VRVET
Non-Destructive Testing

Deliverable D3.1 - Scenarios For Practical Application Cases, Which Will Be In The NDT Examination Platform With Penetrant Testing

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Non-Destructive Testing

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Executive Summary

This deliverable, "D3.1 Scenarios for Practical Application Cases, which will be in the NDT Examination Platform with Penetrant Testing," outlines the design and development of practical application scenarios for a Virtual Reality (VR)-based training platform in Non-Destructive Testing (NDT). The primary goal is to present a detailed design of actionable scenarios that will be implemented in the NDT examination platform, ensuring the training is realistic, immersive, and aligned with industry standards.

The document is structured into the following main sections:

- **Introduction**

Provides an overview of the document, explaining its purpose and scope.

- **VR Structure**

Details the structure of the VR platform, focusing on the nine stages of the process. This section also covers the target audience (NDT operators, VET students, trainers, and industry professionals) and the learning outcomes (knowledge acquisition, skill development, and cognitive growth).

- **Framework for Scenario Design**

Explores the framework used to design the scenarios, focusing on the Activity Theory-Based Model for Serious Games Analysis and Conceptual Design (ATMSG).

- **Application of ATMSG Framework**

Explains how the ATMSG framework is applied to design the scenarios, ensuring they are learner-centric, interactive, and aligned with instructional goals.

- **Technical Considerations**

Discusses the technical infrastructure of the platform, including hardware (HTC Vive Focus Vision) and software (Unity 3D and other tools). It also covers integration strategies to ensure seamless communication between hardware, software, and the Learning Management System (LMS).

- **Pedagogical and Learning Requirements**

Outlines the pedagogical principles that underpin the platform, including Kolb's Experiential Learning Model.

- **Learning Analytics**

Explains the role of learning analytics in optimizing training performance.

In summary, this deliverable presents detailed, practical application scenarios for the NDT examination platform, supported by a robust technical and pedagogical framework. It ensures that the platform provides a scalable, immersive, and effective training solution for NDT operators, vocational education and training (VET) students, trainers, and industry professionals. By focusing on realistic scenarios and their integration into the platform, this deliverable lays the groundwork for a training system that bridges the gap between theoretical knowledge and practical application, preparing trainees for real-world NDT inspections.

Introduction

This deliverable, "D3.1 Scenarios for Practical Application Cases, which will be in the NDT Examination Platform with Penetrant Testing," outlines the design and development of practical application scenarios for a Virtual Reality (VR)-based training platform in Non-Destructive Testing (NDT). The primary goal of this deliverable is to present a detailed design, actionable scenarios that will be implemented in the NDT examination platform, ensuring that the training is realistic, immersive, and aligned with industry standards.

Each stage of the scenario is designed to replicate real-world NDT workflows, incorporating interactive tools, realistic defect visualization, and immediate feedback. These scenarios are not only critical for skill development but also ensure that trainees can practice in a risk-free, controlled environment before applying their knowledge in real-world settings.

To support these scenarios, the deliverable also provides an overview of the platform's technical infrastructure, including hardware (HTC Vive Focus Vision) and software (Unity 3D, and other tools). The platform will be integrated with a Learning Management System (LMS) to enable performance tracking, and assessment, ensuring that the training is measurable and meets industry requirements.

The scenarios are designed using the Activity Theory-Based Model for Serious Games Analysis and Conceptual Design (ATMSG), which ensures that the training activities are learner-centric, interactive, and aligned with instructional goals. Additionally, the platform incorporates Kolb's Experiential Learning Model, supporting skill acquisition through concrete experience, reflective observation, abstract conceptualization, and active experimentation.

The structure of the document is organized to systematically also address the design, technical, pedagogical, and integration aspects of the platform. It begins with an introduction to the VR structure, outlining the nine key stages of the process. The document then explores the framework for scenario design, detailing the selection and application of the ATMSG framework. Technical considerations are discussed next, including hardware and software requirements, followed by pedagogical and learning requirements that ensure the platform is educationally effective. The document concludes with integration strategies and learning analytics, which support performance tracking and continuous improvement.

In conclusion, this deliverable presents detailed, practical application scenarios for the NDT examination platform, supported by a robust technical and pedagogical framework. It ensures that the platform provides a scalable, immersive, and effective training solution for NDT operators, vocational education and training (VET) students, trainers, and industry professionals. By focusing on realistic scenarios and their integration into the platform, this deliverable lays the groundwork for a training system that bridges the gap between theoretical knowledge and practical application, preparing trainees for real-world NDT inspections.

VR Structure

The VR structure for liquid penetrant testing is designed to simulate each step of the non-destructive testing (NDT) process in an immersive, interactive environment (see Annex D3.1). It guides users through a realistic workflow, from initial surface preparation to defect identification and final reporting. The structure includes ten key stages: introduction and contextualization, surface preparation, verifications of test conditions and verifications of equipment and consumables, penetrant application, excess penetrant removal, developer application, observation of indications, final cleaning, documentation and reporting, and revaluation with practice scenarios (see Annex D3.1). Each stage features detailed simulations with interactive tools, realistic defect visualization, and immediate feedback, ensuring a comprehensive and engaging learning experience. The inclusion of safety protocols, decision-making scenarios, and a scoring system enhances the practical application and retention of knowledge, effectively bridging theoretical concepts with real-world skills.

Stages of VR Simulation

1. **Introduction and Contextualization**
   - Overview of Liquid Penetrant Testing (LPT)
   - Importance and applications in industries (e.g., aerospace, automotive)
   - Training objectives and safety protocols
2. **Surface Preparation in VR**
   - Cleaning the test surface using virtual tools (e.g., sprays, brushes, cloths)
   - Evaluating the level of cleanliness
   - Surface drying using compressed air or drying area
3. **Verifications of Test Conditions and Verifications of Equipment and Consumables**
   - Surface Conditions: Confirm surface roughness is within acceptable limits and that the surface is free of contaminants/oxidation.
   - Lighting Conditions: Verify adequate visible light (lux levels) and/or UV lamp irradiation levels for fluorescent penetrant testing.
   - Temperature Conditions: Ensure the testing environment and components are within the recommended 10°C to 50°C range.
   - Equipment Conditions: Check calibration, functional status, and proper identification of all testing equipment (including Wood lamps).
   - Consumables Conditions: Confirm penetrant materials, developers, and cleaners comply with ISO 3452-2

requirements, and verify expiry dates to prevent using outdated sprays or chemicals.

4. **Applying the Penetrant in VR**
   - Selecting the penetrant type (colored, fluorescent)
   - Applying the penetrant using appropriate techniques
   - Monitoring dwell time with a virtual timer
5. **Excess Penetrant Removal in VR**

- Using virtual tools (cloths, solvent sprays) to remove excess penetrant
- Testing and evaluating the effectiveness of the cleaning under properly lighting
- Scenarios showing the consequences of improper cleaning

6. **Applying the Developer in VR**
    - Selecting the developer type (dry, water-based, non-aqueous)
    - Applying the developer in thin, uniform layers
    - Observing the developer's drying process and defect visibility
7. **Observation of indications in VR**
    - Switching between white light and UV light inspection modes
    - Identifying and classifying defects (e.g., cracks, porosity)
    - Using virtual tools to zoom in, mark, and document defects
8. **Final Cleaning in VR**
    - Removing the developer using virtual cleaning tools
    - Final surface check for residues
9. **Documenting and Reporting Results in VR**
    - Completing virtual reports with detailed information on defects
    - Receiving feedback on the accuracy and completeness of documentation
10. **Re-evaluation and Practice Scenarios in VR**
    - Scenarios for repeating the process for complex defects
    - Free practice mode for rehearsal and skill improvement

Interactive Features and Feedback System

- **Virtual Instructor**

Provides real-time guidance, feedback, and safety instructions.

- **Pop-up Information**

Displays relevant data about tools, penetrants, and developers.

- **Feedback and Evaluation**

Detailed feedback on cleaning effectiveness, defect identification accuracy, and documentation quality.

- **Scoring System**

Points are awarded for correct actions and decisions, enhancing engagement.

The VR structure, target audience, and learning outcomes align with the ATMSG (An Activity Theory-Based Model for Serious Games Analysis and Conceptual Design) framework used in the VR-VET project:

- **Gaming Activity**

Interactive simulations, realistic scenarios, and engaging challenges enhance user motivation and learning.

- **Learning Activity**

Step-by-step guidance and immediate feedback support knowledge acquisition and skill mastery.

- **Instructional Activity**

Integrated safety protocols, decision-making scenarios, and detailed reporting ensure comprehensive learning.

The VR structure ensures a realistic, immersive learning experience that effectively bridges theoretical knowledge and practical application, supporting the overall objective of the VR-VET project.

Target Audience

The VR-VET platform is designed for a diverse range of users, including NDT operators and specialists, vocational education and training (VET) students, VET trainers, and industry professionals. It caters to aspiring NDT operators seeking hands-on training, experienced specialists looking to enhance their skills, and students pursuing technical careers in industries like aerospace, automotive, and construction. VET trainers can leverage the immersive simulations to enrich their teaching methods, while industry professionals, including engineers, safety inspectors, and quality managers, can use the platform to deepen their knowledge of non-destructive testing and improve their inspection and quality assurance processes.

Primary Target Groups

1. **NDT Operators and Specialists**
   - Aspiring operators seeking hands-on training without real-world risks.
   - Experienced NDT specialists looking to refine and update their skills.
   - Professionals preparing for certification or recertification exams.
2. **Vocational Education and Training (VET) Students**
   - Students in technical schools or VET programs specializing in NDT.
   - Learners pursuing careers in industries using NDT (e.g., aerospace, automotive, construction).
3. **VET Trainers and Instructors**
   - Educators aiming to incorporate innovative VR training methods.
   - Trainers seeking to enhance their teaching methods using immersive simulations.
4. **Industry Professionals**
   - Engineers and technicians requiring NDT knowledge for quality assurance.

Safety inspectors and quality managers in manufacturing and construction sectors.

Learning Outcomes

The VR-VET platform aims to achieve comprehensive learning outcomes, focusing on knowledge acquisition, skill development, and cognitive growth. Users will understand the fundamentals of liquid penetrant testing, including its principles, applications, and safety protocols. They will develop practical skills in performing each step of the NDT process, from surface preparation to defect identification and reporting. Additionally, users will enhance their critical thinking and decision-making abilities through interactive scenarios that simulate real-world challenges, promoting effective problem-solving and informed decision-making. The platform's immersive environment and detailed feedback system support continuous improvement and mastery of NDT techniques.

Knowledge Outcomes

Fundamentals of Liquid Penetrant Testing (LPT)

- Understanding the principles and physics behind LPT.

- Knowledge of different penetrant types (colored vs. fluorescent) and their applications.
- Awareness of safety protocols and chemical handling procedures

Surface Preparation and Cleaning Techniques

- Identifying and using the appropriate cleaning tools and methods.
- Understanding the importance of cleanliness for accurate inspection results.

Verifications of test conditions and verifications of equipment and consumables

- Understand the conditions necessary to perform the test correctly.
- Demonstrate knowledge of equipment and consumables requirements.

Application and Removal of Penetrant

- Proper techniques for applying and removing penetrants.
- Importance of dwell time and its effect on defect detection.

Developer Application and Defect Visualization

- Selecting and applying the right developer type.
- Recognizing how defects become visible through developer application.

Skill-Based Outcomes

Practical Skills in NDT Procedures

- Step-by-step mastery of the entire LPT process, from surface preparation to final cleaning.
- Accurate application of penetrant and developer using virtual tools.
- Performing inspections under white light and UV light modes.

Defect Identification and Classification:

- Recognizing different defect types (e.g., cracks, porosity, laps) in virtual scenarios.
- Accurately classifying defects into relevant and non-relevant categories.

Safety and Environmental Protocols

- Correct use of personal protective equipment (PPE).

- Safe disposal of chemical waste and contaminated materials.

Cognitive and Decision-Making Outcomes

Critical Thinking and Decision-Making

- Making informed decisions during the inspection process.
- Evaluating and documenting inspection results.
- Determining the acceptability of parts based on industry standards.

Problem-Solving and Scenario Analysis

- Navigating complex scenarios with varying defect types and contamination levels.
- Understanding the consequences of incorrect cleaning, application, or inspection.

Continuous Improvement and Reevaluation:

- Identifying mistakes and learning through feedback and practice scenarios.
- Repeating inspection processes for improved accuracy and efficiency.

Framework for Scenario Design

This section outlines the process of selecting an appropriate framework to design Virtual Reality (VR) scenarios. A proper design framework is necessary to produce effective learning experiences that satisfy the training objectives, learning achievements, and technical needs. Different frameworks were researched, and each was graphed to its ability to structure the VR training, offer interactive learning, and satisfy the project goals. This section discusses various frameworks and the rationale for selecting the ATMSG framework (An Activity Theory-Based Model for Serious Games Analysis and Conceptual Design) as the reference scenario design model.

Introduction to Framework Selection

Selecting an appropriate framework for VR learning scenario design is critical to ensuring that the resulting learning experience is well-organized, interactive, and effective. The appropriate framework not only provides the sorely lacking structure for interactive activity design, decision points, and mechanisms for feedback but also ensures that the learning experience aligns with the learning goals and project technical requirements.

In this project, selecting the most suitable framework was particularly critical to serve a series of fundamental requirements: alignment with desired learning outcomes, potential to allow interactivity, and flexibility to adapt to the evolving needs of VR-based training. The frameworks of interest for this project were considered based on their ability to fulfill these considerations. These models were assessed for suitability in creating structured learning activities, promoting active learner participation, and making it possible to simulate complex decision-making scenarios effectively within an interactive VR learning environment.

Framework Consideration Criteria

This section explains how to assess a variety of possible frameworks to establish which would facilitate the attainment of the established learning outcomes. The frameworks were analyzed on the following:

Alignment with Learning Objectives

One of the most important aspects of framework selection was the capability to facilitate alignment with the target learning outcomes. The chosen framework must facilitate the development of VR scenarios that can facilitate knowledge, skill, and behavior change. Having the capability to ensure that the framework would facilitate the achievement of the target learning outcomes while designing the scenario was of the highest priority.

Systematic Scenario Design

There needs to be a systematic and structured method of scenario development for building structured and logical learning processes. The framework should be capable of supporting the task analysis into phaseable steps with logical flow and identification of appropriate decision points. The framework should also enable provision for the inclusion of processes of feedback to allow learners to track their progress, reinforce their learning, and refine their skills in the process.

Scalability and Flexibility

The selected framework should be scalable and flexible across different learner profiles and environments. It should be scalable to provide flexibility in scenario design to address the different learner needs, ranging from novices to experts, and support different cognitive abilities and learning styles. Scenario scalability in difficulty and complexity enabled the framework to be used with learners of different needs.

Technological Compatibility

The other vital consideration involved the framework's compatibility with the VR infrastructure. The framework needed to be compatible with the existing software and hardware platforms to be capable of supporting the effective utilization of developed scenarios. The requirement for compatibility ensured that the framework would be viable to use in the context of then-existing VR technologies without involving special or advanced resources.

Theoretical and Practical Support

The final aspect to be considered was the extent to which every framework was theoretically based and supported by evidence. Frameworks that were well-supported by theories and had already proven to be used effectively in comparable contexts were favored. This factor served to ensure that the chosen framework was not only theoretically sound but also practically effective in stimulating the required learning outcomes.

Exploration of Relevant Design Frameworks

Guided by the known selection criteria, several frameworks were examined for their capability to enable the systematic design of VR learning scenarios. Each of the frameworks was reviewed for its applicability in designing VR-based learning experiences, to be aligned with learning goals, and to offer a systematic process of scenario development. The frameworks examined include:

1. **VR-Based Design Framework**

Focusing on spatial and interaction design for virtual environments, the VR-based design Framework emphasizes user immersion and engagement. The framework allows for a structured methodology in designing VR experiences that consider principles of spatial navigation, object interaction, and user experience. It appears to be quite effective in ensuring that virtual environments are intuitive and supportive of user interaction, which is then an important consideration in developing engaging learning scenarios.

However, although the framework provides good technical guidance on VR environment design, it does not necessarily include a systematic approach to linking scenarios with pedagogical goals. Its main emphasis is still on the technical and experiential sides and not on the systematic incorporation of learning goals. Therefore, although it provides good insights into the design process, other pedagogical frameworks were needed to make sure that VR scenarios were not only engaging but also educationally sound [1].

2. Scenario-Based VR Framework

The Scenario-Based VR Framework focuses on the structured development of interactive learning experiences by scenario-based instruction. The framework is intended to support the design of real-world training environments in which learners take part in decision-making activities and problem-solving exercises. Through simulating real situations, the framework allows learners to acquire practical skills in a controlled, interactive environment.

This model was under consideration based on its focus on structured learning environments that are highly compatible with the tenets of experiential learning.

While it gives a solid basis for scenario design, it does not have a specific methodology for integrating adaptive learning processes, learner feedback loops, and performance measurement. Its usability in VR-based training is useful, but a more full-scope approach was necessary to integrate structured learning objectives and interactive processes fully [2].

3. M-SG Framework (Model-Based Scenario Generation)

The M-SG Framework entails model-based scenario generation, where learning scenarios are created according to predefined instructional models. The framework offers the potential to build scenarios in a structured way that denotes the mapping to learning outcomes, which is extremely beneficial for training program planning that needs to be guided step-by-step and advanced accordingly. This model was considered due to its ability to develop structured, objective-driven learning scenarios that engage the learner in interaction. Its structured authoring ensures that scenarios are developed with a pedagogical purpose, scaffolding critical concepts with interactive exercises. Its use, however, entails high customization and technical setup, which may limit its flexibility in being used in a broad range of learning situations. In providing an extensive theoretical foundation for structured scenario planning, flexibility was required such that it would be possible for application across different VR-based learning environments [3].

4. Design-Based Framework

The framework focuses on iterative design and continuous improvement of learning activities. It employs user feedback, real-time performance monitoring, and iterative refinement in a bid to optimize the quality of learning activities. This approach aligns well with the agile instructional design principles for the development of VR-based training scenarios in an iterative manner. This model was considered due to its iterative and adaptive nature, with the potential to refine training content continuously based on learner performance and feedback. Its emphasis on iterative design, however, does not provide a pre-established framework for scenario development, so it is less suitable as a standalone instructional design methodology. While it is a helpful support technique, a more structured framework was needed to guide the initial scenario-designing process [4].

5. **ATMSG Framework (An Activity Theory-Based Model for Serious Games Analysis and Conceptual Design)**

The ATMSG Framework (An Activity Theory-Based Model for Serious Games Analysis and Conceptual Design) is an Activity Theory-based comprehensive model for the analysis and conceptual design of serious games and interactive learning systems. The framework offers a systematic way of analyzing the components of a learning activity system, i.e., the subject (learner), object (learning outcomes), tools (mediating artifacts), rules, community, and division of labor. This holistic approach ensures that every dimension of the learning process is considered, and it becomes possible to create virtual learning experiences that are pedagogically sound and engaging. The model encourages consistency between learning outcomes and game mechanics to a point where all the components of the game are leveraged to help in the attainment of the learning outcomes. By parallelism between in-game action and real-world knowledge and skills, the ATMSG model facilitates the development of fun as well as pedagogically relevant scenarios [5].

The ATMSG model has the following advantages:

Structured Scenario Development

The model provides a structured approach to scenario development that is explicitly mapped to learning goals in a manner that all activity supports and reinforces intended learning outcomes [5].

Learner-Centric Design

With a focus on interactivity, the ATMSG model promotes engagement and facilitates active assimilation and retention of learning [5].

Holistic Component Analysis

The scope of the ATMSG framework over the elements of the learning activity system facilitates setting and assembling required tools, rules, and community dimensions that give a smooth and integrated supportive environment to learning [5].

Adaptability and Versatility

ATMSG framework is versatile in its approach to how it would be utilized over multiple education environments and topic domains and thus stands as a versatile model to be used for VR scenario designing [5].

Its completeness ensures that all aspects of the learning activity are provided for hence enabling the creation of effective, interactive, and pedagogically rich virtual environments.

