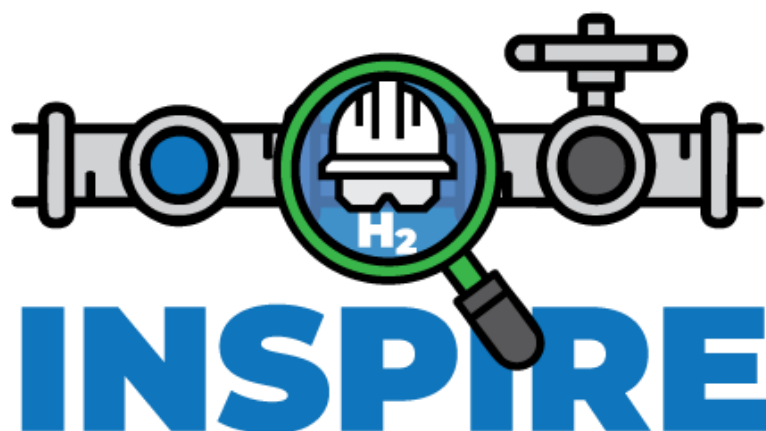




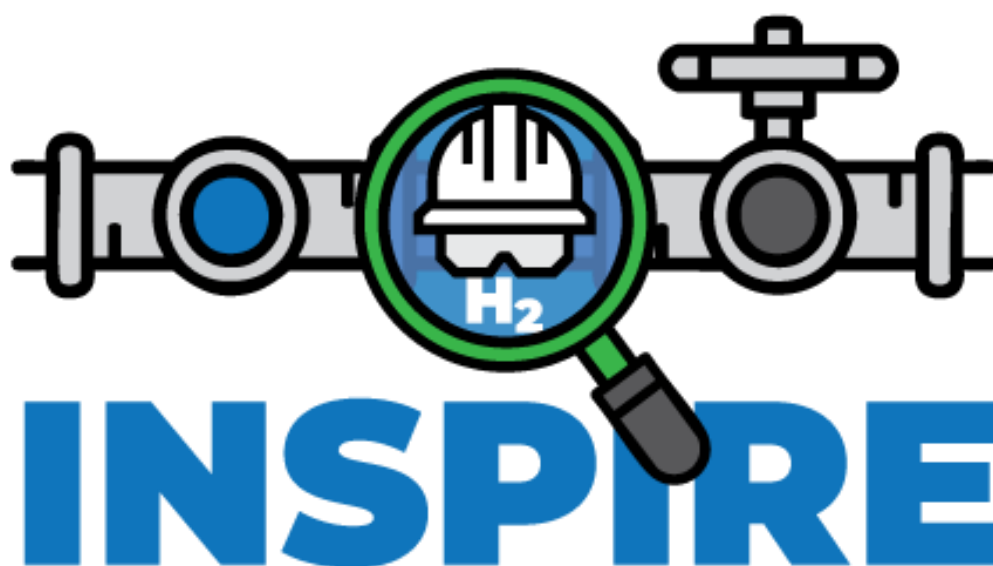
Guide for the Implementation of AR-Based Training in VET Centres

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INDEX OF THE DOCUMENT

1. Introduction	4
Purpose of the Guide.....	4
Welding Inspection Learners and Trainees.....	4
Scope and technology neutrality	5
2. AR in Vocational Education and Training	7
2.1 Definitions and Key Concepts.....	7
2.2 Benefits and Opportunities in Welding Inspection Training	9
2.3 Challenges and Barriers	10
3. Technical Requirements for Implementation	12
3.1 Hardware Options	12
3.1.1 AR/MR headsets with spatial AR	12
3.1.2 Assisted Reality headsets	13
3.1.3 Mobile devices/tablets.....	15
3.1.4 Desktop PCs / Laptops / cloud compute	16
3.1.5 Why the Hardware Layer Matters	16
3.1.6 Choosing hardware: functional requirements to procure against.....	17
3.2 Software Platforms.....	18
3.3 Infrastructure Needs	20
3.4 Data Protection and GDPR Compliance.....	21
3.5 Health, Safety and Ergonomics of Head-Mounted Devices	22
3.6 Accessibility, Inclusion and Equivalent Alternatives	24
4. Pedagogical Integration	25
4.1 Curriculum Alignment and Theoretical Knowledge Delivery	25
4.2 AR for Practical and Simulation-Based Training	26
4.3 Assessment and Validation Using AR Tools.....	28
4.4 Enhancing Learner Engagement and Attractiveness of VET	29
4.5 Preparing Trainers	30
5. Implementation Roadmap and Institutional Readiness	31
5.1 Phase 1 – Diagnosis and Institutional Planning	31
5.2 Phase 2 – Pilot Implementation	32
5.3 Phase 3 – Scaling and Integration	32
5.4 Continuous Quality Assurance and Evaluation	33
5.5 Institutional Readiness and Sustainability.....	34
5.6 Cost, Procurement and Continuity	34
6. Conclusion	36



References.....	37
Annex A – Implementation Checklist.....	38



1. Introduction

Purpose of the Guide

This guide supports the integration of Augmented Reality (AR) technologies into Vocational Education and Training (VET), drawing on their application within the European Welding Inspector (EWI) qualification and focusing particularly on hydrogen pipeline inspection.

