup positions<br>six stop points<br>one rubber band<br>one ball |
| 1.2 | D | Clamping angle information |
| 1.3 | W | Dismantlability of the catapult |
| 1.4 | W | Aging of the rubber belt |
| 1.5 | W | Influence of the rubber band tensioning time |
| 1.6 | W | Bouncing of the catapult after firing |
| | | |
| 2 | | **Lean Management, Six Sigma** |
| 2.1 | D | Teaching of the PDCA cycle |
| 2.2 | D | Application of the PDCA cycle |
| | | |
| 3 | | **Virtual Reality / Programming** |
| 3.1 | D | Implementation of the programming |
| 3.2 | D | Selection/use of hardware |
| 3.3 | D | Analyze and define advantages of VR |
| 3.4 | W | Investigate involvement of multiple people |
| 3.5 | D | Interactive design |
| 3.6 | D | Time limited to 20-25 minutes |
| | | |
| Legend: Pos. = Position, D = Demand, W = Wish | | |

The virtual realization was based on these requirements. For description purposes, the implementation is divided into three parts (A, B, C, see Figure 2). The VLE starts with a welcome message for the user and additional instructions on how to carry out the training on a notice board (A, see Figure 2). At the same time, the goals of the learning environment are defined. Afterwards, the two-part active execution of the PDCA method takes place, which consists of an active experimental design and subsequent execution. The first step is to set up the experimental design on a blackboard according to the PDCA method (B, see Figure 2). For this purpose, signs with different tasks and a PDCA cycle are given on the board. These signs are to be assigned individually to the respective PDCA phase according to the theoretical knowledge of the users (drag-and-drop). After complete assignment, the users receive coloured feedback on their result and the possibility to correct corresponding errors. This preparatory activity supports the targeted implementation of the training and serves as a practical application of the PDCA cycle. This is followed by the practical application of the sequence created on the blackboard by the user (C, see Figure 2). For this purpose, a catapult is to be used to hit a movable container five times in succession. Three balls of different weights as well as different settings on the catapult itself are available as setting options. The last aspect includes the parameters clamping angle, stop rod, rubber band length as well as the position of the ball cup. The execution is supported by an automatic measurement of the target distance as well as a visual display of the flight line to take advantage of the VR. A second display panel shows the settings used with the result achieved.