Therefore, the ATMSG framework has proved to be the most suitable framework to base the design and development of the project VR learning scenarios.

How the VR Structure Informs Framework Selection

The comprehensive VR structure for Penetrant Testing (PT) training encompasses stages that replicate real-world PT procedures. These stages include equipment setup, surface preparation, penetrant application, excess removal, developer application, visual inspection, and documentation/reporting. This detailed simulation emphasizes interactive, scenario-based learning with real-time feedback, closely mirroring actual PT workflows. To ensure that VR training is both effective and educationally sound, selecting an appropriate design framework is crucial.

The VR system's capability to simulate detailed, step-by-step PT procedures necessitates a framework that supports experiential and procedural learning. Such a framework should facilitate the replication of hands-on tasks, allowing users to engage with virtual tools and materials in a manner that closely resembles actual PT processes. This alignment ensures that learners can effectively transfer skills acquired in the virtual environment to real-world applications.

Integration considerations are paramount, given the VR structure's focus on interactive tools and real-time feedback. The chosen framework must seamlessly incorporate these elements to enhance the learning experience. It should support the inclusion of virtual equipment, safety protocols, and defect identification processes, ensuring that each stage of the PT procedure is accurately represented and interactive within the VR environment. This integration fosters an immersive learning experience that reinforces correct techniques and safety measures.

The immersive nature of the VR structure influences several design aspects within the framework. Authentic scenario development is essential; the framework should enable the creation of realistic scenarios that mimic actual PT conditions, including various types of contaminants and defects. High-fidelity simulations of tool handling and material responses are crucial to providing users with a realistic sense of engagement and skill application. Incorporating immediate, context-sensitive feedback helps users understand the consequences of their actions, reinforcing correct techniques and highlighting areas for improvement. These design considerations ensure that the training is both comprehensive and practical.

In summary, the detailed VR structure for PT training significantly informs the selection of a design framework. A framework that accommodates immersive, interactive, and procedurally accurate simulations will leverage the VR system's capabilities, providing a robust platform for effective skill development in penetrant testing.

Relevance of ATMSG (An Activity Theory-Based Model for Serious Games Analysis and Conceptual Design)

According to the above-defined criteria for the specification of an effective framework for VR learning environment design, the ATMSG framework is an appropriate choice. The level of its approach in designing serious games and interactive learning systems design is reliable with the level of large-scale training requirements of VR.

Structured Scenario Design

ATMSG follows a systematic approach to scenario development in a way that each step of training, from the introduction of equipment to the final step, is designed specifically as per individual learning objectives [5].

Learner-Centered Design

Since the concern is to align learning outcomes with game playing, ATMSG renders learning more interactive and stimulating. Virtual reality training means active engagement by users in simulations of actual environments and enhancing their knowledge [5].

Flexibility and Adaptability

With widespread application across various industries, the flexibility of the ATMSG enables adaptability in training settings to accommodate special industry procedures and needs. The variability enhances the functionality and application of VR training across various environments [5].

In summary, the ATMSG framework's structured, learner-focused, and holistic approach makes it an ideal choice for developing VR-based training scenarios, ensuring that they are both pedagogically sound and practically applicable.

Having established the ATMSG model as the most appropriate model to be utilized in the development of VR-based training scenarios, the next step is to observe how it can practically be utilized in designing Penetrant Testing (PT) training scenarios. It is a case of utilizing the ATMSG model step by step to design interactive and engaging learning experiences that align with instructional goals and enhance learner participation.

Application of ATMSG Framework

Following the theoretical basis of the Activity Theory-based Model of Serious Games (ATMSG) framework, this section then broadens its application to the design of Virtual Reality (VR)-based Penetrant Testing (PT) training scenarios. The aim is to apply the ATMSG model in a structured process to design interactive learning scenarios that reflect instruction targets and enhance learner engagement [5].

The initial objective of this section is to connect the theoretical understanding of the ATMSG model with its effective application in cases of VR-based PT training. Through a critical examination of the ATMSG model, this section will demonstrate how certain elements of the ATMSG model can be applied practically to design innovative and educationally useful PT training modules [5].

The ATMSG model tracks three basic activities:

- **Game Activity**

It involves the player's interaction with the game, i.e., game rules, game mechanics, and game dynamics making the game exciting and enjoyable [5].

- **Learning Activity**

It is the learning content and process through which the students learn new knowledge or skills. It is the alignment of the game activities to some desired learning outcomes [5].

- **Instructional Activity**

These are the strategies employed to facilitate learning while the game is being played, such as feedback loops, scaffolding, and assessment instruments [5].

The interplay of these interacting activities through the ATMSG framework means that all elements of the game work together to create a positive learning experience.

Working within the ATMSG framework for PT training is a step-by-step process (see Annex D3.1):

- **Define Learning Objectives**

Define specifically the exact skills and information trainees need to learn, e.g., PT procedure, safety rules, and machine maintenance.

- **Design Gaming Activities**

Design interactive training tasks that mimic actual PT work, e.g., obstacles and problem-solving to keep trainees engaged.

- **Integrate Instructional Strategies**

Embed the environment with guidance, and assessment. Such integration can take the form of tips, performance criticism, or difficulty levels.

Through such a structured process, the ATMSG framework facilitates the creation of VR-based PT training scenarios which are both pedagogy and immersion, providing learners with the chance to train in simulated and supportive environments.

The ATMSG framework is described in detail in the subsequent section, which outlin es its principles and components.

ATMSG (An Activity Theory-Based Model for Serious Games Analysis and Conceptual Design)

The Activity Theory-based Model of Serious Games (ATMSG) is a theoretical model proposed to systematically explore and guide the design of serious games for education. Rooted in activity theory, ATMSG offers a systematic approach to understanding the way various components of a serious game interact with each other to achieve some educational objectives [5].

Basic Principles of ATMSG

Activity theory is the foundation paradigm of ATMSG, and it emphasizes the importance of understanding human practices and developmental processes as being within a systemic setting. In serious games, this perspective calls for the consideration of the game as being part of a dynamic, complex system with human agents—such as players, teachers, and designers—and the interests driving their interactions with the game [5].

Core Activities in ATMSG

ATMSG identifies three core interdependent activities undertaken involving serious games for learning (see Figure 1):

- **Gaming Activity**

This activity concerns the player-game interaction driven by intrinsic motivators such as entertainment, challenge, or self-gratification. The emphasis in this case is mostly on playing the game as an experience [5].

- **Learning Activity**

This activity relates to acquisition of knowledge, skill, or competency by the learner with an extrinsic motive like fulfilling academic requirements, professional growth, or expertise in a particular content area [5].

- **Instructional Activity**

This activity relates to the activities of teachers or game designers in facilitating and guiding the learning process. Their motives may be to enhance learner engagement, align with curriculum standards, or achieve pre-determined education outcomes [5].

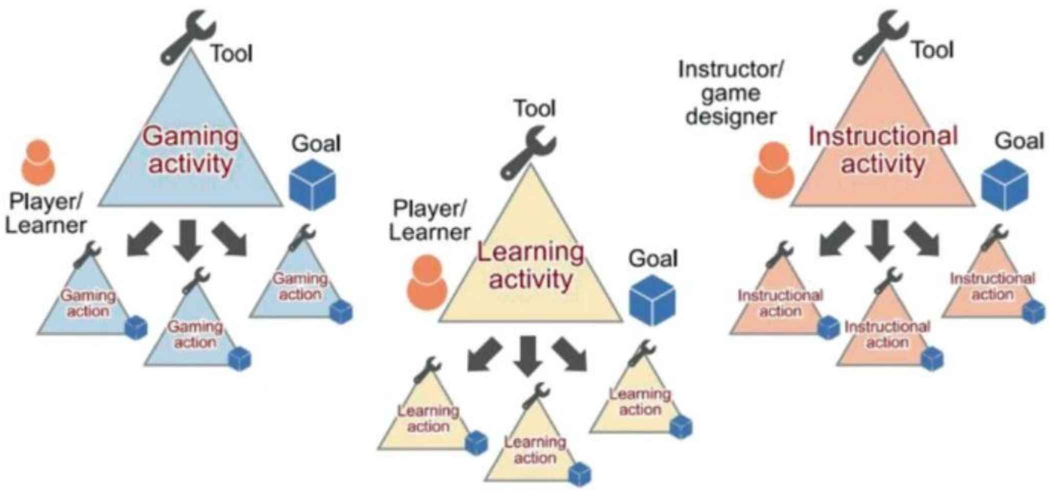


Figure 1: Overview of ATMSG Methodology

These activities are similar, they share features such as the serious game itself but differ in topics and intrinsic motivations. For instance, while the gaming and learning activities both engage the player, the former is intrinsically motivated by enjoyment, whereas the latter is extrinsically motivated by outside educational objectives.

Intrinsic and Extrinsic Instructional Activities

Within the instructional activity, ATMSG distinguishes two subcategories (see Figure 2):

- **Intrinsic Instructional Activity**

It involves instructional components that are incorporated into the game design itself. Tutorials in the game, contextual tips, feedback systems, and learning features that adapt and offer hints to the learner during play are some examples of this category. These components are crafted by designers to improve learning objectives intrinsically [5].

- **Extrinsic Instructional Activity**

This is external instructional guidance by instructors or facilitators outside the immediate context of the game. Such support may be provided before, during, or after game play and could be in the form of preparatory briefings, supplementary instructional materials, or facilitated discussions that assist in reinforcing and situating the learning outcomes derived from the game [5].

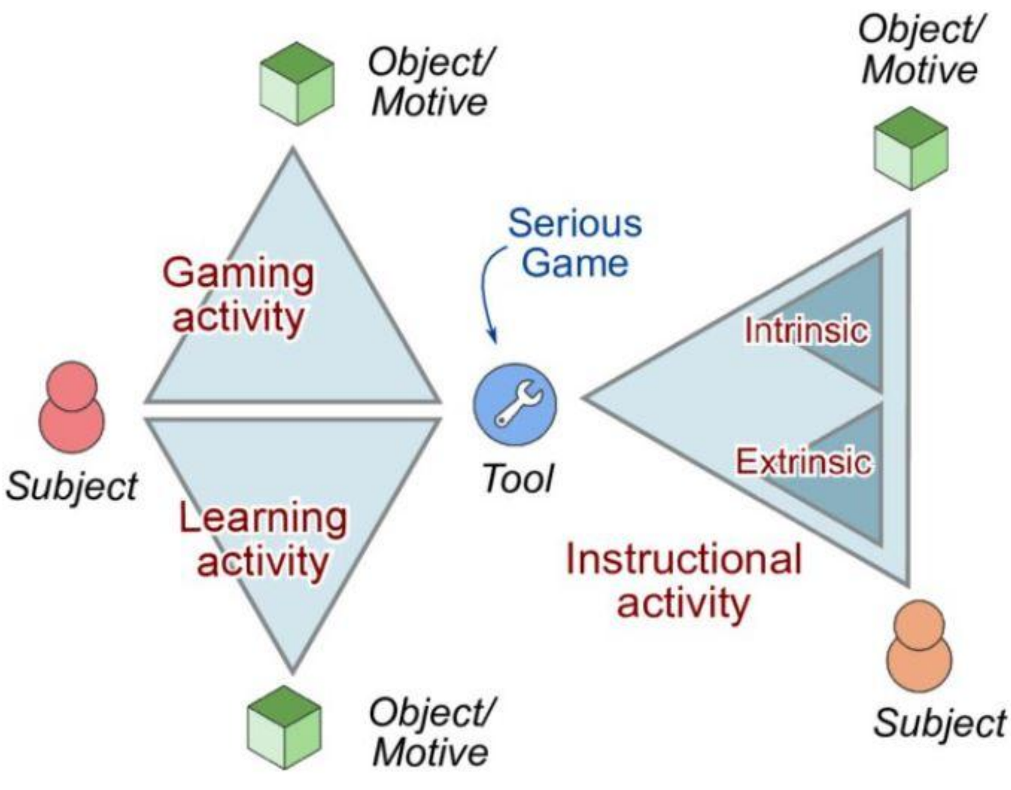


Figure 2: The ATMSG Model: The figure represents the higher level of the activity system involved

Hierarchical Structure and Component Analysis

ATMSG applies a hierarchical analysis to decompose each activity into minute components (see Figure 3):

- **Actions**

These are specific, goal-directed tasks or actions taken by the subject in an activity, mediated by tools to achieve certain ends. An example is solving a puzzle in the game to apply a learned rule [5].

- **Tools**

Artifacts or instruments that facilitate actions. For serious games, these are game elements such as characters, tokens, help messages, interactive interfaces, and other in-game assets that facilitate the intended actions [5].

- **Goals**

The intended outcomes or results that activities within the activity aim to produce. These could range from the acquisition of a specific concept, proficiency in a skill, or attainment of a specific in-game milestone that advances educational objectives [5].

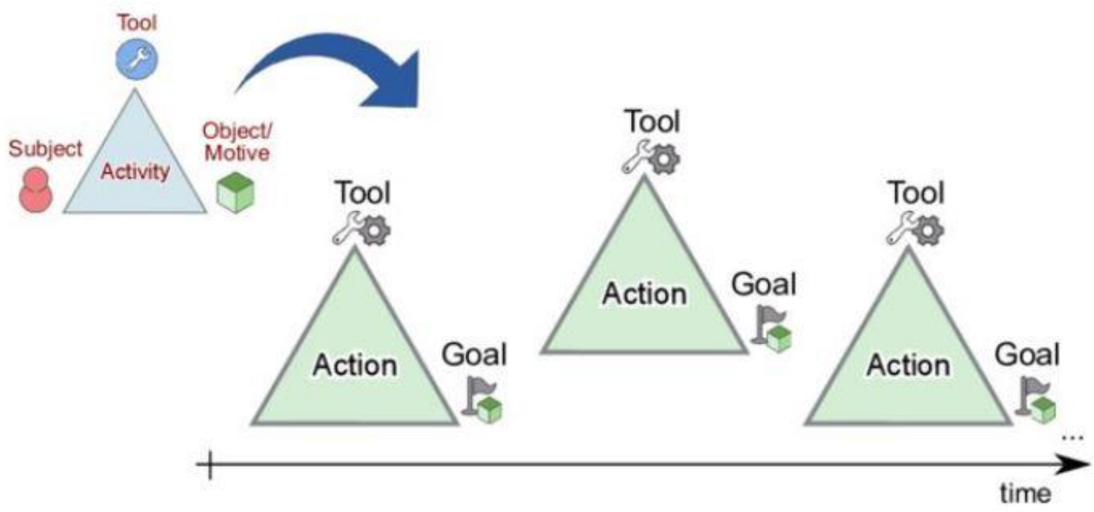


Figure 3: Each Activity is Formed by a Sequence of Actions. These Actions Mirror The Triangle of Activity: They Are Also Mediated by Tools, With Specific Goals

By decomposing activities into actions and tools, ATMSG enables instructors and designers to visualize how each element of the game is affecting both the game experience and the learning outcome. This level of specificity facilitates the identification of conflicting activities, ensures game design consistency with learning objectives, and optimizes the overall impact of the serious game as an educational tool (see Figure 3).

ATMSG for Analysis and Designing Learning Environments

The ATMSG model serves two functions:

- **Analytical Tool**

It provides a systematic method for evaluating existing serious games by defining how game components map to learning objectives. The analysis can be employed to establish whether the game is effective in achieving its intended learning objectives and where it must be enhanced [5].

- **Design Process**

ATMSG could be used to design serious games and learning environments by embedding learning goals into enjoyable and interactive activities. By scrutinizing the hierarchical activity model of activities, actions, and tools, ATMSG helps designers create systems that are immersive as well as pedagogically impactful. For example, in a serious game, ATMSG ensures that learning objectives are aligned with game mechanics, thereby making the game an effective learning instrument. Similarly, in a learning situation, ATMSG can result in the creation of interactive scenarios, simulations, or engagement and retention of knowledge [5].

Briefly, the ATMSG is a structured and organized model of design for serious games, learning environments, and other interactive systems where the primary interest is educational or instructional objectives. This makes it a resource for teachers, instructional designers, and developers across a broad spectrum of disciplines.

This sub-section introduces the Activity Theory-based Model of Serious Games (ATMSG). ATMSG is a comprehensive model for the analysis and design of serious games and learning environments for assurances of instructional goals and fun aspects of gaming. Regarding related activities—gaming, learning, and instruction activities—this model supports active and effective learning environments.

In the next sub-section, ATMSG will be utilized in scenario design to show how it can be applied to the design of learning scenarios that balance educational objectives with interactive play. This will provide a more practical examination of how the model can be applied within real educational settings.

Application of ATMSG to Scenario Design

In this sub-section, the practical application of the ATMSG model in scenario design will be presented. The process involves creating comprehensive, contextually rich learning scenarios integrating game, learning, and teaching activities. Through the use of the ATMSG framework, all elements of the scenario can be custom designed to meet precise learning goals with the capacity to stimulate an engaging user experience.

This section presents a four-step approach that systematically guides the application of the ATMSG model to design, offering a clearer understanding of how learning takes place. The approach moves from a high-level analysis of activities to identifying the concrete components that implement them. The taxonomy of serious game components supports the identification of these elements [5]. The four steps of this approach are outlined (see Figure 4), with each step clearly defined.

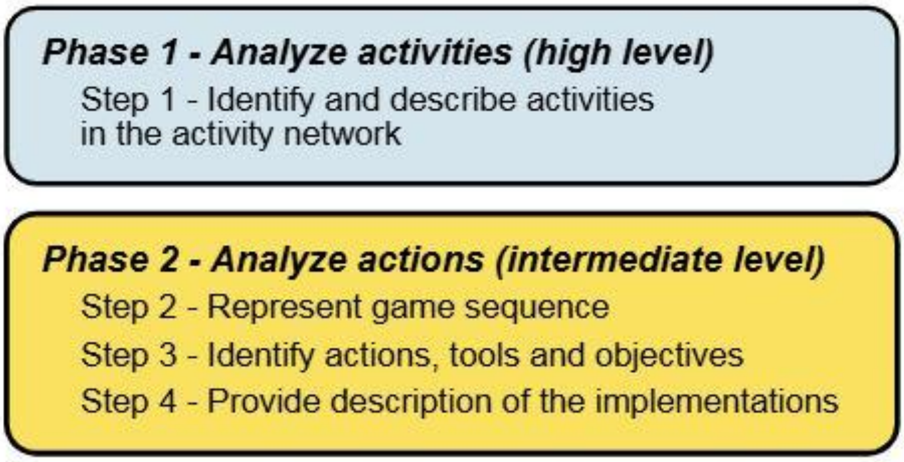


Figure 4: The four-step approach for applying the Activity Theory-based Model (ATMSG)

Step 1: Describe the Activities

In the initial step, the primary activities of the activity system are outlined, along with their respective subjects and underlying motives. This step also makes clear the nature of the learning environment by determining the key components of each activity. Examining the learning environment from some complementary perspectives assists in gaining a wider overview of its structure and purpose.

Table 1 is a detailed summary of the game activities (Step 1). This includes a systematic summary of each activity, its function, primary players, and underlying reasons. By systematically outlining these elements, the table provides a clearer understanding of how different activities contribute to the overall learning and gameplay experience.

Activity / Aspect	Subject / Actor	Description
Gaming ***(Who is the player?)***	• Trainers/teachers from CDI institutes and from the university/academic environment • People who want to become operators/specialists in non-destructive examination (e.g. by the penetrant liquid method) • Specialists / engineers who want to develop their knowledge in this field	Trainers utilize the VR platform to demonstrate Non-Destructive Testing (NDT) techniques, providing an interactive teaching tool that enhances engagement and facilitates effective learning
Learning ***(Who is the learner?)***	• NDT Operators/Specialists	Learners engage with the VR training to acquire practical skills in NDT methods, such as the penetrant liquid method. The immersive environment provides hands-on experience without the risks associated with real-world training
Intrinsic Instruction ***(Who designed/produced the game?)***	• Developers, lecturers, and Computer Scientists involved in the project	Developers create the VR training platform to facilitate experiential learning in NDT, bridging theoretical knowledge and practical application

Table 1: Activities Description

Table 1 is a detailed summary of the activities:

- **Gaming**

In this context, "gaming" refers to the interactive experience provided by the VR platform. Trainers and teachers utilize the VR environment to demonstrate and practice NDT techniques, offering a safe and controlled setting for both teaching and learning.