It provides a practical roadmap for VET centres, trainers, and learners to adopt AR-based training tools in a structured, safe, and pedagogically robust way. The guide aims to help VET institutions move towards digitally enhanced learning environments that strengthen learners' engagement and accuracy in inspection practices.

AR technologies can improve the visualisation of complex welding inspection scenarios, support more consistent decision-making, and help reduce material use and waste during training. This way, AR supports both digital transformation and sustainability goals within the VET ecosystem.

Welding Inspection Learners and Trainees

To support initial training, upskilling and reskilling through simulated inspection environments based on real-world hydrogen pipeline conditions.

VET Centres – to assist institutional leaders and curriculum coordinators in planning the integration of AR tools into welding inspection programmes.

Trainers and Instructors – to provide practical approaches for implementing AR learning experiences, aligned with competence-based learning outcomes and assessment practices.

Welding Inspectors and Trainees – to familiarise learners with virtual inspection environments that simulate real-world conditions in hydrogen pipeline projects.



The scope of this guide includes the technical, pedagogical, and organisational dimensions required to introduce AR training tools effectively into welding inspection programmes.

Scope and technology neutrality

Although the guide focuses primarily on AR, several elements of the implementation approach, including readiness assessment, curriculum mapping, piloting, evaluation and scaling, may also be adapted to VR and MR. Technology-specific requirements should nevertheless be assessed separately.

This guide is deliberately technology-neutral. Devices, platforms and suppliers are named only as examples available at the time of writing, and no product is recommended or endorsed by the INSPIRE consortium. The market for immersive hardware moves quickly: at least one device referred to in Section 3 has already been discontinued by its manufacturer. Section 3 should therefore be read as a set of functional requirements to procure against rather than as a shopping list. Any solution that satisfies the requirements in Sections 3.1.6 and 3.2 can deliver the training described here.

The guide can be used in three ways. Institutional leaders will find the decision framework in Sections 3 and 5. Trainers will find the pedagogical and assessment guidance in Section 4. Those preparing a concrete rollout can work directly from the checklist in Annex A.

This guide is part of the outcomes of the [INSPIRE Project](#) (modularisation of the welding inspector profile to respond to the needs emerging from hydrogen programmes towards a greener Europe), co-funded by the Erasmus+ Programme of the European Union.

INSPIRE contributes to:

- Digital transformation in VET through the development of digital readiness, resilience, and capacity.
- Environmental sustainability, by supporting workforce preparedness for hydrogen-related technologies.
- Adaptation of VET to labour market needs, ensuring qualification systems remain flexible, modular, and responsive.



The integration of AR tools supports the Erasmus+ horizontal priority of addressing digital transformation through the development of digital readiness, resilience and capacity. It is also consistent with European work on the digital transformation of VET and the need to strengthen digitally enabled vocational education and training (Cedefop, 2025; Herrero et al., 2024).

This guide therefore supports INSPIRE's goal of modernising the training of European welding inspectors, ensuring that future professionals are digitally competent and environmentally responsible.



2. AR in Vocational Education and Training

2.1 Definitions and Key Concepts

Augmented Reality (AR) is a technology that adds digital content, such as graphics, data, labels, instructions or three-dimensional models, to the user's view of the real-world environment. Unlike a conventional screen, AR can position digital elements in relation to physical objects and locations, allowing information to appear as though it were part of the user's surroundings.

Spatial AR systems use technologies such as simultaneous localisation and mapping (SLAM), six degrees of freedom (6DoF) tracking, model targets and spatial anchors to understand the environment and determine the position and orientation of the device within it. These capabilities allow digital objects and instructions to remain aligned with specific physical objects, such as a weld, pipe section or inspection area, as the user moves.

Assisted Reality is a related but less spatially complex approach. Instead of anchoring digital content to physical objects, Assisted Reality displays information within the user's field of view, typically through a monocular or head-mounted display. This information may include instructions, checklists, manuals, alerts, live data or a remote expert's video feed. Assisted Reality supports the user during a task but does not necessarily require environmental mapping, depth perception or precise alignment between digital content and physical objects.

In contrast, Virtual Reality (VR) replaces the user's view of the physical environment with a fully computer-generated environment. Mixed Reality (MR) combines physical and digital elements and enables users to interact with virtual content that is spatially integrated into the real environment. Extended Reality (XR) is commonly used as an umbrella term for technologies that combine or replace aspects of physical reality, including AR, MR and VR.

In Vocational Education and Training (VET), these technologies can help learners visualise and practise complex procedures that may be difficult, costly or unsafe to reproduce repeatedly using conventional training methods alone. In welding inspection training, potential applications include the visualisation of weld geometry, inspection sequences, defect characteristics, measurement procedures and acceptance criteria.