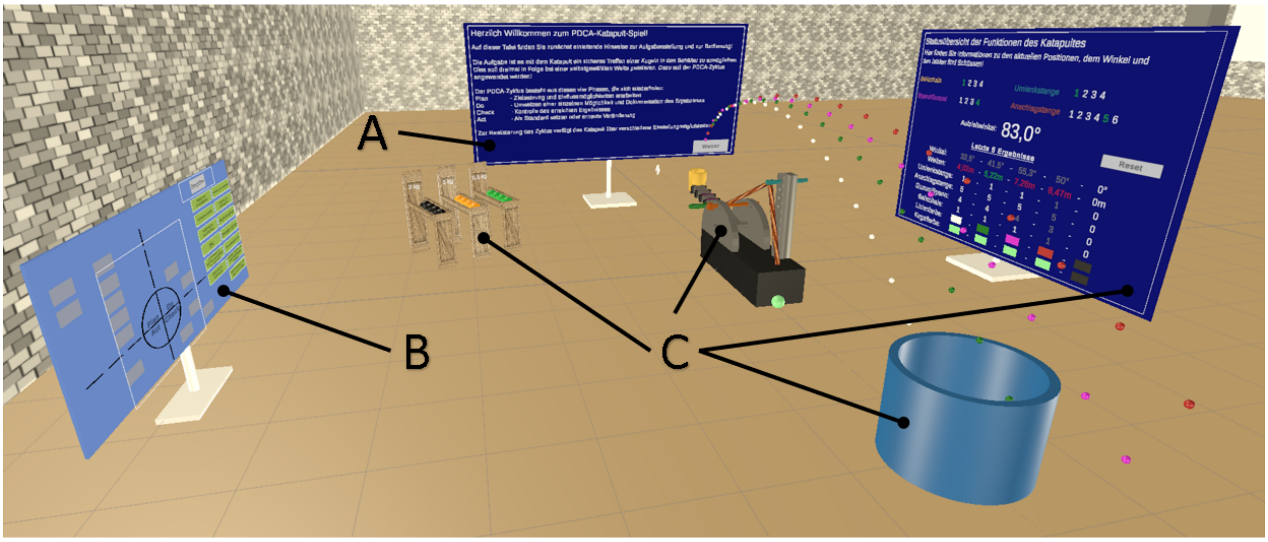


Figure 2: Representation of the virtual catapult and PDCA setting

From the requirements catalogue of Table 1, only the demand requirements were fulfilled in the concept. The requirements for Lean Management, Six Sigma (Pos. 2) were integrated by the blackboard (Pos. 2.1) and the practical implementation at the catapult (Pos. 2.2). The Virtual Reality / Programming (Pos. 3) requirements were also integrated. In this category, the inclusion of several persons was investigated, but not implemented, since this is partly also contrary to the time-individual execution of the test persons. The wishes from the requirement catalogue were not fulfilled, which is justified in the following. The catapult (Pos. 1) contains the necessary components (Pos. 1.1) and the clamping angle information (Pos. 1.2). The dismantlability (Pos. 1.3) as well as the bouncing (Pos. 1.6) of the catapult after a shot have not been implemented, since this catapult, in contrast to a real catapult, does not have to be or is not mobile. Likewise, the aging of the rubber band (Pos. 1. 4) and an influence of the tensioning time of the rubber band (Pos. 1.5) have been neglected, since these do not show any significance in the virtual environment.

For the validation, a two-part questionnaire was created. The first part is given to the users before entering the VLE and provides instructions on how to conduct the experiment. In addition, this collects demographic data, information about prior experience with VR, and knowledge level about the PDCA method. The second part is handed over after the virtual experience and is again separated into two sections. In the first section, the knowledge of the PDCA method and usability is recorded. The created questions are based on ISO 9241/10 questionnaire [19] but are adapted to the task and supplemented by free text expression. The second section covers the user experience. This section is based on the user experience questionnaire [20] but has been reduced by the category originality. In both sections, mainly the format of two bipolar word pairs on a seven-part, endpoint-based scale is applied. In this process, different word pairs are assigned to a category.

### 3.2 Virtual PDCA application in practice

In the first test run, the training of the PDCA method was now implemented with the help of a virtual catapult game. For the subsequent validation, the methods of thinking aloud and the semi-structured interview were chosen in addition to the previously explained questionnaires. Six persons took part in the validation for the exploration test, consisting of mechanical engineering students who thus overlap with the main target group of the training due to their theoretical prior knowledge in the field of lean management. The implementation took place in the Learning and Research Factory (LFF) of the Chair of Production Systems (LPS) at Ruhr University Bochum. Based on this, the participants were able to carry out the training in a VR replica of the LFF. The recognition value of the learning environment was positively evaluated by the participants. The participants first had the opportunity to familiarize themselves with the virtual mode of operation and then to try out the VLE without time restrictions. Afterwards they were asked to answer the developed questionnaire. For the first prototype, this evaluation was supplemented by a semi-structured interview. In this interview, questions were asked about the perception of the VR experience and conspicuities in the visual design. Likewise, the perception of the functionality of the catapult as well as the connection between the catapult and the PDCA method was queried. In addition, the interview allowed individual suggestions to be recorded and queries from the users to be clarified. The interviews and the thinking aloud also yielded suggestions for further optimizing the prototype used in a later revision. The results of the questionnaire after the test are shown in Figure 3.