- **Learning**

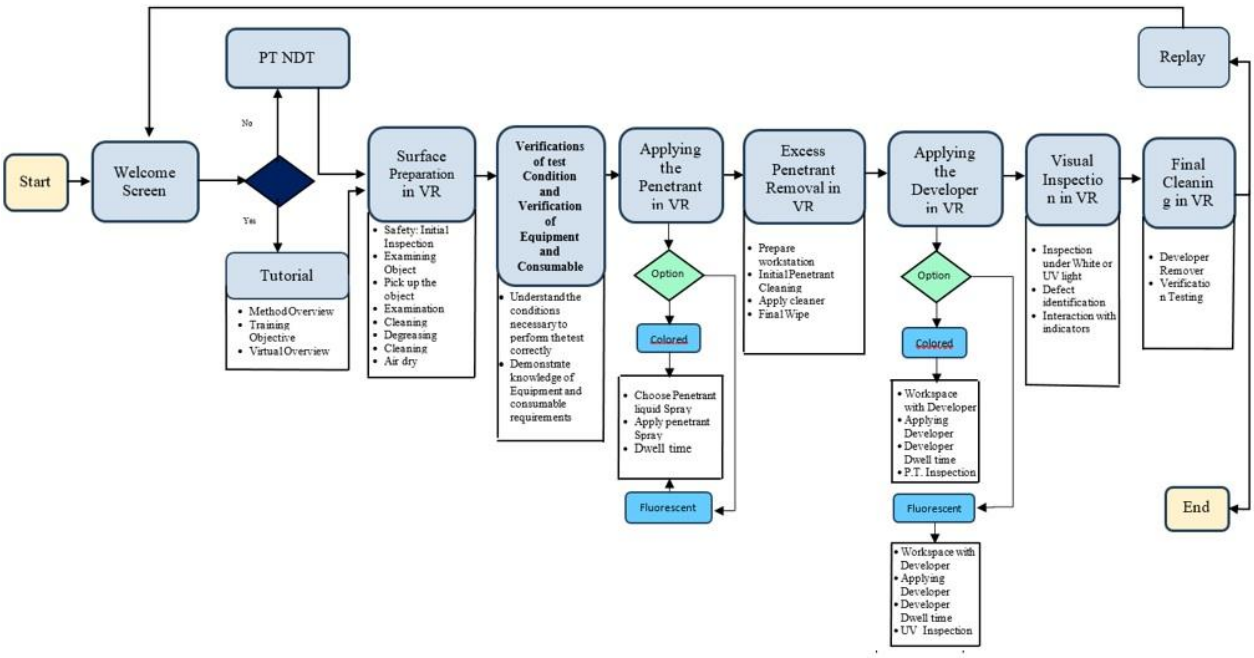
The learners, including aspiring NDT operators and specialists, interact with the VR training modules to develop and refine their skills. The immersive nature of the VR experience allows learners to practice NDT methods, such as the penetrant liquid method, in a risk-free environment, facilitating experiential learning.

- **Intrinsic Instruction**

Developers, lecturers, and computer scientists are responsible for creating the VR training platform. The objective is to design an effective learning tool that bridges theoretical knowledge and practical application, ensuring that learners can accurately perform NDT techniques in real-world scenarios.

Step 2 and Step 3: Representing the Game Sequence and Identifying Actions, Tools, and Goals

When designing learning environment scenarios using the ATMSG, it is essential to prepare a sequence diagram of the scenarios in detail (see Table 2). Table 2 shows the sequence diagram where the path through which the sequence of activity goes on and gets interconnected across the learning process is shown. In this manner, event sequence mapping provides the developers with a view of how each component is building towards learning goals. This method guarantees all the components are correctly connected to form desired learning outcomes, makes it simple to identify redundancies or gaps, and helps to provide clarity on design ideas for instructors, developers, and other stakeholders, thus supporting collaborative development. The addition of a game sequence diagram supports learning activity mapping to pedagogical aims and interactive and educationally valuable learning environment design [5].



Gaming	**Actions**	Read Information/ Listen to	Obtain help/Move/Teleport/ Watch / Listen to / Read Information	Obtain help/Capture/Move/ Teleport/Watch / Listen to / Read Information	Move/Teleport/Obtain Help/, Watch / Listen to / Read Information	Move/Teleport/Obt ain Help/, Watch / Listen to / Read Information	Obtain Help/Teleport/Watch/ Listen to/Read Information	Capture/Listen to/Read Information/Obtain Help/Teleport/Watch/Colle ct
	Tools	-	Information/Advice and Assistance/Tips/Cha llenges/Tutorial	Information/Advice and Assistance/Tips/Challenges	Advice and Assistance/ Challenges	Advice and Assistance/ Challenges	Information/Advice and Assistance/Tips/	Complete Information/Achievement/S uccess/Advice
	Goals	-	Collect Information/Learn to Use Interface	Collect Information/ Form/ Discover Goals	Form/Discover Goal/Perform Task	Form/Discover Goal/Perform Task	Perform Task	Perform Task
Learning	**Actions**	-	Observe/Read/Selec t/Explore/Complete/ /Examine/Perform action/task	Observe/Read/Select/Explore/Comp lete//Examine/Perform action/task	Observe/Read/Find more Information about/Choose/Complet e Goal/Make/Perform action/Task/Analyse/E xamine/Identify/Select /Decide/	Observe/Read/Find more Information about/Complete Goal/Make/Perfor m action/Task/Analys e/Examine/Decide/	Observe/Read/Descri be/Calculate/Complet e Goal/Perform Action/Task/Estimate	Observe/Read/Recognize/D istinguish/Complete Goal/Examine/Interpret/Per form Action/Task/Identify/Asses s/Decide/
	Tools	-	Videos/Information/ /Texts/Tips	Videos/Information//Texts/Tips	Challenges/Problems/I nformation/Texts/Tips	Challenges/Proble ms/Information/Or ganization/Texts/T ips	Challenges/Problems/ Information/Texts/Ti ps	Challenges/Problems/Concl usions/Information/Texts
	Goals	-	Understanding/Lear ning How to Learn	Understanding/Analysing/Learning How to Learn	Understanding/Analysi ng/Learning How to Learn/Active Experimentation/Foun dational Knowledge/Learning How to Learn	Understanding/An alysing/Learning How to Learn/Active Experimentation/F oundational Knowledge/Learni ng How to Learn	Understanding/Analy sing/Applying/Active Experimentation/Lear n How to Learn	Understanding/Analysing/A pplying/Organization/Activ e Experimentation/Applicatio n
Instrinctic Instructions	**Actions**	Present Material	Present Material	Present Material	Present Material/Present Problem/Suggest Improvements	Present Material/Present Problem/Suggest Improvements	Present Material/Suggest Improvements	Assess Performance/Suggest Improvements
	Tools	-	Challenge/Help Text/Tips/Assistanc e	Challenge/Help Text/Tips/Assistance	Challenge/Help Text/Tips/Assistance	Challenge/Help Text/Tips/Assistan ce	Challenges/Help Text/Limited Set of Choices/Tips/Assista nce	Help Texts/Tips/Assistance/Chall enges/Help Text/Limited Set of Choices/Tips/Assistance
	Goals	Attention	Inform the Learner of the Objective/Relevanc e/Confidence	Inform the Learner of the Objective/Relevance/Confidence	Gain Attention/Inform Learner of the Objective/Provide Feedback/Attention/Re levance/Confidence	Gain Attention/Inform Learner of the Objective/Provide Feedback/Attentio n/Relevance/Confi dence	Assess Performance/Attentio n/Relevance/Confide nce/Satisfaction	Attention/Relevance/Confid ence/satisfaction/Assess Performance

Table 2: Sequence Diagram – ATMSG

The above sequence diagram (see Table 2) illustrates the step-by-step process of Penetrant Testing (PT) in the VR scenarios (see Annex D3.1). The visual structure allows users to comprehend and follow the logical steps of the PT process, making it engaging for them to learn and memorize the process.

Table 3 below presents a comprehensive account of the implementations in the VR scenarios mapping to the steps outlined in the sequence diagram (see Annex D3.1).

Game sequence	Gaming	Learning	Intrinsic instruction
1. Start and Introduction	Users start and view a tutorial.	Introduces the PT NDT process and objectives	Provides an overview of the training experience
2. Tutorial (Optional)	Users who select "View Tutorial" watch an overview of the Penetrant Testing (PT) process	Provides foundational knowledge of PT procedures	Delivers concise instructional content through animations and narrations
3. Training Session	Users engage in the hands-on PT simulation.	Applies learned concepts in a practical environment	Real-time feedback and guidance throughout the simulation
4. Safety: Initial Inspection	Users pick up and examine the object for defects.	Highlights the importance of initial inspection	Guides users through safe object handling
5. Verifications of test conditions and verifications of equipment and consumables	Users engage in a quick scenario to confirm environmental readiness (temperature, lighting) and check each piece of equipment (UV lamp calibration, penetrant expiry dates), earning points for accurate verifications.	Reinforces best practices for ensuring correct test conditions and maintaining valid consumables, emphasizing how compliance prevents false readings or test failure.	Offers real-time prompts to guide users through calibration checks, expiry confirmations, and condition assessments, fostering a structured approach to reliable, standards-compliant penetrant testing.
6. Cleaning and Degreasing	Users clean the object with sprays and clothes	Emphasizes surface preparation for PT	Teaches correct cleaning techniques
7. Air Drying	Users use compressed air to dry the surface	Shows why drying is essential before PT	Demonstrates proper drying methods
8. Choosing Penetrant Liquid	Users select between colored and fluorescent penetrants	Explains different penetrant types	Guides appropriate selection

9. Applying the Penetrant	Users spray the penetrant evenly on the surface	Demonstrates application techniques	Ensures even coverage with real-time feedback
10.Dwell Time	A visual timer counts down dwell time	Reinforces the importance of dwell time	Users wait for proper penetration duration
11.Initial Penetrant Cleaning	Users apply cleaner and wipe excess penetrant	Teaches proper cleaning techniques	Feedback provided on correct cleaning methods
12.Final Wipe	Users perform a final wipe-down	Ensures thorough removal of excess penetrant	Highlights the impact of improper cleaning
13.Applying Developer	Users select and apply developer (Coloured/Fluorescent)	Demonstrates developer application methods	Guides users on the uniform application
14.Developer Dwell Time	The timer tracks the developer's dwell time	Reinforces time-based defect development	Users monitor and adjust dwell time
15.White Light and UV Inspection	Users inspect under white or UV light	Teaches for correct defect detection	Demonstrates how to switch between light modes
16.Defect Identification	Users interact with indicators showing defects	Reinforces defect recognition skills	Users categorize defects as relevant or not
17.Developer Removal	Users remove excess developers to finalize results	Demonstrates the importance of proper removal	Guides correct removal techniques
18.Final Cleaning	Users clean the surface to complete the PT	Highlights the importance of post-inspection cleaning	Guides users through final cleaning procedures
19.End and Replay Option	Users complete the training or replay	Allows repetition for better retention	Users can refine skills through practice.

Table 3: Description of The ATMSG Application

This table aligns with the principles of the ATMSG model for serious game analysis and conceptual design, ensuring that each component is purposefully designed to enhance both the gaming experience and the educational outcomes (see Annex D3.1). By systematically representing the PT process and its associated learning objectives, the scenario fosters a deeper understanding of the Penetrant Testing procedure, effectively bridging the gap between theoretical knowledge and practical application.

Technical Considerations

Hardware

Hardware choice is central to implementing the VR-based NDT training, in terms of delivering an immersive, precise, and scalable VR experience. Due to the complexity inherent in penetrant testing (PT) and other NDT processes in terms of precise defect detection, enterprise-level performance, high-definition optics, accurate tracking, low-latency interaction, etc., are expected of the VR hardware.

HTC Vive Focus Vision was chosen based on its self-contained form factor, enhanced visual fidelity, business-class tracking, and business-class VR features. Compared to consumer-grade VR headsets, Vive Focus Vision supports wireless operation, high-compute performance, and extensibility through modular configurations. It is hence best suited for industrial training applications like VR-assisted NDT inspection, and defect. Inspection, and procedure training.

Figure 5: HTC Vive Focus Vision

The device facilitates accurate monitoring, natural hand interactions, and high-definition visualization of defects, all of which are crucial for simulating real-world NDT processes.

Below (see Table 4) is a detailed breakdown of the hardware specifications and their relevance to the VR-based NDT training platform:

Category	Technical Specification	Relevance to VR PT NDT Scenarios
Display	5K resolution (2448 x 2448 pixels per eye)	High-resolution visuals ensure clarity for detecting surface defects, cracks, and material inconsistencies in VR-based NDT training.
Field of View (FoV)	Up to 120°	Expands the visible area, allowing users to inspect larger surface regions without excessive head movement, enhancing usability in NDT
Processing Power	Qualcomm Snapdragon XR2 processor	Optimized for real-time defect simulation, 3D models rendering, and interactive training scenarios
RAM and Storage	8GB LPDDR5 RAM, 128GB UFS 3.1 storage (expandable up to 2TB)	Enables high-speed data processing for complex VR workflows, ensuring seamless training experiences
Tracking System	Inside-Out 6DoF with four external tracking cameras	Eliminates external sensor dependency while providing high-accuracy hand tracking and motion precision for detailed NDT tasks
Standalone and PC-VR Mode	Wireless standalone mode and PC-VR via USB-C and Wi-Fi streaming	Enables flexibility for training or higher-quality simulations via PC tethering for intensive workflows
Haptics and Controllers	Precision 6DoF controllers with ergonomic grip design	Allows accurate manual interactions, critical for VR-based tool handling, defect marking, and procedural training exercises
Battery System	26.6Wh Li-polymer swappable battery, fast-charging	Supports long-duration VR sessions with interchangeable power units, ensuring minimal downtime during multi-user training
Audio and Communication	Dual microphones with echo cancellation, directional 3D spatial audio speakers	Provides realistic audio cues for safety alarms, procedural guidance, and instructor-led remote feedback
Connectivity and Expansion	Wi-Fi 6, Bluetooth 5.2, dual USB 3.2 Gen-1 Type-C ports	Enables cloud-based assessment tracking, LMS integration, and hardware expansion (e.g., haptic

		gloves, external sensors) for enhanced realism in PT and NDT workflows

Table 4: HTC Vive Focus Vision (Technical Specifications)

HTC Vive Focus Vision: Key Features

High-Resolution Detection of Surface Defects

- The two LCD screens offer 4896 × 2448 pixels (2448 × 2448 per eye) resolution, offering high-definition visualization of surface detail, hairline crack, and marking defect, all of which are critical in NDT processes.
- 120-degree field of view (FoV) enables trainees to see larger chunks of surfaces with less head movement, realizing optimal defect detection for immersion and productivity.

Performance-Optimized Processing Unit

- Equipped with the Qualcomm Snapdragon XR2 processor, Vive Focus Vision is performance-optimized for real-time physics simulation, 3D objects rendering, and AI-driven defect analysis without needing access to external computing resources.
- It is paired with 8GB LPDDR5 RAM and 128GB UFS 3.1 built-in storage, expandable up to 2TB, so the headset can load and execute multi-level VR simulations simultaneously.

Standalone Wireless and PC-VR Hybrid Mode

- Vive Focus Vision employs a wireless standalone mode without needing to employ external tracking stations at the expense of 6 degrees of freedom (6DoF) tracking.
- It is also augmented with wired PC-VR mode via USB-C and wireless PC streaming for viewing high-fidelity simulation content for even more intense NDT training sessions.

High-fidelity 6DoF Inside-Out Tracking and Hand Recognition

- Four front-facing tracking cameras are integrated into the headset, providing sub-millimeter accuracy for user interaction, which is critical for high-fidelity VR tool manipulation and flaw inspection procedures.
- 26-point simultaneous hand tracking for natural hand movement enables customers to utilize VR-based NDT tools like they are conducting real inspections.

Long-Term Use with Ergonomic Design Principles

- Symmetrical rear battery support for evenly distributed weight to avoid fatigue during prolonged training.
- Swappable battery for uninterrupted use, enabling long-term training for industrial-scale applications.

Enterprise Connectivity and Expandability

- Wi-Fi 6 standard and Bluetooth 5.2 for cloud test monitoring and Moodle integration of LMS.
- Two USB 3.2 Gen-1 Type-C ports for hardware extension, for example, haptic gloves or external sensors, to bring in more realism enhancement of PT and NDT processes.

The HTC Vive Focus vision meets the hardware requirements for VR-based NDT training, offering high-resolution clarity, precise tracking, scalable storage, and enterprise-grade connectivity. This choice ensures that the training platform remains future-proof, adaptable, and optimized for learning. By leveraging its wireless functionality, PC-VR compatibility, and ergonomic design, trainees can perform real-world inspection tasks in a controlled, immersive VR setting, reinforcing procedural accuracy and defect identification skills.

The hardware selection aligns with the design, ensuring that technological infrastructure enhances user experience, knowledge retention, and hands-on skill development in NDT training scenarios.

Software

Software libraries selected to be used in the VR-based NDT training system play an important role in delivering real-life-like, interactive, and affordable training experiences and offer support for scalability requirements and futureproofing. Softwares like Unity 3D can offer high-fidelity three-dimensional world rendering, physics simulation, and interactive user interfaces required to mimic real-world NDT workflow processes. Libraries like the Unity XR Interaction Toolkit and the OpenXR natively support the HTC Vive Focus Vision, including hand input, 6DoF tracking, and high-fidelity motion control. Tools like Blender and other model creation software will also be employed to design high-fidelity 3D assets, with visual fidelity and accuracy in defect inspection and procedural simulation.

Below (see Table 5) is a detailed breakdown of the software components and their relevance to the VR-based NDT training platform:

Category	Software/Tool	Relevance to VR Training
3D Rendering Engine	Unity 3D	Provides high-fidelity 3D rendering for realistic defect visualization, surface textures, and tool interactions. Supports real-time physics simulations for accurate procedural training
Physics Simulation	Unity Physics (NVIDIA PhysX integration)	Enables realistic material behaviour, fluid dynamics (e.g., penetrant application), and tool interactions, which are critical for replicating real-world NDT workflows
User Interface (UI) Design	Unity UI Toolkit	Ensures an intuitive and user-friendly interface for trainees, allowing easy navigation, tool selection, and procedural guidance
XR Development Libraries	Unity XR Interaction Toolkit, OpenXR Plugin, VIVE Wave SDK for Unity	Provides standardized APIs for VR development, ensuring compatibility with the HTC Vive Focus Vision and enabling features like 6DoF tracking, hand tracking, and controller interactions
Audio Processing	Unity Audio Spatializer (FMOD or Wwise integration)	Provides realistic spatial audio cues for procedural guidance, safety alarms, and environmental sounds, enhancing immersion and situational awareness
Data Analytics	Unity Analytics	Enables tracking of trainee performance, defect detection accuracy, and procedural efficiency, providing actionable insights for improving training outcomes
3D Modeling Software	Blender	Essential for creating high-quality 3D models of NDT tools, defects, and training environments. Blender is particularly recommended for its open-source nature and robust feature set
Texture and Material Design	Substance Painter or Adobe Photoshop	Used for creating realistic textures and materials for 3D models, ensuring high visual fidelity in the VR environment

Animation Tools	Blender Animation Tools or Unity Animation System	Enables the creation of procedural animations for tools, defects, and trainee interactions, enhancing the realism of the training scenarios
Version Control	Git (GitHub/GitLab) with Unity Collaborate	Ensures collaborative development, version control, and seamless updates to the VR platform as new features or training scenarios are added

Table 5: Software Components and Their Relevance

Key Features

Unity 3D Physics Simulation and Rendering

- Unity 3D serves as the main rendering engine of the realistic 3D world and actual NDT operation simulation.
- Unity Physics (NVIDIA PhysX) offers a realistic simulation of material and fluid behaviors, e.g., penetrant application and surface interaction.
- Offers realistic visualization of defects and procedural accuracy, which are the keys to successful NDT training.

User Interface (UI) Design

- Unity UI Toolkit enables the development of a user-friendly and easy-to-use interface through which the trainees will easily access the virtual reality environment and be able to utilize tools and guides.
- Simplifies training and allows the trainees to focus on the training material.

XR Development Libraries

- Unity XR Interaction Toolkit provides a shared foundation for VR interactions like 6DoF tracking and controller input.
- OpenXR Plugin Supports big VR devices like the HTC Vive Focus Vision.
- VIVE Wave SDK for Unity Optimized to be used on HTC Vive hardware to support high-end capabilities like hand tracking and precise motion control.
- Tunes hardware support and provides reliable VR capability that simplifies the training process.

3D Modeling and Animation

- Blender is a free and open-source 3D modeling application for the creation of high-fidelity assets like NDT devices, defects, and training simulations.

- Substance Painter/Adobe Photoshop will be used for realistic texture and material creation.
- Unity Animation System supports procedural animation of trainee-tool interaction.
- Delivers high visual quality and realism in the VR environment to support overall training.

Audio Processing

- Unity Audio Spatializer (FMOD/Wwise integration) delivers natural-sounding audio cues for spatial direction, warning safety alerts, and ambient sounds.
- Improves situation awareness and immersion and thus effectiveness and efficiency during training.

The software elements utilized for designing and developing the VR-based NDT training platform and scenarios will deliver an immersed, actual, and scalable learning experience. The platform and scenarios will be designed and developed using Unity-specific virtual reality workflow utility libraries.

Integration Strategies

The integration of hardware, software, and the external Learning Management System (LMS) is a critical aspect of the platform supporting VR-based NDT training. The technical solutions adopted here to achieve interoperability, scalability, and performance across all the components are detailed. The solutions are chosen to meet the project objectives to provide an immersive, accurate, and scalable training experience. From a design perspective, all these components have to be combined to develop a coherent and effective training platform that can meet the demands of industrial NDT training. The solutions ensure that the hardware, software, and LMS are integrated in a manner that promotes consistency and usability for both the instructors and the learners.

1. Hardware-Software Integration

HTC Vive Focus Vision integration with Unity 3D is accomplished with the help of the Unity XR Interaction Toolkit and OpenXR Plugin. Unity XR Interaction Toolkit provides a unified API for VR interactions, which helps in supporting features such as 6DoF tracking, hand interactions, and controller input. This implies that the hardware capabilities of the Vive Focus Vision, such as its high-definition display, precise tracking, and ergonomic comfort, are engaged to their fullest potential in the VR experience. The OpenXR Plugin is a cross-platform API and will, therefore be supported by the Vive Focus Vision as well as other future VR devices. It provides low-latency rendering and precise motion tracking, which are essential for realistic training simulations. In addition, the VIVE Wave SDK, which is customized for HTC Vive hardware, allows for more profound integration with higher-level features such as sub-millimeter tracking accuracy and enterprise-level performance optimization. This level of integration is of utmost priority to achieve a smooth and immersive experience from the VR platform, where trainees can manipulate virtual tools and defects in the same way as they would with real-world ones.

2. Unity 3D and LMS integration

The VR platform needs integration with the Moodle LMS to allow tracking of trainee progress, assessment, and certification. It is achieved by RESTful API integration in which trainee data (i.e., progress, assessment results) is exchanged between the VR platform and LMS in real-time. Central management of data is facilitated by this, in addition to providing instructors with the capability to track trainee performance effectively. Single Sign-On (SSO) is also utilized to allow trainees to sign in once and not need any further credentials to access the VR platform and Moodle, adding a touch of convenience and security to the users. Trainee performance metrics collected within the VR platform, such as defect detection accuracy and procedural efficiency, are exported to Moodle for analysis and reporting of data. From a design perspective, this integration is such that the platform is not only immersive but also measurable and traceable, meeting industry standards for training and certification.

3. Physics and Simulation Integration

Physics simulation integration is key to simulating real-world NDT processes. Unity NVIDIA PhysX engine is used to simulate real-world material behavior and fluid dynamics, such as penetrant application and surface interaction. This provides procedural training simulations that are realistic and immersive. As an example, the physics engine can mimic the flow behavior of penetrant fluid over different surface textures so that the trainees can practice their defect detection in a realistic virtual environment. The combination of high-fidelity 3D visualization and physics simulations assures the trainees of realistic defect visualization and procedural accuracy, which are key in effective NDT training. From a design perspective, such integration assists the training setup in simulating real conditions effectively and thus enables easier transfer of learning from a virtual environment.

4. Asset and Environment Integration

Immersive training setup requires high-fidelity 3D assets and environments. Blender will be utilized for creating 3D NDT tool, defect, and training environment high-detailed models. They are brought into Unity via optimized pipelines (e.g., FBX or GLTF format), creating high-fidelity assets with realistic textures and animations. Substance Painter will be utilized to author realistic material textures to add visual fidelity to 3D models. Procedural animation for tools, defects, and trainee interactions is provided by the Unity Animation System, making the training environment even more realistic. This serves to maintain the equipment and training grounds to appear realistic and interesting, improving the quality of the training. At a design level, this integration serves to enable the platform to provide a visually stimulating and realistic environment, something that is vital in maintaining trainees' interest and improving learning outcomes.

5. Audio Integration

Immersive audio will be included to enhance the interaction and effectiveness of the training system. Spatial audio processing, realistic audio cues for procedural guidance, safety alerts, and ambient sound will be provided by Unity 3D.

6. Data Analytics and Performance Tracking

The platform utilizes Unity Analytics to monitor trainee performance, defect detection accuracy, and procedural efficiency. This data is collected and analyzed to provide actionable insights for enhancing training outcomes. Performance metrics are then transmitted to the LMS, where they are stored and organized. This integration enables instructors to track trainee progress, generate comprehensive reports, and make data-driven decisions to improve training effectiveness.

The integration strategies discussed above enable the hardware and software components to communicate with each other effectively in an attempt to realize an immersive, realistic, and scalable VR-based NDT training platform. The use of frameworks such as Unity XR Interaction Toolkit, OpenXR, and Moodle RESTful APIs allows the platform to meet interoperability, performance, and user experience requirements. These strategies not only meet short-term demands but also provide a base for improvement in the future so that the platform is agile enough to map itself with evolving industrial demands. From the design perspective, these integration strategies are also crucial to the design of a properly integrated and effective training system that can meet industrial NDT training needs so that the trainees acquire the skills and knowledge that are necessary in real inspection practice.

Pedagogical and Learning Requirements

In the previous section, technical considerations like the hardware, software, and integration strategies were addressed. The technology will enable the platform to deliver experiential, precise, and scalable training. Technical skills alone are not adequate to make learning efficient. This element is interested in the pedagogic and learning requirements that make the VR platform technologically accurate as well as pedagogically accurate.

The pedagogic and learning requirements guide how the VR platform will support the learning of skills, knowledge retention, and motivation of trainees. Such requirements are significant in the sense that they ensure that the VR training scenarios are designed with clearly articulated learning objectives, sound instructional design, and active user interfaces. By translating the technological superiority of the platform into proven educational principles, a learning environment in which trainees are taught essential skills to perform real NDT inspections without losing focus and attention will be supported.

In short, while the previous sections described how the platform operates, this section provides the reason it operates in terms of learning. It makes the platform not only a technology platform but an end-to-end training solution with industrial NDT training requirements.

Instructional Strategies: Mapping Kolb's Experiential Learning Model

Instructional design in the VR platform is based on Kolb's Experiential Learning Model [7]. Kolb's Experiential Learning Model has four steps: Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation [7]. The model provides a systematic framework for designing functional skills, reinforcement of theory, and analytical capacity. Trainees are provided with the ability to construct practical Non-Destructive Testing (NDT) skills through repeated learning by realistic simulation, systematic feedback, theory reinforcement, and adaptive tests.

1. **Concrete Experience: Simulation of NDT Processes through Virtual Reality**

The learners will be given realistic simulations of the field environments based on VR without any risk to actual tests. The key activities include:

- Clean the surface and application of penetrant to make defects visible.
- Simulated flaw detection.
- Excess penetrant wiped off in simulation of regular industry practice.

These 3D environments of high fidelity and immersion allow the learners to construct experiential learning of procedural compliance and defect detection upon industry best practices.

2. Reflective Observation: Performance Review and Feedback

Following task completion, trainees monitor themselves through automatic feedback, including:

- Defect detection accuracy, procedural compliance, and error detection.
- Task completion time and workflow efficiency measures.
- Error cues to provide visual feedback for defect omission of technique.

The platform will provide structured in-task feedback, allowing trainees to self-assess and refine their approach. Formal assessment results and performance tracking are managed separately within LMS for evaluation reporting.

3. Abstract Conceptualization: Theory Enrichment and Concept Synthesis

After reflective practice, integrated theoretical modules are contributed towards a conceptual understanding of NDT techniques, for example:

- Fundamental principles of liquid penetrant testing (LPT).
- Effect of dwell time on defect visibility and detection sensitivity.
- Safety protocols, chemical handling procedures, and regulatory compliance.

These theory training modules are best practice within the industry, where hands-on experience is translated into theory.

4. Active Experimentation: Skills Application

The learning is applied to more complicated NDT conditions, and problem-solving and decision-making competencies are obtained. Tasks include:

- Inspection of surfaces with varying defect types, requiring technique adaptation.
- Comparison of different penetrant types (fluorescent vs. visible dye) to assess defect visibility.

- Adjusting procedures based on contamination levels and material properties.

By engaging in iterative scenario-based training, trainees develop the ability to adjust techniques dynamically based on environmental and operational variables.

Integration of Kolb's Model to the VR Platform

The VR environment is designed to support all four stages of Kolb's Experiential Learning Model through:

- Immersive Simulation → Supports experiential hands-on training (Concrete Experience).
- Automated Feedback and Analytics → Supports regular measurement of performance (Reflective Observation).
- Guided Theory Modules → Supports conceptualization (Abstract Conceptualization).
- Scenario-Based Challenges → Ongoing practice of skills again and again (Active Experimentation).

This instructional approach ensures a structured approach supporting progressive skill development [7].

Assessment and Performance Evaluation

Experiential learning and formative feedback practice are provided in the VR environment, but formal assessment, monitoring of competence, and examination are all addressed in LMS. This includes:

- Performance tracking, error rate, and procedural competence tracking.
- Scenario testing, procedural adherence, and tracking of problem-solving capability.

To ensure a comprehensive evaluation of trainee performance, the following parameters will be assessed using the matrix below:

Parameter	What is Measured	How it is Measured	Acceptable Level
Defect Detection Accuracy	Percentage of correctly identified defects	Automated system tracks correct vs. incorrect defect identification	≥ 90% accuracy

Procedural Compliance	Adherence to the correct sequence of steps in the PT process	System monitors step-by-step actions and flags deviations from the standard process	100% compliance
Time Efficiency	Time taken to complete each stage of the PT process	System tracks time spent on each task and compares it to optimal benchmarks	Within ±10% of optimal time
Safety Protocol Adherence	Compliance with safety protocols (e.g: proper handling etc.)	System monitors safety-related actions and flags violations	100% compliance

Table 6: Performance Evaluation Criteria

This matrix ensures that trainees receive detailed feedback on their performance, allowing them to identify areas for improvement and refine their skills through repeated practice. By focusing on these key parameters, the VR platform provides a robust framework for assessing and enhancing trainee competence in NDT inspections.

User Engagement Techniques

User engagement is a major component of the VR platform because it plays a direct role in determining the success of the training environment [8][9]. Motivated trainees will not only be motivated but also learn and develop the skills needed to perform real-world NDT inspections. Trainees will consequently either fail to complete the training or not learn well if proper interaction techniques are not applied. To overcome this, the platform will employ a range of user engagement techniques to make the learning process engaging and interactive.

1. Immersive Environments

The platform will utilize high-fidelity 3D graphics and spatial audio to create realistic and immersive training environments. For example, trainees can inspect for defects on surfaces using virtual UV lights, and the environment responds dynamically to their actions. Immersive sound, such as realistic sound effects like machinery whirring or the sound of cleaning chemicals being applied, also helps create presence. Immersion to this level causes trainees to feel as if they are performing actual real-world inspections and enhances training to be more realistic and interactive.

Immersive environments improve learning and skill gain by presence and interaction to a very high degree [8].

2. Real-Time Feedback

The platform will provide real-time feedback regarding trainee activity, i.e., accuracy of defect detection or accuracy of procedural steps. For example, if a trainee does not detect a defect, the platform highlights the error and indicates the reason for it. Real-time feedback will enable trainees to learn from mistakes and improve performance. Real-time feedback is effective in maintaining interest and generating continuous improvement [9].

3. Gamification: Feedback Mechanisms

Gamification will be added to the platform in the form of feedback mechanisms that encourage the trainees to get immediate and context-specific feedback regarding their performance. For example:

- Trainees will receive instant feedback regarding their work, e.g., accuracy of defect detection or precision in procedural procedures. In case a trainee misses a defect, the platform mentions the flaw and explains the same so they can learn and correct it.
- Achievement notifications will be used to reward trainees for completing tasks properly. For example, an achievement notification can be given to a trainee for successfully identifying all the defects in a complex situation.

By providing immediate and useful feedback, the system allows learners to learn from mistakes and be motivated to improve performance.

The user engagement techniques used in the VR-VET platform are critical for maintaining motivation, enhancing learning outcomes, and fostering a positive learning experience. By making the learning process enjoyable and rewarding, these techniques keep trainees motivated to complete their training and achieve their goals. Engaged trainees are likelier to retain knowledge and develop skills, leading to better performance in real-world inspections. Additionally, a well-designed and engaging platform creates a positive learning environment, encouraging trainees to return for further training and development.

Assessment

The Assessment and Evaluation process is a process to leverage both the VR training environment and Moodle. The trainees undertake tasks in the VR environment, where the platform tracks performance, detects errors and captures performance data. The data is then passed on to Moodle for marking, tracking, and reporting.

1. Error Detection and Task Completion in VR

The learners will perform activities such as surface cleaning, application of penetrants, detection of flaws, and reporting within the VR environment. Their work is tracked by the system and detected for errors in real time, including:

- **Correct Errors**

Correctly detected and identified flaws.

- **Incomplete Errors**

Incorrectly marked or partially detected flaws.

- **Missed Errors**

Completely missed the flaws.

The VR system measures these and sends them to Moodle to be graded and analyzed.

This approach is technically feasible, as the VR platform will be capable of tracking user interactions and detecting errors with high precision. Research shows that VR-based training systems can accurately simulate real-world tasks and provide detailed performance metrics [8].

2. Data Transmission to Moodle (using xAPI)

The performance information gathered in the VR environment is transferred to Moodle in the form of xAPI statements. These are published to a Learning Record Store (LRS), which is linked to Moodle. The LRS records and aggregates the information so that it can be pulled out for reporting and analysis [10]

xAPI allows communication between Moodle and the VR environment for the express purpose of allowing performance data to be transferred and processed securely.

To track training effectiveness, xAPI will log key performance indicators:

Indicator	Data Captured	xAPI Statement Example
Time for Penetrant Application	Duration of application	"verb": "applied_penetrant", "result": {"duration": "PT3M"}
Correct Cleaning Method Used	Selected cleaning technique	"verb": "cleaned_surface", "result": {"correct_method_used": true}

Defect Identification Accuracy	% of correct identifications	"verb": "identified_defect", "result": {"accuracy": 90%}
Sequence Adherence	Steps completed correctly	"verb": "completed_step", "result": {"order_correct": true}
Safety Compliance	PPE usage confirmation	"verb": "used_ppe", "result": {"success": true}

Table 7: Key Performance Indicators for xAPI Tracking

This ensures comprehensive performance tracking within the Moodle LMS.

3. Assessment

Moodle uses the performance data received from the VR platform to conduct assessments**:**

- **Formative Tests**

Instantaneous feedback on trainee performance in the form of correct, incomplete, and missed errors.

- **Progress Monitoring**

Monitoring trainee progress over time to identify improvement areas.

Moodle's monitoring tools, with xAPI added on, are reliable for measuring trainee performance [9] [10].

Accessibility

Accessibility will be incorporated into the VR platform's design in a way that the interface itself will be rendered accessible, intuitive, and inclusive for all. A user interface (UI) not only helps in improving learning [11] but also in enabling the platform to adhere to universal design laws so that it is usable by people with different abilities.

Below are core factors that can be used to establish accessible design:

1. Intuitive Navigation and Interaction

The VR platform will have intuitive navigation and interaction functionality to make the training scenarios more accessible to the users. These entail:

- **Clear Menu Structures**

Menus and options should be well-defined and logically organized properly with clear and comprehensible locations to reduce cognitive load [11].

- **Controls**

The UI to communicate within the VR environment will need to have user-friendly controls, i.e., controller input, that are easy to learn and operate [11].

2. Visual Accessibility

Visual accessibility will ensure that the users possess varying visual acuity and yet be in a position to utilize the platform successfully. Some of the significant considerations could be:

- **High Contrast and Readable Text**

Text and graphics should have a high contrast ratio and sufficient size so that they can be read easily [12].

- **Colorblind-Friendly Design**

Use color as the only method of conveying information. Utilize patterns, icons, or text labels to differentiate between things [12].

The Web Content Accessibility Guidelines (WCAG) 2.1 gives comprehensive standards of visual accessibility that define the requirement of flexible and perceivable content [12].

3. Cognitive Accessibility

Cognitive accessibility will render the platform usable by individuals with varying cognitive abilities:

- **Consistent Design**

Provide consistency in structure, navigation, and interaction patterns to avoid confusion [13].

- **Simple Instructions**

Provide clear and simple instructions and refrain from using jargon and technical terms [13].

By following these principles of accessibility in the UI design of the VR platform, the platform is not only made industry-compliant, but it also provides an accessible and effective learning experience to all learners. Accessibility is not just about compliance; it is a critical element of good design that provides maximum usability, engagement, and learning.

The pedagogical and learning requirements explained in this section are essential to the technologically possible and educationally effective nature of the VR platform. Through the use of Kolb's Experiential Learning Model and with a vision for user engagement strategies, the platform stands to deliver skill acquisition, knowledge retention, and motivational support. Through these principles, the VR training is experiential, interactive, and relevant to real-world NDT inspection requirements.

In the next section, the focus will shift to learning analytics**,** which builds on these pedagogical foundations by analysing data generated from user interactions within the platform. Learning analytics will provide insights into trainee performance, engagement, and areas for improvement. This data-driven approach will ensure that the platform not only will deliver effective training but also continuously evolves to meet the needs of learners and industry standards.

Learning Analytics

This section explains the role of Learning Analytics (LA) in the design process. Learning analytics is mainly accountable for optimizing training performance by collecting, analyzing, and interpreting the data resulting from trainee interactions. It facilitates the identification of knowledge gaps, the provision of personalized feedback, and the optimization of training scenarios based on the individual needs of a trainee and industry demands. LA enables instructors to make data-informed decisions that power skill acquisition, knowledge retention, and motivation by monitoring performance metrics, engagement levels, and faults.

Definition of Learning Analytics

The term LA was first defined by Siemens and Long at the “First Conference of Learning Analytics and Knowledge” (LAK) in 2011.

“Learning analytics is the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs” [14].

Data Collection

This data collection assists in understanding the performance of the trainees, where they are deficient, and optimization of the overall training process. This data assists in understanding the performance of the trainees, where they are deficient, and learning process optimization.

The important types of data would be:

Performance Metrics

- Accuracy data in defect detection, technical step compliance, and task completion time.
- **Example**

Measurement of the accuracy with which a trainee identifies defects in simulated inspection.

Error Analysis

- Records of missed defects, incorrect procedures, and workflow inefficiencies.
- **Example**

Identification of repeated errors, i.e., not applying penetrant properly or not identifying defects in inspection.