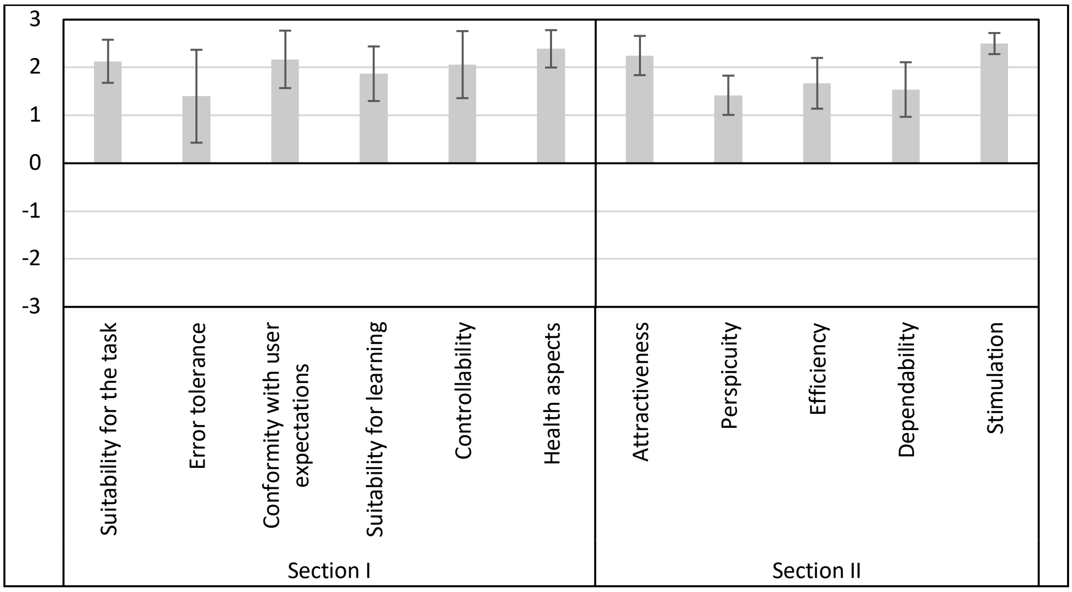


Figure 3: Results of the Questionnaires

Figure 3 shows the results of the individual categories of the word pairs of the questionnaire. The height of the bar represents the mean, and the small lines represent the confidence interval in both directions. The scale values range from -3 to +3. Across all categories, there is a mean of at least 1.4 (error tolerance) to a maximum of 2.5 (stimulation), which can be considered positive. The confidence interval varies between 0.22 (stimulation) and 0.98 (error tolerance). The large deviation of the error tolerance is due to no to few errors in the execution, so that the error tolerance did not appear. The stimulation and the high attractiveness underline the desire to use the VLE more often for other methods.

In summary, all participating subjects successfully completed the VLE and did not have to take an unplanned break or abort. All subjects spent between 10 to 20 minutes in the VR. The application is scheduled for up to 20-25 min, so the duration so far is within reasonable limits. The longer dwell time could be explained in the subsequent evaluation with the help of increased motivation and determination of the participants. In addition, the movement in the VR was evaluated as intuitive by the test persons. Furthermore, the VLE was perceived as motivating, entertaining and innovative, which is cited as the overall result of the exploration test. Based on the above results, minor improvements to the concept could already be implemented.

## 4. Summary and outlook

The training of quality methods with the help of VR glasses is a promising field of application, which has still received little attention in research, teaching and industry. Digital assistance systems for training purposes offer many advantages compared to classical classroom training, e. g. time independence of the training per participant. To address this emerging need for research, a test run for training the PDCA method was implemented and validated with a first group of test persons. Hereby, first important aspects of the design of virtual learning environments for VR assistance systems could be analysed. Furthermore, it became clear that there is a need for further research in this field, because, for example, the perception of the technology in the training has a significant influence on the experience and thus on the quality of the training. As a further step, the outstanding sub-steps of the ARIM, part A and B of the Design phase, are to be realized and tested. This means above all to work out the immersive technology acceptance model (A) for the evaluation as well as to carry out the assessment test. Subsequently, phase 3 of the validation will start.

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