This data is collected through automated systems that track user actions in real time, providing a comprehensive and objective view of trainee performance. The use of multimodal data collection methods, such as tracking interactions in VR environments and integrating data from LMS, ensures a holistic understanding of the learning process [15, 16].

Data Analysis and Insights

The performance of trainees through the VR training session will be used to identify the skill gaps, and these will be utilized as inputs for enhancing learning. Skill gaps will also be measured by putting a number to such performance indicators as accuracy in defect detection, procedure compliance, and time taken [14].

For example, if the trainee keeps failing to recognize a specific type of defect while performing the inspection activity, the system can recognize it as an area of weakness. The VR system will then adapt and provide feedback, suggesting solutions or adjusting the difficulty of subsequent tasks to address these gaps. By doing this, trainees receive individualized feedback within the VR environment, resulting in improved skill development and overall performance.

Ethical and GDPR (General Data Protection Regulation) Considerations

The scenarios and platform are designed to adhere to ethical principles and General Data Protection Regulation (GDPR) guidelines, ensuring proper utilization of learners' data. Ethical considerations are at the forefront of maintaining trust and ensuring that the platform protects the privacy and rights of the users.

Data minimization is also a key concept, that only such data shall be collected that will lead to better training outcomes. Therefore, will avoid the collection of excessive and irrelevant data and will follow the GDPR's principle of keeping the processing of data to the bare minimum that is necessary [17]. For example, the platform will collect measurement for performance and analysis of errors but avoid collection of personal data.

To protect learners' data, the platform will incorporate stringent security measures, such as encryption and access controls. These measures will rule out unauthorized access, data leak, or misappropriation of sensitive information, exemplifying the necessity of secure data handling [15].

The scenarios and platform will abide by GDPR's data storage and deletion principles. Data will be stored only to the extent necessary to fulfill its purpose and will be deleted securely once it is no longer needed. This adheres to GDPR's storage limitation principle and reduces the likelihood of data misuse [17].

By the use of these ethical and GDPR-compliant practices, the platform will ensure that the data of the learners is handled appropriately, promoting trust and compliance with the law requirements [15, 17].

Benefits of Learning Analytics

Learning analytics offers significant benefits, enhancing training results along with the learning process [16]. Through methodical data collection and processing, LA will enable the platform to provide personalized, scalable, and effective training solutions.

Some of the main benefits include improved training outcomes. LA identifies strengths and provides individualized feedback, hence allowing the trainees to learn what they should. If, for example, the trainee is still not able to identify certain types of defects, the system can select this as an area of improvement and provide suggested improvement. The individualized process improves competency and assures industry standards by the trainees [14].

LA stimulates trainees' engagement and motivation. Continuous feedback and progress monitoring render the learning process an interactive process with trainees and encourage them to be interested in their learning [14].

With all these benefits, the VR-based NDT training platform will offer trainees high-quality, effective, and engaging training that better equips them for real-world NDT inspections.

Conclusion

The development of the VR-based NDT training platform is one of the significant innovations in vocational education and training (VET), an effective and cost-saving way of acquiring Non-Destructive Testing (NDT) skills, an experiential learning. The VR platform offers a virtual experience-based learning system that fills the gap between theory and practice.

Platform development is facilitated by the Activity Theory-Based Model for Serious Games Analysis and Conceptual Design (ATMSG), upon which training scenario design is carried out based on predicted learning outcomes. ATMSG facilitates a systematic process of scenario design with emphasis on learner-centered, interactive, and compatible instruction design. Following Kolb's Experiential Learning Model, the platform facilitates skill acquisition through concrete experience, reflective observation, abstract conceptualization, and active experimentation.

Technical requirements, including the application of high-capacity hardware and software, ensure that the platform delivers an interactive and smooth learning experience. The VR platform’s integration with the Learning Management System

(LMS) enables tracking and analysis of performance and provides trainers with feedback on trainee progress and areas for improvement.

Pedagogic and educational standards are kept at their best level so that there is a technologically upgraded as well as pedagogically suitable platform. Pedagogy elements like interactive learning areas, feedback, and gaming aspects are used so that trainee engagement, as well as maximum learning performance, is attained. Usability as well as ethics are kept in check as well so that the platform becomes accessible as well as in compliance with data protection policy.

In conclusion, the VR-based training system for NDT is a significant solution for NDT vocational education and training. Based on pedagogy and promising technology, the system renders the trainees at all times capable of performing actual inspections with competence and confidence. The system has the potential to revolutionize the nature of NDT training by making it more accessible, interactive, and effective for a broad audience, from beginners to professionals.

Co-funded by the European Union

VRVET

Non-Destructive Testing

[Annex for D3.1]

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VRVET Non-Destructive Testing

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2nd	11.03.2025	IIS	Updated info 7 t o12
3rd	13.03.2025	ISIM	Updated info 1 to 6
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5th	25.03.2025	BIBA	Adding Annex D3.1 to the current document
6th	25.03.2025	BIBA	Formating of complete documet

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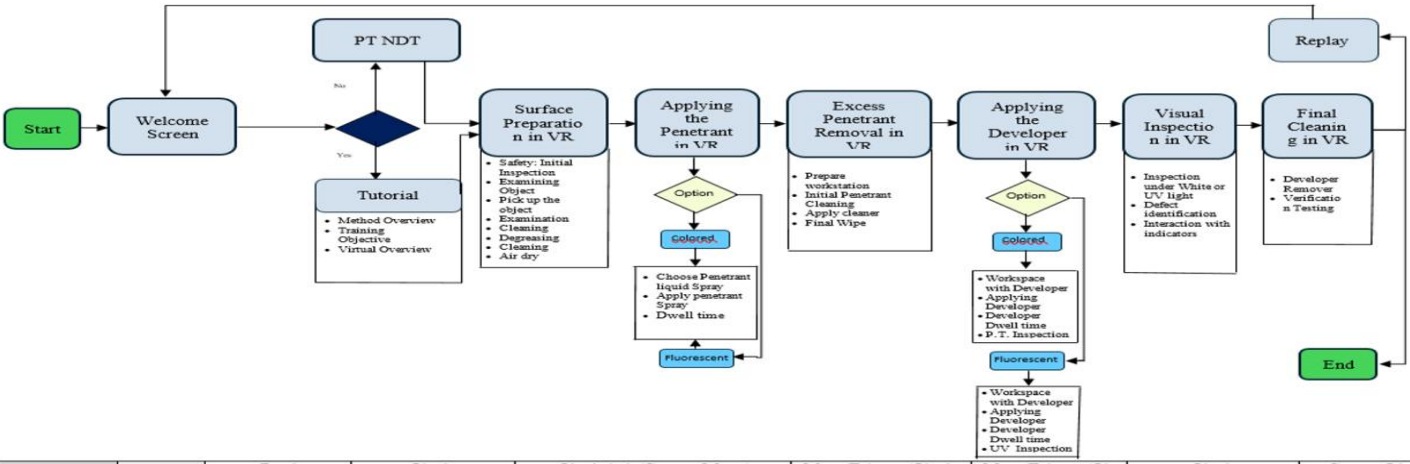

Gaming	Actions	Read Information/ Listen to	Obtain help/Move/Teleport/ Watch / Listen to / Read Information	Obtain help/Capture/Move/ Teleport/Watch / Listen to / Read Information	Move/Teleport/Obtain Help/, Watch / Listen to / Read Information	Move/Teleport/Obtain Help/, Watch / Listen to / Read Information	Obtain Help/Teleport/Watch/ Listen to/Read Information	Capture/Listen to/Read Information/Obtain Help/Teleport/Watch/Collect
	Tools	-	Information/Advice and Assistance/Tips/Challenges/Tutorial	Information/Advice and Assistance/Tips/Challenges	Advice and Assistance/ Challenges	Advice and Assistance/ Challenges	Information/Advice and Assistance/Tips/	Complete Information/Achievement/Success/Advice
	Goals	-	Collect Information/Learn to Use Interface	Collect Information/ Form/ Discover Goals	Form/Discover Goal/Perform Task	Form/Discover Goal/Perform Task	Perform Task	Perform Task
Learning	Actions	-	Observe/Read/Select/Explore/Complete/ /Examine/Perform action/task	Observe/Read/Select/Explore/Complete//Examine/Perform action/task	Observe/Read/Find more Information about/Choose/Complete Goal/Make/Perform action/Task/Analyse/Examine/Identify/Select /Decide/	Observe/Read/Find more Information about/Complete Goal/Make/Perform action/Task/Analyse/Examine/Decide/	Observe/Read/Describe/Calculate/Complete Goal/Perform Action/Task/Estimate	Observe/Read/Recognize/Distinguish/Complete Goal/Examine/Interpret/Perform Action/Task/Identify/Assess/Decide/
	Tools	-	Videos/Information/ /Texts/Tips	Videos/Information//Texts/Tips	Challenges/Problems/Information/Texts/Tips	Challenges/Problems/Information/Organization/Texts/Tips	Challenges/Problems/ Information/Texts/Tips	Challenges/Problems/Conclusions/Information/Texts
	Goals	-	Understanding/Learning How to Learn	Understanding/Analysing/Learning How to Learn	Understanding/Analysing/Learning How to Learn/Active Experimentation/Foundational Knowledge/Learning How to Learn	Understanding/Analysing/Learning How to Learn/Active Experimentation/Foundational Knowledge/Learning How to Learn	Understanding/Analysing/Applying/Active Experimentation/Learn How to Learn	Understanding/Analysing/Applying/Organization/Active Experimentation/Application
Instrinctic Instructions	Actions	Present Material	Present Material	Present Material	Present Material/Present Problem/Suggest Improvements	Present Material/Present Problem/Suggest Improvements	Present Material/Suggest Improvements	Assess Performance/Suggest Improvements
	Tools	-	Challenge/Help Text/Tips/Assistance	Challenge/Help Text/Tips/Assistance	Challenge/Help Text/Tips/Assistance	Challenge/Help Text/Tips/Assistance	Challenges/Help Text/Limited Set of Choices/Tips/Assistance	Help Texts/Tips/Assistance/Challenges/Help Text/Limited Set of Choices/Tips/Assistance
	Goals	Attention	Inform the Learner of the Objective/Relevance/Confidence	Inform the Learner of the Objective/Relevance/Confidence	Gain Attention/Inform Learner of the Objective/Provide Feedback/Attention/Relevance/Confidence	Gain Attention/Inform Learner of the Objective/Provide Feedback/Attention/Relevance/Confidence	Assess Performance/Attention/Relevance/Confidence/Satisfaction	Attention/Relevance/Confidence/satisfaction/Assess Performance

Game sequences - ISIM

1. Start and Introduction

Gaming	Users start and view a tutorial
Learning	Introduces the PT NDT process and objectives
Intrinsic instruction	Provides an overview of the training experience

Information: Define the purpose of PT NDT, basic objectives, and user interface instructions.

The **first phase** of the **VR training experience** for **Penetrant Testing (PT) NDT** is designed to introduce users to the training environment, objectives, and fundamental concepts. This **introductory** sequence serves as an onboarding experience, ensuring that users are comfortable navigating the VR interface before engaging in practical tasks.

Information to be Delivered in This Phase

Purpose of PT NDT

Penetrant Testing (PT) is a widely used **non-destructive testing (NDT) method** designed to detect **surface-breaking defects** in non-porous materials such as metals, plastics, and ceramics. The main goal is to identify discontinuities such as **cracks, laps, porosity, and lack of fusion** in components, ensuring structural integrity and safety in industries like aerospace, automotive, and manufacturing.

Basic Objectives of the VR Training

- Introduce users to the PT NDT process in a structured, immersive format.
- Familiarize users with the VR environment and interactive controls.
- Provide an overview of the steps involved in PT NDT, setting expectations for subsequent learning sequences.
- Ensure users understand the safety requirements associated with PT NDT procedures.

User Interface Instructions

Users will receive a guided introduction to the VR controls and interaction mechanics. The VR interface will include:

- Hand tracking or controller navigation: Explaining how to use VR controllers to interact with tools and menus.
- Movement and teleportation mechanics: Users will learn how to navigate within the virtual environment.
- HUD (Heads-Up Display) elements: A floating UI panel will display objectives, progress tracking, and contextual tips.
- Voice and text guidance: Audio instructions and pop-up text will provide key information.

Implementation in the VR Experience

Setting the Scene

The user will start in a virtual training room designed to resemble a modern NDT laboratory. This space will have realistic elements, including workstations, PT materials, and instructional posters displaying key PT NDT concepts. The environment will be well-lit and visually engaging, setting a professional yet welcoming tone.

Interactive Tutorial and Storyline Integration

Welcome Sequence: Upon starting, a virtual instructor (AI-driven guide or avatar) will greet the user and provide an introduction to the training session. The instructor will briefly explain why PT NDT is essential, using animated examples of defect detection.

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Background

Cracks on surfaces that occur during the production of technical components, or pores that may be present mainly in castings and are cut by turning or milling can be made visible by appropriate procedures. Penetrant testing (PT) is one of these methods and a comparatively simple examination method of non-destructive material testing. It is used to indicate surface defects such as pores, cracks, binding defects, laminations and forging laps that are open to the surface.

The main applications are:

- (Mainly) testing of non-ferromagnetic materials
- Mobile inspection of pipelines, boilers and chemical plants
- Testing of light metal and titanium components in aircraft and automobile construction

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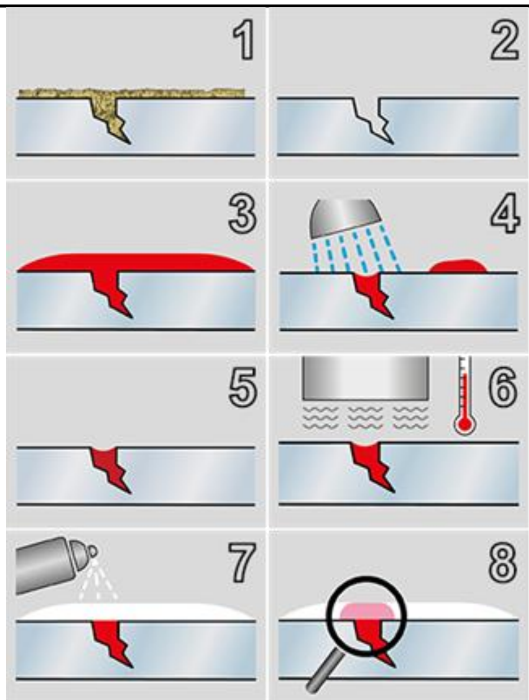

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Advantages of Penetration or Penetrant Methods

- Optional on site use
- Can be used on almost all solid materials, including ceramics or plastics

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• Simultaneous testing for surface cracks and pores in one operation • The procedure is hardly influenced by the geometry of the test specimen • Low expenditure for testing equipment, therefore cost-effective

User Interaction Training: Users will engage in an interactive onboarding tutorial, where they learn to pick up objects, inspect surfaces, and interact with UI elements.

Virtual Screens or Projection Displays: Large virtual screens or holograms will display animated infographics, showing a high-level overview of the PT NDT process.

First-Person Perspective Training: Users will be required to perform simple interaction exercises, such as selecting the correct PPE (Personal Protective Equipment) before proceeding to the main training module.

Intrinsic Instruction and Feedback Mechanisms

Step-by-Step Breakdown of the Training Experience: The instructor will outline what the user will be doing in the upcoming sequences, ensuring clarity.

Real-Time Feedback: If a user struggles with navigation or selecting the right tool, the system will offer real-time guidance through subtle highlights or AI hints.

Practice Mode Option: Users uncomfortable with VR can redo the tutorial before moving on to the hands-on training phases.

Expected Outcomes of the Introduction Phase

Users are comfortable with the VR environment and controls before engaging in complex tasks.

A foundational understanding of PT NDT is established, helping users grasp the significance of the training.

Users are motivated and engaged, with gamified elements reinforcing key learning objectives.

Clear expectations are set, ensuring that the user is prepared for hands-on PT NDT simulations in the following game sequences.

2. Tutorial (Optional)

Gaming	Users who select "View Tutorial" watch an overview of the Penetrant Testing (PT) process

Learning	Provides foundational knowledge of PT procedures
Intrinsic instruction	Delivers concise instructional content through animations and narrations

Information: Overview of PT steps with labeled animations showing tools, materials, and workflow.

Optional but highly recommended segment of the **VR training experience for Penetrant Testing (PT) NDT**. It provides users with a step-by-step visual overview of the PT process, ensuring a clear understanding of the workflow, tools, and materials before engaging in hands-on training. This sequence is particularly beneficial for first-time users or individuals with limited prior knowledge of PT procedures.

Overview of PT Steps

The tutorial will present a structured and sequential breakdown of the Penetrant Testing process through labeled animations and narrations, guiding users through each step:

1. **Surface Preparation**
    a. The animation will show a metallic test piece contaminated with oil, dirt, and oxidation.
    b. A virtual brush, solvent spray, and lint-free cloth will be demonstrated as cleaning tools.
    c. A comparison will illustrate a contaminated vs. properly cleaned surface, emphasizing the importance of proper surface preparation.
2. **Penetrant Application**
    a. A labeled animation will display a red-dye or fluorescent penetrant being sprayed or brushed onto the test piece.
    b. The correct dwell time will be shown via a countdown timer, reinforcing the importance of allowing the penetrant to seep into surface discontinuities.
    c. The animation will highlight how the penetrant flows into microcracks and porosity, providing a magnified view of the defect detection mechanism.

3. **Excess Penetrant Removal**

    a. Different removal methods (solvent wiping, water spray, and emulsification) will be illustrated, depending on the penetrant type used.

    b. The animation will show a user performing an incorrect removal technique, leaving penetrant in non-defect areas, followed by a corrected demonstration.

4. **Developer Application**

    a. A labeled animation will show a thin, uniform layer of developer being applied via a spray can or immersion technique.

    b. The contrast effect will be demonstrated by revealing penetrant indications as the developer absorbs excess penetrant from defects.

5. **Inspection Process**

    a. A UV light for fluorescent penetrants and visible light for red-dye penetrants will be shown in action.

    b. Users will be presented with different types of defects, including linear cracks, porosity, and inclusions, with labeled indicators.

    c. The animation will compare a properly conducted inspection vs. a rushed or incorrect evaluation, reinforcing best practices.

6. **Final Cleaning and Documentation**

    a. Users will watch a final cleaning sequence where excess developer is removed.

    b. The documentation process will be shown, including filling out inspection reports and marking defect locations.

    c. The tutorial will conclude with a summary screen reinforcing the sequence of PT steps.

Implementation in the VR Experience

Interactive Storytelling and Animation

The tutorial will be presented as a narrated animation that plays in a virtual training lab, using floating labels, diagrams, and zoomed-in visualizations to emphasize key points. Users will be able to:

- Pause, rewind, or fast-forward through the tutorial for better comprehension.
- Toggle between a guided walkthrough and an interactive practice mode, where they can perform some steps virtually before moving on to full simulations.

Virtual Instructor and Real-Time Feedback

A virtual instructor (voice-over narration or AI-driven avatar) will provide concise explanations of each PT step while animations illustrate the process. The instructor will emphasize best practices and highlight common mistakes, ensuring that users internalize the correct techniques.

Labeled 3D Models and Tool Demonstrations

As each step is introduced, **3D models of tools and materials** will be displayed with labels and brief descriptions. For example:

Expected Outcomes of the Tutorial Phase

Users gain a clear, structured understanding of the PT NDT process before performing hands-on training.

Users become familiar with VR-based interactions, ensuring smooth transitions into practical simulations.

Common mistakes are preemptively addressed, reducing errors during full practice scenarios.

Confidence and readiness are increased, making users feel prepared for real-world PT inspections.

3. Training Session

Gaming	Users engage in the hands-on PT simulation.
Learning	Applies learned concepts in a practical environment
Intrinsic instruction	Real-time feedback and guidance throughout the simulation

Information: Specify simulation controls, tools (e.g., sprays, cloths), and expected outcomes.

Simulation Controls and User Interaction

Users will have full control over the PT process using VR hand tracking or controllers, allowing them to pick up, manipulate, and operate tools naturally. The system will support the following interaction methods:

- **Hand gestures** (for VR systems with hand tracking) or controller-based grips to handle tools.
- **Grab, rotate, and zoom functions** to inspect components from different angles.
- **Virtual menus** appearing on the HUD (Heads-Up Display) to select tools, check progress, and access instructions.

Tools and Equipment Available in the Simulation

Users will interact with a range of **realistic virtual tools** used in the PT process, each behaving as it would in a real-world scenario:

- **Surface Preparation Tools:**
    - Solvent Cleaner Spray – Removes dirt and contaminants before penetrant application.
    - Lint-Free Cloths – Wipes surfaces clean to prevent false indications.
    - Compressed Air Nozzle – Ensures surfaces are completely dry before proceeding.

- **Penetrant Application Tools:**
  - Red-Dye or Fluorescent Penetrant Spray – Applies the penetrant in a uniform layer.
  - Timer Interface – Simulates dwell time, ensuring proper penetration into defects.
- **Excess Penetrant Removal Tools:**
  - Cloth with Solvent – Used for solvent-removable penetrants.
  - Water Spray Gun – Demonstrates the rinse-off method for water-washable penetrants.
  - Emulsifier Solution – Used when testing with post-emulsifiable penetrants.
- **Developer Application Tools:**
  - Non-Aqueous Developer Spray – Allows users to apply a thin, even layer.
  - Dry Developer Powder Dispenser – Simulates the dusting of dry developer.
  - Developer Dwell Timer – Controls waiting time before inspection.
- **Inspection and Evaluation Tools:**
  - White Light Flashlight – Used for visible dye penetrant testing.
  - UV Light (Blacklight Lamp) – Used for fluorescent penetrant testing.
  - Magnifying Glass / Zoom Function – Helps examine small defect indications.
  - Reference Chart – Displays different defect types for comparison.
- **Final Cleaning and Documentation Tools:**
  - Cleaning Cloth and Detergent – Removes residual developer.
  - Digital Notepad or Report Sheet – Allows users to log findings, classify defects, and generate reports.

Real-Time Feedback and Guidance System

To ensure proper execution and reinforce best practices, the VR training system will include intrinsic instructional support, such as:

- On-Screen Prompts and Tooltips: Hovering over a tool will display its name and purpose.
- Haptic Feedback: When using a spray can, controller vibrations simulate resistance and spray pressure.
- AI-Driven Virtual Instructor: Guides users through each step and alerts them to errors (e.g., "Penetrant applied too heavily—reduce the spray duration.").
- Live Error Detection: If a user skips a step (e.g., forgetting to clean excess penetrant), the simulation highlights the mistake and prompts correction.
- Graded Performance Metrics: After completing a task, users receive a performance score, evaluating accuracy, efficiency, and adherence to best practices.

Implementation in the VR Experience

Scenario Setup and User Progression

The training session begins with users selecting a sample test component from a menu, such as an aircraft engine part, a welded joint, or a cast metal component. Users are then guided through each stage of the PT process:

1. **Preparing the Surface** – Users clean the test piece, with the system validating proper cleaning techniques before allowing progress.
2. **Applying Penetrant** – Users must spray a uniform coat of penetrant and wait for the dwell time countdown before proceeding.
3. **Removing Excess Penetrant** – The system provides feedback if too much penetrant remains on the surface, requiring additional cleaning.
4. **Applying Developer** – Users select the correct developer method and apply it evenly, with real-time visual feedback on the effectiveness of the layer.
5. **Inspecting for Defects** – The UV lamp or white light reveals defect indications, which users must correctly analyze and classify.
6. **Final Cleaning and Documentation** – Users record their findings in a virtual defect report, ensuring correct documentation practices.

Advanced Features and Realism Enhancements

- **Time-Based Scenarios**: Users must wait for real-time dwell periods, emphasizing the importance of timing in PT processes.
- **Randomized Defect Locations**: Each test piece will have different defects on each training run, keeping inspections dynamic.
- **Environmental Variables**: Factors like lighting conditions and viewing angles will impact defect visibility, requiring careful examination.
- **Multi-Level Training**:
    - **Beginner Mode** – Provides full guidance and allows users to correct mistakes.
    - **Expert Mode** – Requires users to complete the PT test independently, with only final performance evaluation.

Gamification and Progress Tracking

- XP (Experience Points) System: Users earn points for correct execution and efficiency.
- Leaderboards (Optional): Instructors can track student progress and compare performance.
- Achievement Badges: Users unlock badges for milestones (e.g., "Perfect Penetrant Application" for flawless technique).
- Simulated "Real-World" Test: At the end of training, users will complete a final assessment scenario, determining whether they have mastered PT procedures.

Expected Outcomes of the Training Session

Users demonstrate proficiency in PT NDT procedures, handling tools correctly and following industry-standard protocols.

Users develop critical decision-making skills, evaluating defects accurately based on penetrant indications.

Errors and inefficiencies are minimized through real-time feedback, helping users develop best practices for real-world inspections.

Performance analytics track progress, allowing instructors to assess skill development and readiness for practical certification.

4. Safety: Initial Inspection

Gaming	Users pick up and examine the object for defects.
Learning	Highlights the importance of initial inspection
Intrinsic instruction	Guides users through safe object handling

Information: List common surface defects (e.g., cracks, porosity) and safety protocols for handling.

The Safety: Initial Inspection phase is a critical step in the VR-based Penetrant Testing (PT) NDT training, designed to introduce users to the process of identifying common surface defects and enforcing safe object handling protocols. This phase emphasizes the importance of carefully inspecting the test component before applying the penetrant, ensuring that the user understands how to recognize potential flaws and handle test pieces safely in a real-world scenario.

Information to be Delivered in This Phase

Common Surface Defects in PT NDT

During the initial inspection, users will examine the test object for **visible surface defects**, which can significantly impact structural integrity. The VR training will introduce users to the following common defects:

1. **Cracks**
   a. Definition: Linear fractures caused by stress, fatigue, or manufacturing defects.
   b. Appearance: Thin, sharp-edged breaks that may vary in depth.
   c. Locations: Often found in welded joints, machined components, and cast materials.
   d. Impact: Cracks can propagate over time, leading to material failure.
2. **Porosity**
   a. Definition: Small, round voids within a material caused by trapped gases during solidification.
   b. Appearance: Clusters of pinhole-like voids, typically seen in weld beads or castings.

c. Locations: Found in welded areas and cast components where molten metal solidifies.

d. Impact: Can reduce the load-bearing capacity of the material and lead to weak points.

3. **Laps and Folds**

    a. Definition: Overlapping layers of material caused by improper metal forming.

    b. Appearance: Thin, raised edges or folded metal layers visible on the surface.

    c. Locations: Found in rolled or forged metal components.

    d. Impact: Can trap contaminants and lead to stress concentration points.

4. **Inclusions (Non-Metallic or Foreign Material)**

    a. Definition: Unwanted materials such as slag, oxides, or impurities embedded in the metal.

    b. Appearance: Irregularly shaped discolorations or embedded particles on the surface.

    c. Locations: Found in weld metal or castings due to contamination during manufacturing.

    d. Impact: Weakens the integrity of the material and can act as a crack initiation point.

5. **Corrosion and Pitting**

    a. Definition: Surface deterioration due to oxidation or chemical reactions.

    b. Appearance: Rough, uneven patches with small holes or indentations.

    c. Locations: Found on surfaces exposed to harsh environmental conditions or improper maintenance.

    d. Impact: Can lead to material thinning, loss of mechanical strength, and eventual failure.

6. **Scratches and Mechanical Damage**

a. Definition: Minor surface abrasions caused by handling, machining, or external contact.

b. Appearance: Shallow grooves or marks that may not always affect the component’s function.

c. Locations: Found on machined parts, pipes, and sheet metal.

d. Impact: May cause cosmetic defects but rarely lead to structural failure unless severe.

Safety Protocols for Handling Test Objects

To ensure proper handling of NDT components, users must follow strict safety procedures to protect themselves and maintain test integrity. The VR system will reinforce the following best practices:

1. **Use of Personal Protective Equipment (PPE)**
    a. Gloves: Prevents contamination of test surfaces and protects against sharp edges.
    b. Safety Goggles: Shields the eyes from debris and chemical exposure.
    c. Lab Coats or Protective Clothing: Minimizes exposure to potential contaminants.
2. **Proper Handling Techniques**
    a. Users should lift test objects securely using both hands to distribute weight evenly.
    b. If handling fragile or sharp-edged objects, users must be instructed to use designated clamps or padded grips.
    c. Components must be placed on stable, non-slip surfaces before inspection begins.
3. **Avoiding Contamination**
    a. Hands must be free of oils, dirt, or chemicals to prevent surface contamination.
    b. The test piece should never be touched with bare hands after cleaning, as it can affect penetrant absorption.
4. **Environmental Considerations**

a. Inspection areas should be free from excessive dust, humidity, or external light sources that could interfere with defect visibility.

b. Temperature conditions must be within recommended ranges to ensure penetrant effectiveness.

5. **Recognizing Defects Without Touching**

   a. Users will learn to visually identify surface defects without unnecessary contact that could alter the surface condition before penetrant application.

   Implementation in the VR Experience

Interactive Defect Identification

The VR training session will present users with various test objects featuring randomized defects, requiring them to perform a visual examination before proceeding with penetrant testing. Users will be able to:

- Rotate and inspect the object in 360 degrees to locate visible cracks, porosity, and other surface defects.
- Use virtual flashlights or magnifiers to enhance defect visibility in low-light conditions.
- Compare defects to a reference chart that categorizes different flaw types based on size, shape, and depth.

Safety Instruction and Real-Time Feedback

- If a user attempts to touch a test piece without gloves, the VR system will issue a warning prompt and prevent further interaction until proper PPE is equipped.
- If a user handles the test object incorrectly (e.g., gripping a fragile area too tightly), haptic feedback will simulate resistance, and a virtual instructor will provide corrective guidance.
- If the user fails to recognize key defects, the system will highlight the missed areas and provide a review session before progressing to the penetrant application step.

Gamification and User Progress Tracking

- Users earn points based on their ability to correctly identify defects within a set time limit.

- If users incorrectly classify a defect, they will receive instant feedback and an opportunity to retry.
- A leaderboard (optional for training institutions) can track individual and group performance, allowing instructors to assess learning outcomes.

Expected Outcomes of the Initial Inspection Phase

Users develop a keen eye for identifying surface defects, improving accuracy in defect recognition.

Safe handling techniques are reinforced, reducing the risk of contamination or damage to test objects.

Users gain confidence in pre-inspection assessments, ensuring they enter the PT process with a clear understanding of what to expect.

Error rates decrease in later testing stages, as users become proficient in recognizing defect characteristics before applying penetrant materials.

5. Cleaning and Degreasing

Gaming	Users clean the object with sprays and clothes
Learning	Emphasizes surface preparation for PT
Intrinsic instruction	Teaches correct cleaning techniques

Information: Detail cleaning agents (e.g., solvent types), tools, and surface preparation standards.

Information to be Delivered in This Phase

Purpose of Cleaning in PT NDT

Before applying **penetrant materials**, the surface of the test object must be **completely free of contaminants** that could interfere with the capillary action of the penetrant. Proper cleaning ensures:

- Full penetration of the testing liquid into defects.
- Elimination of false indications caused by surface contamination.
- Compliance with industry standards, ensuring accurate and repeatable results.

Cleaning Agents and Solvent Types

Users will learn to differentiate between various cleaning agents and their appropriate applications:

1. **Solvent-Based Cleaners (Solvent Removable Method)**
    a. Purpose: Used to dissolve oils, greases, and organic contaminants from the surface.
    b. Examples: Acetone, isopropyl alcohol, MEK (Methyl Ethyl Ketone).
    c. Application: Applied using a lint-free cloth or spray bottle.
    d. Best Practices: Must be fully evaporated before penetrant application to avoid residue contamination.
2. **Aqueous (Water-Based) Cleaners**
    a. Purpose: Used when testing components that tolerate water-based cleaning.
    b. Examples: Mild detergents, alkaline-based solutions.
    c. Application: Applied via spray, immersion, or scrubbing with a soft brush.
    d. Best Practices: Requires thorough rinsing with clean water to ensure no detergent residues remain.
3. **Emulsifiers (For Post-Emulsifiable Penetrants)**
    a. Purpose: Used in cases where penetrants require controlled removal.
    b. Examples: Lipophilic and hydrophilic emulsifiers.
    c. Application: Applied as a thin, controlled layer, followed by a water rinse.
    d. Best Practices: Timing is critical—leaving emulsifier too long can remove penetrant from defects.

Tools for Cleaning and Degreasing

Users will interact with a range of **realistic virtual tools** that simulate industry-standard cleaning techniques:

- Lint-Free Cloths – Used for solvent wiping to ensure no lint or fibers contaminate the test surface.
- Solvent Spray Bottles – Allows controlled application of cleaning agents.

- Brushes and Scrub Pads – Used for mechanical cleaning when dealing with heavy contaminants.
- Compressed Air Nozzle – Removes residual moisture and dust particles after cleaning.
- Absorbent Paper Towels – Used in the final drying step.

Surface Preparation Standards and Best Practices

The cleaning process must meet strict **NDT preparation standards**, including:

- **ASTM E1417 / E1417M** – Standard Practice for Liquid Penetrant Testing, outlining best cleaning procedures.
- **ISO 3452-1** – Specifies penetrant testing techniques, including cleaning requirements.
- **Avoiding Overcleaning** – Aggressive cleaning can alter surface conditions, potentially masking defects.
- **Drying Before Testing** – Any moisture left on the test surface can prevent proper penetrant absorption.

Implementation in the VR Experience

Interactive Cleaning Simulation

The VR training session will simulate various contamination scenarios, requiring users to:

- Identify surface contamination (e.g., grease, oxidation, machining residue).
- Select the correct cleaning agent and tool based on material type and contaminant.
- Apply the cleaning agent correctly, ensuring full coverage without overuse.
- Inspect the surface post-cleaning, verifying no residue remains.

Step-by-Step Cleaning Process

1. Surface Contamination Detection – Users will be presented with a dirty test object, requiring visual inspection.
2. Selecting the Proper Cleaning Agent – A menu-based selection tool will allow users to choose from solvent, water-based, or emulsifier options.

3. Applying the Cleaner – Users will spray, wipe, or brush the test surface, receiving real-time feedback on their technique.
4. Drying the Surface – Users will ensure that no moisture or solvent residue remains before proceeding.

Real-Time Feedback and Gamification Elements

- System Prompts: If a user chooses the wrong cleaning method, the system will highlight the error and provide guidance.
- Haptic Feedback: VR controllers will simulate resistance and weight differences between tools.
- Scoring System: Users will be graded on speed, accuracy, and effectiveness of cleaning techniques.
- Penalty for Overcleaning: If a user scrubs too aggressively or applies excessive solvent, the simulation will display a warning and require adjustments.

Expected Outcomes of the Cleaning and Degreasing Phase

Users demonstrate proper cleaning techniques, ensuring a contaminant-free surface before penetrant application.

Users gain practical experience handling different cleaning agents and tools, improving decision-making skills.

Safety awareness is reinforced, ensuring proper handling of chemical solvents in real-world NDT scenarios.

Users become familiar with industry standards, ensuring compliance with professional testing regulations.

6. Air Drying

Gaming	Users use compressed air to dry the surface
Learning	Shows why drying is essential before PT
Intrinsic instruction	Demonstrates proper drying methods

Information: Specify compressed air pressure ranges and drying time standards for PT readiness.

In **Air Drying**, users learn to remove residual moisture and cleaning agents before the penetrant application. This phase underscores how **adequate drying** is crucial to achieving the **capillary action** needed for penetrant infiltration into surface defects. By mastering **proper compressed air usage** and following recommended drying time standards, trainees ensure that **false indications** are minimized and **accurate inspection results** are obtained.

Note: In certain real-world scenarios, **compressed air drying** may not be feasible if the testing location lacks sufficient air pressure or the necessary equipment. In such cases, **natural air drying** becomes the practical alternative, requiring a longer waiting period to ensure all moisture evaporates from the test surface before proceeding with the penetrant application. Although less efficient than using compressed air, natural air drying must still adhere to recommended standards and best practices, with trainees carefully monitoring environmental conditions—such as temperature and humidity—and verifying that the component is completely free of any visible moisture. This added time investment underscores the importance of planning and awareness in on-site NDT tasks, ensuring reliable defect detection even under resource-constrained conditions.

Why Drying is Essential in PT

1. **Preventing Moisture Interference**
    a. Even trace amounts of water or solvent on the surface can repel or dilute the penetrant, leading to **insufficient defect saturation** and potentially masking discontinuities.
    b. Any leftover liquid can form a barrier that **inhibits capillary action**, a core principle of penetrant testing.
2. **Enhancing Penetrant Adhesion**
    a. A **dry, contaminant-free surface** ensures that the penetrant fully wets the part, allowing deeper penetration into microcracks and pores.
    b. Properly dried components also reduce the risk of **emulsification or reaction** with residual cleaners.

Compressed Air Pressure Ranges

- **Typical Pressure Range**: 0,2–0,4 MPa (2–4 bar), balanced to avoid damaging sensitive materials or dislodging surface indications.

- **Caution Against Excessive Pressure**: Using air at **over 0,4 MPa** risks **blowing contaminant particles** deeper into minute cracks, or even deforming lightweight or thin-walled test components.

Drying Time Standards and Best Practices

1. **Recommended Drying Durations**
    a. **ASTM E1417 / E1417M** suggests verifying dryness through a **visual or timed approach**, typically **2–5 minutes** after last water or solvent contact.
    b. **ISO 3452-1** advises ensuring surfaces show **no visible moisture** or streaking before proceeding to the penetrant step.
2. **Material-Specific Considerations**
    a. **Porous Materials**: May require **longer drying times** to remove embedded moisture fully.
    b. **High-Temperature Alloys**: Heat retention can accelerate evaporation, reducing required drying durations but increasing the risk of flash evaporation.
3. **Ambient Environmental Factors**
    a. **Humidity** and **ambient temperature** significantly affect drying times, prompting additional checks or extended blow-drying periods in humid or cool environments.

Implementation in the VR Experience

Interactive Drying Process

Users encounter a just-cleaned test component still showing water droplets or solvent sheen. They must:

- Pick up a compressed air nozzle or attach an air hose in the virtual environment.
- Adjust air pressure via a dial or gauge, selecting appropriate psi or bar range to avoid damage.
- Direct airflow across the component's surface, visually monitoring moisture evaporation in real-time.

- Observe a dryness indicator: a subtle shading change or text overlay can appear as the surface becomes fully dry.

Real-Time Feedback and Safety Prompts

- Overpressure Warning: If users exceed recommended pressure levels, the system will issue an alert (e.g., "Pressure too high. Reduce to avoid damaging the surface.").
- Incomplete Drying Detection: If water streaks remain, an AI-driven instructor avatar can highlight these areas, instructing the user to apply air more thoroughly.
- Temperature and Humidity Simulations: Optional advanced settings can replicate environmental conditions, prompting longer drying times in humid or cold VR lab scenarios.

Timing and Verification

- The system may require a minimum drying interval (e.g., 2 minutes) before allowing the user to proceed, ensuring compliance with recognized standards.
- Visual or textual cues confirm dryness, or users can re-inspect with a UV or white light to check for residual moisture, tying into the earlier "Initial Inspection" step.

Expected Outcomes of the Air Drying Phase

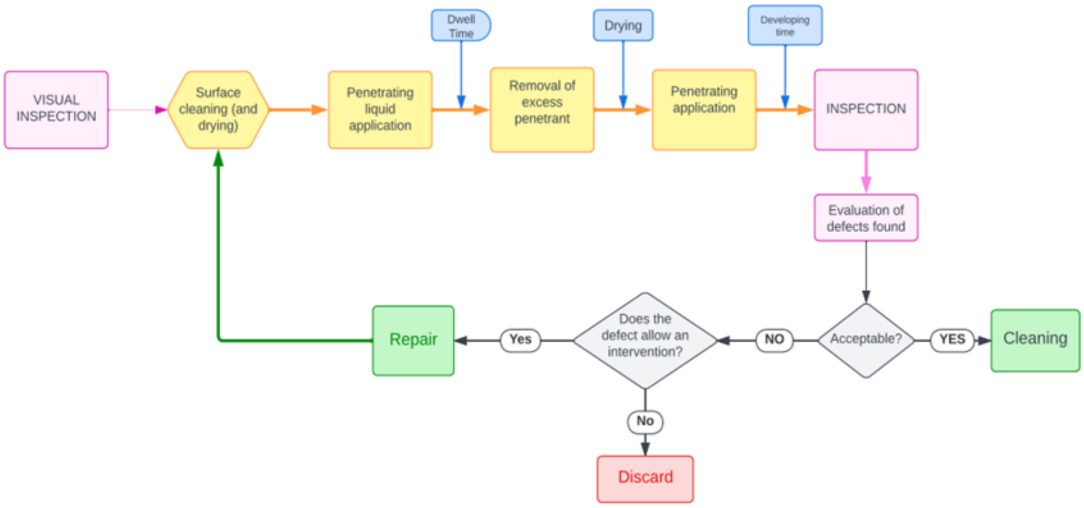
Users develop a practical sense of applying compressed air at safe yet effective pressures.

Trainees comprehend how incomplete drying undermines the subsequent penetrant step, reinforcing best practices for thorough preparation.

Industry standards and drying time recommendations become instinctive, ensuring that the VR training translates effectively into real-world PT scenarios.

Confidence in verifying dryness is established, reducing the risk of false indications and ensuring accurate penetration in the final steps of PT NDT.

Game sequences – IIS



7. Choosing Penetrant Liquid

Gaming	Users shall follow these steps: 1. Evaluate the Test Piece: Check the roughness and cleanliness of the piece. 2. Select the Appropriate Penetrant: Colored or Fluorescent Penetrants: o Consider the Roughness: Choose based on the roughness of the piece. if the roughness is high, there is no point in choosing a very sensitive control method such as Fluorescent. The result would be to observe possible spurious indications (false indications given by high roughness and high capillarity).  *Fig. 1 Sourface Roughness explained*

	o Sensitivity Required: Determine the sensitivity needed for the inspection (for example in terms of roughness). o Type of Component: For example, if inspecting an aerospace component, fluorescent penetrants may be required due to their higher sensitivity and ability to detect minimal defects (in general welded component are inspected by colored penetrant). 3. Review Technical Data: • Check the expiry date, brand (. must be the same for penetrator, developer and cleaner if used. Often these two types of control allow them to be removed by solvent or water.) 
Learning	In penetrant testing there are two primary methods: one using colored penetrants and the other using fluorescent penetrants. Both types are engineered to have low surface tension and excellent wetting properties, allowing them to seep into small surface discontinuities. However, they differ significantly in terms of detection and sensitivity: 1. Colored Penetrants a. Properties and Use: Colored penetrants are typically based on dyes such as aniline compounds, producing visible indications under white light. They are widely

	used in industrial applications where ambient lighting is sufficient for visual inspection. b. Influencing Parameters: i. Viscosity and Surface Tension: Must be low enough to promote capillary action without overfilling the flaws. ii. Temperature: Higher ambient or test piece temperatures reduce viscosity, potentially requiring a shorter dwell time, while lower temperatures demand a longer dwell time for optimal penetration. iii. Surface Roughness: A very smooth surface favors efficient penetration, whereas a rough surface may hinder the process or lead to false indications. c. Selection Criteria: When choosing a colored penetrant, it is essential to consider the type of piece (its geometry and material), the level of contamination, and the surface roughness. In addition, technical parameters such as the serial number, expiry date, and brand consistency (especially with the developer) are critical to ensure that the sensitivity is maintained as certified by the manufacturer. 2. Fluorescent Penetrants a. Properties and Use: Fluorescent penetrants contain fluorescent pigments that, when excited by ultraviolet (UV) light, emit a bright glow. This increased sensitivity makes them ideal for detecting very fine defects, which is particularly important in high-reliability sectors like aerospace, automotive, and precision engineering.

	b. Influencing Parameters: i. Sensitivity: Fluorescent penetrants are formulated for higher sensitivity, capable of revealing smaller discontinuities that might go undetected by colored penetrants. ii. Temperature and Material Considerations: Like colored penetrants, their performance is affected by temperature (affecting viscosity and drying time) and the surface characteristics of the test piece. iii. Application Techniques: The method of application (e.g., spraying from a specific distance) is crucial for obtaining a uniform layer that maximizes defect detection. c. Selection Criteria: As with colored penetrants, the choice of a fluorescent penetrant must take into account the roughness, type of material, and operating temperature. Moreover, to ensure the correct level of sensitivity, the penetrant must be used in conjunction with a developer from the same brand. Mismatching brands can lead to incompatibilities in chemical formulations, undermining the detection sensitivity. Technical Importance of Correct Selection: The performance of both colored and fluorescent penetrants is highly dependent on several parameters: • Surface Condition: The test piece must be pre-cleaned properly to remove contaminants (such as scale, rust, oil, grease, paint, and water) because any residue can impede the penetrant's ability to enter discontinuities.

	• Environmental and Material Factors: Ambient and test piece temperatures affect the fluidity and drying time of the penetrant. Material properties, including surface roughness and porosity, determine how easily the penetrant can access flaws. • Brand Consistency: It is critical that the penetrant and the developer are from the same manufacturer. This compatibility ensures that the chemical properties align perfectly, maintaining the level of sensitivity as per the manufacturer's certification. In summary, selecting the correct penetrant type—whether colored or fluorescent—requires a comprehensive evaluation of the test piece's characteristics (roughness, contamination, material, and geometry), environmental conditions (temperature), and strict adherence to technical specifications (serial number, expiry date, and brand consistency). This careful selection ensures that the penetrant testing method delivers reliable, reproducible results and meets the necessary safety and quality standards.
Intrinsic instruction	Guides appropriate selection by ensuring the user verifies surface conditions and technical data—such as expiration date and brand compatibility etc.—since mismatched products (penetrant and developer from different brands) compromise sensitivity.

Information: Describe penetrant types (colored vs. fluorescent), their properties, and use cases. Technical description and importance of serial number and date.

8. Applying the Penetrant

Gaming	Users apply the penetrant using a spray can held no more than 20 cm from the test piece. In this context, the spray technique uses pressure and the type of nozzle to atomise the liquid, thus ensuring uniform distribution. It is essential to achieve an optimal coverage thickness: thin enough to penetrate into the discontinuities, but not so thick as to hinder removal of the excess. Application tools, such as the spray canister equipped

	with mixing and pressure control valves, play an essential role in replicating the correct movement and ensuring that the entire weld and adjacent areas are evenly covered. (we speak of micrometre thickness of the penetrant)  *Fig. 2 PT - Spray application*  *Fig. 3 correct application*
Learning	Training sessions demonstrate correct application techniques, illustrating the importance of the right spraying distance, constant movement and even distribution. Visual aids and photos highlight how the spraying technique should produce a penetrating film with the appropriate thickness, avoiding both under- and over-application. In addition, application tools are shown to control the pressure and mixing of the liquid, key aspects in achieving an ideal coverage thickness.
Intrinsic instruction	Inherent instruction guarantees homogenous coverage through real-time feedback, ensuring that all discontinuities receive an adequate amount of penetrant. This approach utilises monitoring systems built into the application tools, which allow

	for instant verification of the thickness of the applied film and adjustment of the spraying technique to maintain optimum coverage thickness across the entire surface, thus improving inspection effectiveness.

Information: Define spray techniques, coverage thickness, and application tools. Use photos.

9. Dwell Time

Gaming	At room temperature (around 20°C), a red penetrant generally requires a penetration time (dwell time) of between 5 and 10 minutes. However, in the context of the game, the penetration time could be presented as a choice: for example, selecting 15 minutes yields an ideal result, while 10 minutes yields insufficient penetration of the liquid and thus insufficient indications, over 20 minutes, on the other hand, the penetrant risks drying out. Furthermore, the influence of the ambient temperature is crucial: if it is above 23°C, the time required can be reduced, while if it is lower, the dwell time must be extended. For example, at 5°C the penetration process slows down (due to higher viscosity), taking up to twice as long (approximately 10-20 minutes), whereas at 60°C, due to lower viscosity, the time can be reduced to 3-5 minutes.
Learning	Reinforces the importance of allowing the penetrant to remain on the surface long enough for complete infiltration, while adjusting the dwell time based on ambient temperature (e.g., high temperature accelerates drying, requiring a shorter dwell time, and vice versa).
Intrinsic instruction	Instructs users to select the recommended dwell time considering both the penetrant's properties and ambient temperature, ensuring optimal defect detection without premature drying or insufficient penetration.

Information: Provide standard dwell time ranges (e.g., 5-30 minutes) based on penetrant type and material.

10. Initial Penetrant Cleaning

Gaming	In the 'Gaming' mode for cleaning excess penetrant, the user can choose between two options: cleaning with water or solvent. Here are step-by-step instructions for both methods: Cleaning with Water • Preparation: Ensure that the test piece is placed in a well-lit area and that you have a hose with low pressure water available (use a controlled jet). • Identification of areas: Identify the coloured area (indicative of defects) where the penetrant has penetrated into the discontinuities. Take care not to spray directly onto this area. • Controlled rinsing: Position the hose in such a way as to spray the water on the excess areas, avoiding directly hitting the areas marked with the penetrant. The aim is to remove the excess without 'washing away' the penetrant that has infiltrated the defects. • Visual check: After rinsing, look carefully at the surface to make sure that the excess has been removed, but that the markings (the red colour) remain intact in the discontinuities (this is not always verifiable... if the markings are very deep or otherwise small, you may not see the red right away). • Drying: Let the surface dry naturally or use a low-pressure air jet (or a dry, non-abrasive cloth) to remove residual moisture. Cleaning with Solvent • Cloth preparation:

	Take a non-abrasive, lint-free cloth (e.g. microfibre). Start by applying a small amount of approved solvent (such as Velnet/Solnet) directly on the cloth, not on the test piece. • Gentle cleaning: With light, steady movements, wipe the cloth over the surface of the test piece, taking special care not to rub directly on the coloured area containing the penetrant in the defects. The aim is to remove only excess penetrant. • Verification: After cleaning, examine the surface to ensure that the critical areas retain the penetrant in the discontinuities while the excess has been removed (again, you may not always see the critical areas). • Drying: If necessary, wipe with a dry cloth or use low-pressure compressed air to accelerate drying while avoiding disturbing residual indications. Note: In both cases, the user must act cautiously so as not to remove penetrant from the discontinuities (the indications), but only the excess. This balance is essential to obtain correct results in non-destructive testing, as also indicated in the CND (Non-Destructive Testing) manuals. These instructions make it possible to simulate, in the game, a realistic operation in which the choice and execution of cleaning (with water or solvent) influence the final result of the inspection.

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Fig. 4 Clean with water

Fig. 5 Clean with cleaner- The solvent should be sprayed onto the cloth, which once soaked should be used to clean the surface
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<td>Learning</td>
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Among the approved cleaners and cleaning methods for removing excess penetrant without removing penetrant from within the defects, the following are recommended:

Approved cleaners:

- Velnet/Solnet: A solvent/degreaser specifically for CND controls, widely used for preliminary and final cleaning. It is designed to remove excess penetrant while keeping it stable within the discontinuities.
- Controlled water: Use a low-pressure rinse (not exceeding approx. 280 kPa) at a moderate temperature, possibly supplemented with a mild detergent (Detergent H_2O) to remove residues and contaminants, but without attacking the established penetrant in the flaws.

Cleaning/wiping methods
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	• Gentle wiping: Proceed by dabbing or light wiping using non-abrasive, lint-free cloths (e.g. microfibre or woven fabrics made of non-stretching material). This technique avoids excessive removal of penetrant from cracks. • Use of compressed air: After rinsing, compressed air (low pressure and controlled temperature, e.g. not exceeding 50°C) can be used to aid drying without the use of abrasive methods. • Avoid intense scrubbing: It is essential not to use abrasive sponges or aggressive mechanical methods that can remove penetrant from discontinuities. These approaches, adopted in accordance with standards (e.g. UNI EN ISO 3452-1/2 and ASTM E165), ensure effective removal of excess penetrant, while keeping surface defects intact.
Intrinsic instruction	It provides feedback on the correct cleaning methods so that only the excess is removed, preserving the penetrant within the defects for accurate detection. The system could observe whether the user performs the correct cleaning of the part and then, once the simulation is complete, provide indications of what went wrong with the cleaning: direct jet on the weld, solvent applied directly on the part, etc.

Information: List approved cleaners and wiping methods to remove excess penetrant without over-cleaning. Use photos.

11. Final Wipe

Gaming	Users use a dry cloth to perform a final cleaning on the test piece, removing all moisture and any excess penetrant. This step is very important because if any moisture or penetrant remains on the workpiece, there may be a problem identifying the indications. The developer, if agglomerated, does not allow the normal release of penetrant from the flaws.

	
Learning	Emphasize that proper drying is crucial, as any residual moisture could cause the developer to agglomerate and compromise the inspection. Ensure thorough removal of any residual penetrant and moisture that might interfere with the subsequent developer application, using visual examples and step-by-step photos.
Intrinsic instruction	Highlights the impact of improper cleaning  *Fig. 6 Wrong surface cleaning condition. The developer was applied on a surface still covered with red penetrant.*

Information: Specify final wipe standards and procedure to ensure no residue interferes with developer application. Use photos.

12. Applying Developer

Gaming	In the game, users apply the developer from about 30 cm away, performing a controlled gesture that deposits an even layer on the test piece. At this stage, the player must choose the appropriate type of developer according to the situation:

- Dry Powder: this is ‘dusted’ onto the workpiece to create a light film that draws the penetrant from discontinuities. It is important to avoid an application that is too concentrated, which can lead to agglomeration, or too dispersed, resulting in insufficient coverage.

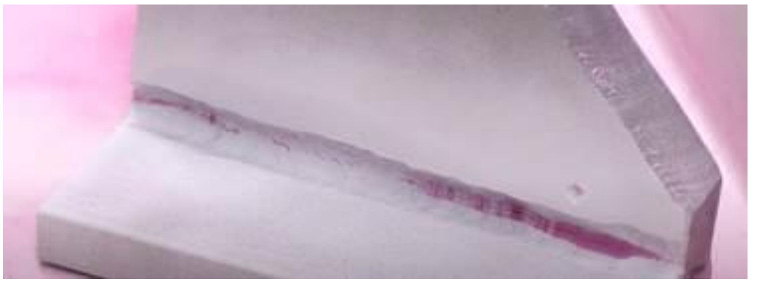
Fig. 7Dry powder application

- Wet Developer (aqueous solution): is sprayed in a controlled manner to form a liquid film that, when dry, highlights the residual penetrant.

Fig. 8 Spray

- Non-Aqueous Developer (solvent) (not suggested for inclusion in the simulation): used in situations where the use of water could interfere with the test; requires careful application so as not to alter the chemical reaction of the penetrant.

The game emphasises the importance of using a developer of the same brand as the penetrant, to ensure chemical compatibility and maintain the certified sensitivity level. In addition, the game emphasises that each batch of developer is identified by a serial number and a production date, information

	that is crucial for traceability and compliance with regulatory requirements.  *Fig. 9 what the result should be*
Learning	The 'Learning' mode visually demonstrates - through pictures and diagrams - the correct methods of applying developer, illustrating the differences between: • Dry Powder: generally applied by the 'dusting' method, which allows a controlled amount of powder to be distributed. • Wet Developer (aqueous solution): applied by spraying to obtain a uniform liquid film that, once dry, highlights the penetrant in discontinuities. • Non-Aqueous Developer (solvent): used in specific cases where water could compromise the test, requiring an application technique similar to spraying but with attention to the effects of the solvent. The pictures illustrate how incorrect deposition (too thick or too thin) can compromise the optimal absorption of the penetrant, reducing the visibility of defects. In addition, the meaning of the serial number and date on the product are explained in detail: this information is essential for verifying the origin, regulatory compliance (e.g. UNI EN ISO 3452) and validity (shelf-life) of the product.
Intrinsic instruction	In this mode, instructions guide the user step by step to achieve a uniform and correctly applied developer layer, which is essential for optimal interaction with the penetrant and visibility of discontinuities. The user is instructed to:

	• Choose the most suitable application method (spray for liquids or dust for powders) and to maintain the recommended distance (about 30 cm) to avoid problems of agglomeration or insufficient coverage. • Apply the product evenly, taking care that the layer is neither too thick (which could prevent adequate absorption of the penetrant) nor too thin (which could result in incomplete coverage). • Use a developer of the same brand as the penetrant to ensure chemical compatibility and achieve certified sensitivity levels. • Record and verify the serial number and date of manufacture, which are crucial for traceability and to ensure that the product has not expired or does not meet the required technical standards.

Information: Detail developer types (dry powder, wet, non-aqueous) and application methods (spray, dust). Technical description and importance of serial number and date.

Game sequences - IPUNTO

13. Developer Dwell Time

Gaming	The timer tracks the developer's dwell time. Users must observe regular and periodic intervals throughout the development time to monitor the appearance of indications. Over time, users can appreciate how the indications emerge during the development process.
Learning	Reinforces time-based defect development Indications appear before or after the developer is applied depending on the size and type of discontinuities. Generally, open and deep discontinuities will generate large and bright indications that appear at the beginning of the

	development time (big cracks, lack of fusion or penetration, surface pores), while closed and fine discontinuities will generate small and/or intermittent indications, appearing after longer development time (small and close cracks).
Intrinsic instruction	Users monitor and adjust dwell time

Information: Provide dwell time guidelines (e.g., 10-60 minutes) based on developer type and defect size. Add photos of before and after and also for excess dwell time as a negative example

Information to be delivered in this phase

Development time begins once the developer has dried.

For dry developer, it begins as soon as it is applied.

For aqueous wet developer, development time starts once it dries. This drying takes several minutes (an oven is used to accelerate drying, taking around 15-30 minutes), as it is the longest drying process among the three types of developers.

For non-aqueous wet developer (solvent-based), which is the most commonly used in "in-situ" work, it only takes a few seconds since the solvent evaporates quickly.

The minimum development time for any type of developer, according to ISO 3452-1, is 10 minutes. There is no maximum time specified in the latest standard (the previous revision limited the maximum development time to 30 minutes), so the maximum time limit is determined by experience.

Open and deep indications require short developer time (between 10 and 15 minutes).

Closed and fine indications require longer developer time (between 15 and 30 minutes).

Development times below the lower limit will make it difficult to detect fine and shallow discontinuities.

Excessive development times will produce larger indications than expected, as penetrant liquid indications will become much larger over time than the discontinuities that caused them, making them less representative. This effect is more pronounced with larger discontinuities.

Implementation in VR Experience

Users must be able to observe when wet developers dry (aqueous wet developers take longer, while non-aqueous solvent-based ones dry in just a few seconds).

Once the dry developer is applied or the wet developers dry, development time will begin. Users will see a clock to monitor development time, and as time progresses, different indications will appear.

It should be evident that large, open, and deep indications will appear immediately and will gradually grow and become brighter.

Conversely, closed and fine indications will appear at the end of the stipulated development time (e.g., after 15 minutes). These will be seen as finer marks and may be intermittent.

Real-Time Feedback and Gamification Elements

System Indications: If a user proceeds to the next phase (Indication Observation) without allowing the minimum development time (10 minutes), the system will highlight the error and warn about the consequences (failure to detect small, closed, and/or fine indications). If the development time exceeds 30 minutes, large and/or open indications will appear less bright and larger, no longer being representative of the discontinuity.

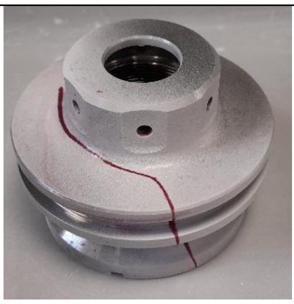
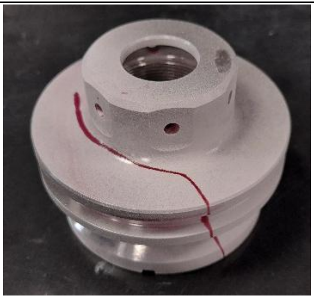
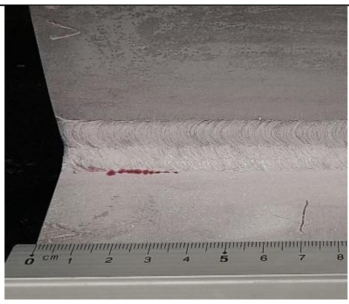
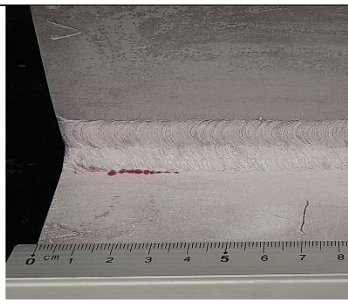
Scoring System: Users will be penalized in scoring if they do not meet the minimum development time. If they comply (between 10 and 30 minutes), they will be scored appropriately based on accuracy. If they exceed the time, they will be penalized less than if they fall short.

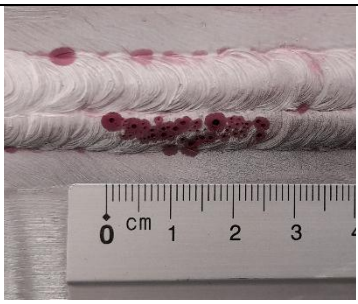
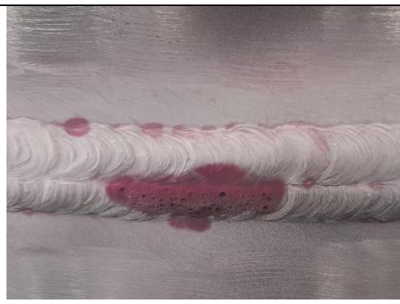
Expected Results of the Development Time Phase

Users demonstrate knowledge of minimum and optimal development times according to the size of the sought discontinuities.

Additionally, they understand when development time begins, depending on the type of developer used.

Images

Open and Deep Discontinuity		
		
Open and deep discontinuity just apply the developer, make an indication who appears soon, clear and bright (0 mins developer time)	Open and deep discontinuity in correct developer dwell time, make a indication representative of the discontinuity (10 mins developer time)	Open and deep discontinuity in excessive developer time, make a indication not clear and not representative of the discontinuity (20 mins developer time)
Closed and Small Discontinuity		
		
Cosed and small discontinuities just apply the developer, make an indication who dosen´t appear soon. (0 mins developer time)	Cosed and small discontinuities in correct developer dwell time, make an indication representative of the discontinuity (20 mins developer time)	Cosed and small discontinuities are not affected by excessive development time (30 mins developer time)
Rounded and Grouped Discontinuity (Surface pores)		

		
Rounded and grouped discontinuities just apply the developer, make an indication who appears soon, clear and bright (0 mins developer time)	Rounded and grouped discontinuities in correct developer dwell time, make an indication representative of the discontinuity (10 mins developer time)	Rounded and grouped discontinuities, make an indication less bright but it is representative of the discontinuity and not affected by excessive development time (30 mins developer time)

14. White Light and UV Observation

Gaming	Users inspect under white or UV light. Depending on the type of penetrant used, the user must illuminate the part with the appropriate light type: white light for visible penetrants and UV light in darkness for fluorescent penetrants.
Learning	Teaches for correct defect detection. Without proper illumination, it will not be possible to locate all defects.
Intrinsic instruction	Demonstrates how to switch between light modes. Guidelines on minimum values according to international standards (ISO 3059) and instructions from different international standards for proper and uniform illumination.

Information: Define light intensity requirements (e.g., 1000 μW/cm² for UV) and inspection conditions.

Information to be delivered in this phase

Observation conditions according to ISO 3059:

- **For visible penetrants**, a minimum of 500 lux of white light.

In some cases, a minimum of 1000 lux may be required.

Avoid inspector glare by preventing direct light exposure to the eyes.

Illumination must be uniform. Avoid glare and reflections. In LED lamps, a single defective LED can cause uneven illumination.

- **For fluorescent penetrants**, a minimum of 1000 μW/cm² UV-A light and a maximum of 20 lux white light are required.

The UV-A lamp's wavelength must be 365 nm ± 5 nm.

The test surface must receive uniform radiation. A single LED can generate uneven irradiation.

Depending on the lamp type, preheating may be required (e.g., mercury lamps require at least 10 minutes of preheating).

Tinted glasses that darken under test conditions should not be used.

Vision adaptation is necessary (at least 1 minute) when transitioning between dark and light areas and vice versa to conduct proper observations.

Implementation in VR Experience

Users must be able to choose the necessary lighting equipment or have it provided by the scenario (natural light, artificial room lighting, directional light (white light flashlight if conditions are not met), UV lamp, darkroom setup for observing fluorescent pigments).

They should be able to direct the light towards the area of interest.

Real-Time Feedback and Gamification Elements

- **System Indications:** Correction if the user begins observation with an inappropriate lamp or incorrect lighting levels.

For fluorescents, correction if preheating is not performed and if the user does not allow time for their eyes to adapt.

- **Haptic Feedback:** Users can experience glare effects if they shine the lamp directly into their eyes or when transitioning between a darkroom and a brightly lit room, and vice versa.

- **Scoring System:** A small quiz on the mandatory values according to standards, scored based on accuracy in identifying different values and their units.

Expected Results of the Indication Observation Phase

Users will learn the minimum parameters required for lighting conditions and the detrimental effects of improper use of different lamps.

15. Indication Evaluation

Gaming	Users interact with indicators showing indication. Users must be able to characterize indications (identify the type and measure them).
Learning	Reinforces indication recognition skills
Intrinsic instruction	Users categorize indications as relevant or non-relevant, or false.

*Information: List defect types (e.g., cracks, laps, inclusions) with NDT terminology, dimensions, and acceptance standards (**EN ISO 23277:2015** - Non-destructive testing of welds - Penetrant testing - Acceptance levels. **EN ISO 3452-1:2021** - Non-destructive testing - Penetrant testing. **EN 10228-2** for forgings or **EN 1371-1** for castings). Use photos / graphic representation of various types of defects.*

Information to be delivered in this phase

According to various standards, users must understand indication classification, proximity criteria, recording limits, and acceptance limits of these indications.

Evaluation Criteria according to ISO 23277:2015 - Welded Joints

- **Indication Classification:**
  - **Elongated Indication:** An indication whose length is greater than three times its width.

Examples: cracks, lack of fusion, lack of penetration, aligned pore clusters.

  - **Non-Elongated Indication:** An indication whose length is less than or equal to three times its width.

Examples: an isolated pore, grouped indications that meet the above criteria (scattered pore clusters, weld cracks, etc.).

- **Proximity Criteria:**

Indications that are approximately aligned and separated by less than the length of the smallest indication should be considered a single continuous indication.

- **Recording Criteria:**

Only indications deemed rejectable will be recorded.

- **Acceptance Levels for Indications:**

According to ISO 23277:2015, indications will be acceptable based on the following table:

Indication Type	Acceptance Level **(Note)**		
	1	2	3
Elongated indication l=indication length	l ≤ 2 mm	l ≤ 4 mm	l ≤ 8 mm
Non-Elongated Indication d=major axis dimension	d ≤ 4 mm	d ≤ 6 mm	d ≤ mm
(Note) Acceptance levels 2 and 3 may be specified with a suffix "X," indicating that all detected elongated indications must be evaluated according to level 1.			

Evaluation Criteria according to ISO 10228-2:2016 - Forged Steel Parts

- **Indication Classification:**
  - **Isolated Linear Indication:** An indication whose length is greater than three times its width and is separated from another indication by more than five times the length of the longest of the two indications.

Examples: cracks, folds, seams.

  - **Grouped Linear Indications:** Two or more aligned indications that must be considered as one single indication if the distance between them is less than or equal to five times the length of the longest of the two indications considered.

Examples: aligned cracks, folds, or seams.

- **Rounded Indication:** An indication whose length is less than or equal to three times its width.

Examples: an isolated pore, grouped indications that meet the above criteria (scattered pore clusters, weld cracks, etc.).

- **Recording Criteria and Acceptance Levels for Indications:**

According to EN 10228-2:2016, indications will be acceptable based on the following table:

Parameters	Acceptance Level (Note)			
	1	2	3	4
Recording Level (mm)	≥ 7	≥ 3	≥ 3	≥ 1
Maximum Allowable Length L of Isolated Linear Indications and Maximum Allowable Length Lg of Grouped Indications	≤ 20 mm	≤ 8 mm	≤ 4 mm	≤ 1 mm
Maximum Allowable Accumulated Length of Linear Indications on the Reference Surface (A6=148 mm x 105 mm)	≤ 75 mm	≤ 36 mm	≤ 24 mm	≤ 5 mm
Maximum Allowable Size of Isolated Rounded Indications	≤ 30 mm	≤ 12 mm	≤ 8 mm	≤ 3 mm
Maximum Allowable Number of Indications on the Reference Surface	15	10	7	5
(Note) Acceptance levels 2 and 3 may be specified with a suffix "X," indicating that all detected elongated indications must be evaluated according to level 1.				

Evaluation Criteria according to EN 1371-1:2012 - Cast Parts

- **Indication Classification:**

Considering the following: L = Length; W = Width; P = Penetrant Liquid

- **Isolated Linear Indication (LP):** An indication where L > 3W.

Examples: cracks, cold shuts.

- **Non-Linear Indication:** An indication where L ≤ 3W.
    - **Isolated (SP):** Example: a pore.
    - **Grouped (CP):** A zone of multiple indications where the distance between them is not measurable (can be considered a single indication).

Example: pore clusters, grouped cracks.

- **Aligned Indication (AP):**
    - Linear: The distance between two indications is less than the length of the largest discontinuity.
    - Non-Linear: The distance between two indications is less than 2 mm, with at least three indications present.
- **Recording Criteria and Acceptance Levels for Indications:**

According to EN 1371-2:2012, indications will be recorded and acceptable based on the following tables:

Parameters	**PT Severity Levels** **Non-Linear (SP) or Grouped (CP) Indications**							
	SP 01 CP01	SP 02 CP02	SP 03 CP03	SP 1 CP 1	SP 2 CP 2	SP 3 CP 3	SP 4	SP 5
Recording Level (mm)	0,3	0,5	1	1,5	2	3	5	5
Maximum Number of Allowable Non-Linear Indications	5	6	7	8	8	12	20	32
Maximum Allowable Size of Isolated Indications (SP)	1	1	1,5	3	6	9	14	32
Grouped Indications (CP)	3	4	6	10	16	25	-	-

Parameters	PT Severity Levels Linear (LP) or Grouped (AP) Indications								
	LP 001 AP001	LP 01 AP01	LP 1 AP 1	LP 2 AP 2	LP 3 AP 3	LP 4 AP 4	LP 5 AP 5	LP 6 AP 6	LP 7 AP 7
Recording Level (mm)	None	0,3	1,5	2	3	5	5	5	5
Maximum Allowable Length of Isolated (LP) and (AP) Indications (mm)	None	1	2	4	6	10	18	25	45
Maximum Allowable Length of Grouped (LP) and (AP) Indications (mm)	None	1	4	6	10	18	25	45	70

Implementation in the VR Experience

Users should have sufficient tools to observe different indications from all angles, characterize them, measure their dimensions, and position them from a given origin. They should be able to view indications in detail and measure both their width and length to classify them as linear or non-linear. Once the indication has been dimensioned and characterized, the user can perform an evaluation (acceptable or unacceptable) based on the applicable standard.

Real-time Feedback and Gamification Elements

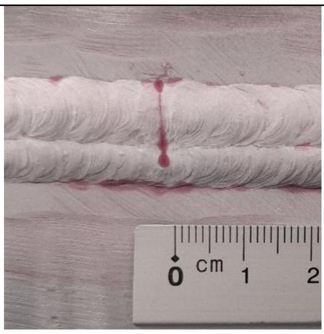
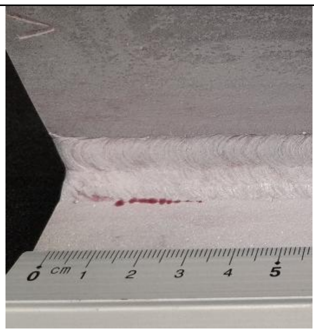
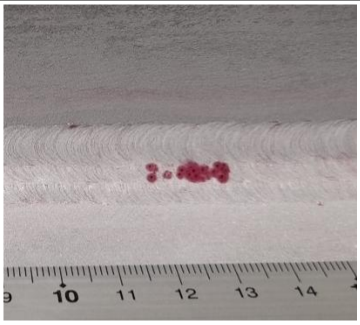
- **System indications:** When approaching an indication, its dimensions should appear for registration. An option will appear for the user to classify it as linear or non-linear, providing correction if the classification is incorrect.
- **Scoring system:** Based on the measurements obtained throughout the inspection process, users will be scored by the percentage of accuracy compared to pre-established solutions. Points will be awarded for correct

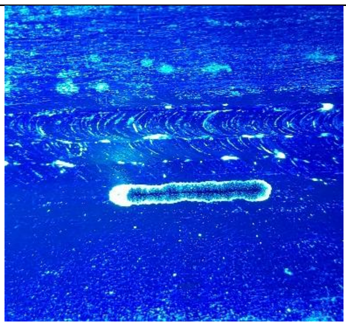
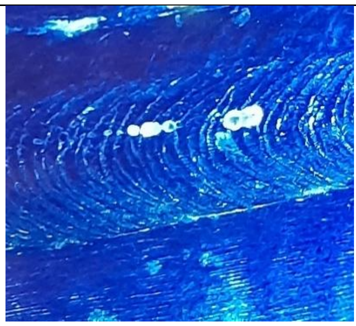
characterization and the correct classification of acceptability based on standards.

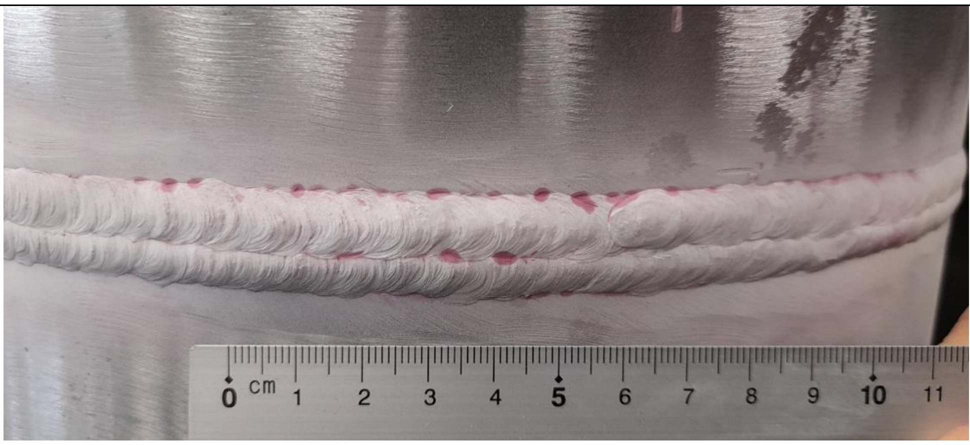
Expected Outcomes of the Indication Evaluation Phase

Users will learn to manage different PT-related standards, classify indications according to each standard, and, by measuring the dimensions of indications, evaluate and determine whether the indications found are acceptable or rejectable (defects).

They will also learn to distinguish between false or non-relevant indications and relevant ones.

Relevant Indication Classification (Dye Penetrant)		
		
Linear indication. Open Transversal Crack on weld	Intermittent linear indication. Closed Crack in ZAT	Rounded and grouped indication. Surface pores on weld

Relevant Indication Classification (Fluorescent Penetrant)		
		
Linear indication. Open Longitudinal Crack on HAT.	Intermittent linear indication. Closed Crack on Weld.	Grouped lineal indication. Lineal Surface Pores on weld.

Non-relevant or false indications

Round, non-bright indications between weld and base material or between weld bead passes. Poor cleaning of excess penetrant

16. Developer Removal

Gaming	Users remove excess developers to finalize results. With the help of cloths and solvents, or more sophisticated techniques such as compressed air, users will remove residual waste left from the penetrant liquid test.
Learning	Demonstrates the importance of proper removal. Incomplete removal can negatively impact subsequent processes or the lifespan of the piece.
Intrinsic instruction	Guides correct removal techniques

Information: Specify removal techniques (e.g., solvent wipe, air blast) and tools to avoid contamination.

Information to be provided in this phase

The cleaning of developer residues is performed using a cloth. If using dry developer, compressed air can also be used with an air gun. This cleaning should be carried out in well-ventilated areas or with forced air extraction to avoid dust clouds.

Implementation in the VR Experience Users should be able to choose between using a cloth or an air gun for developer removal. The mode of use will be similar to previous sections.

Real-time Feedback and Gamification Elements

- **System indications:** A cloth will provide better results for wet developers (aqueous or solvent-based) than compressed air. For dry developer, both techniques are equally effective. This will be reflected in the cleaning operation taking longer if compressed air is used to remove wet developers (aqueous or non-aqueous).
- **Haptic feedback:** More dust will be generated when using the air gun.

Expected Outcomes of the Developer Removal Phase

Users should understand that the best way to remove the developer is with a cloth in a well-ventilated area or with adequate extraction.

17. Final Cleaning and Protection

Gaming	Users clean the surface to complete the PT
Learning	Highlights the importance of post-inspection cleaning
Intrinsic instruction	Guides users through final cleaning procedures

Information: Detail post-inspection cleaning agents and methods to restore the surface.

Information to be provided in this phase

Final cleaning of PT residues is performed when penetrant products could interfere with subsequent processes, further tests, or service requirements. Special care should be taken if the piece is intended for O2 storage companies or industries related to rocket peroxide.

It is usually done as a routine operation, but it is only necessary in the cases mentioned above.

Cleaning is typically performed with a cloth to remove developer residues and with the direct application of solvent on the piece to remove any remaining penetrant in crevices more effectively.

The products used should always be compatible with the element being removed and the piece itself to prevent damage.

If using dry developer, compressed air with an air gun can also be used.

If the piece originally had an anti-corrosion protective layer, it should be reapplied using a cloth.

Implementation in the VR Experience

Users can pick up different tools for final cleaning, such as cloths, solvents, and penetrant residue removers.

They can use them as in previous steps.

Residue from penetrant products will be visible to indicate insufficient cleaning.

Real-time Feedback and Gamification Elements

- **System indications:** In scenarios where thorough cleaning of penetrant residues is required, users will be corrected if they do not perform adequate cleaning.
- **Haptic feedback:** Residue will be visible before this step and will gradually disappear the longer the user spends on final cleaning.
- **Scoring system:** The quality of the cleaning will determine the score. If proper cleaning is required but not performed, the user will be penalized. Even if cleaning is not mandatory, performing it will always be rewarded.

Expected Outcomes of the Final Cleaning and Protection Phase

Users should understand when it is mandatory to clean PT residues and the different ways to do so. Users should develop the habit of cleaning such residues as a routine operation within the PT method. Users should know that any protective layer removed for inspection purposes must be restored.

18. End and Replay Option

Gaming	Users complete the training or replay. Users will have the option to repeat any phase they wish, with a recommendation to retry those where their score was below 70%.
Learning	Allows repetition for better retention

Intrinsic instruction	Users can refine skills through practice.

Information: Provide performance metrics (e.g., accuracy, time) and replay benefits for skill mastery.

Implementation in the VR Experience

Once users complete the test, a screen will display all phases and their scores. Phases scoring 70% or higher will be marked in green, while those scoring below 70% will be marked in red with a message stating, "It is recommended to repeat this phase."

Users can access each score and see a breakdown of "points obtained/total points" for each scorable action within that phase.

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