When appropriately aligned with learning outcomes, immersive and assisted technologies can support experiential learning, spatial understanding and competence-based training. They do not replace practical experience with real equipment and materials but can complement it by providing structured guidance, repeatable scenarios and opportunities for formative feedback.

Key distinctions:

Table 1 - Relationship between physical and virtual environments across immersive technologies

Technology	Description
AR (Augmented Reality)	Adds digital content to the real-world environment and may spatially anchor that content to physical objects or locations.
Assisted Reality	Displays non-anchored digital information within the user's field of view to support the performance of a task.
VR (Virtual Reality)	Fully immersive 3D environments using headsets.
MR (Mixed Reality)	Combines real and virtual elements with interaction in real time.
XR (Extended Reality)	An umbrella term commonly used for technologies that combine or replace aspects of physical reality, including AR, MR and VR.

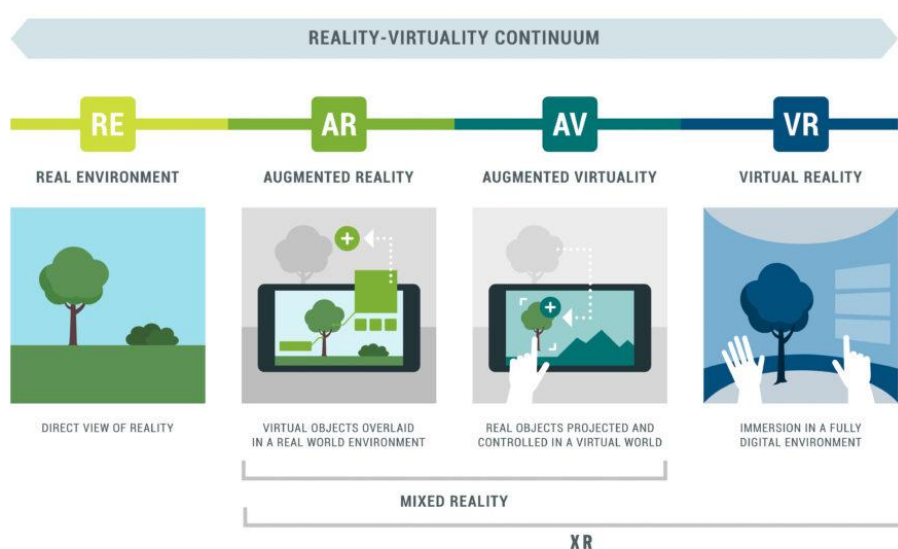


Figure 1 - Reality-virtuality continuum and the relationship between AR, augmented virtuality, VR and XR.



2.2 Benefits and Opportunities in Welding Inspection Training

The introduction of AR into welding inspection training aligns with the EU's ambition for digital readiness and innovation in VET.

When effectively implemented, AR offers multiple benefits across pedagogical, technical, and environmental dimensions:

- **Visualising the invisible:** internal weld geometry, defect morphology, hydrogen diffusion paths and the inside of a pipe can be shown in three dimensions at the point of use, which two-dimensional material cannot achieve.
- **Safe exposure to rare situations:** learners can meet a rejectable weld, a leaking joint or an incident scenario as often as needed, without waiting for one to occur and without the risk of the real event.
- **Guided practice with immediate feedback:** a procedure displayed in the field of view lets a trainee work through an inspection sequence correctly the first time and be corrected as they go rather than afterwards.
- **Remote expert support:** a trainer or a certified inspector can see what the learner sees and intervene without travelling, which makes scarce expertise reusable across sites and countries.
- **Repeatability and consistency:** every learner receives the same sequence, the same acceptance criteria and the same reference images, which reduces variation between trainers and between centres.
- **Documentation of practice:** sessions can be recorded and reviewed, which supports moderation, appeals and trainer development.
- **Reduced consumption:** fewer test pieces, less penetrant and developer, fewer consumables per learner, and a corresponding reduction in waste and disposal.
- **Less travel:** remote sessions and shared scenarios reduce the need to move learners, trainers and equipment between locations.

These benefits are conditional rather than automatic. They materialise only where the AR activity is mapped to a defined learning outcome, where the trainer has been prepared, and where the technology is reliable enough not to consume the training time it was meant to save. Section 2.3 sets out the corresponding barriers.

Pedagogical Benefits	Technical and Professional Benefits	Sustainability and Green Transition
• Enhanced visualisation: Trainees can view internal weld structures or hidden defects through digital overlays. • Safe and controlled learning: AR reduces exposure to heat, fumes, or high-pressure environments while maintaining realism. • Immediate feedback: Learners receive real-time corrections and performance analytics, supporting self-regulated learning. • Active engagement: AR promotes problem-solving and experiential learning consistent with constructivist pedagogical models.	- Simulation of hydrogen-specific challenges: AR enables realistic training on hydrogen embrittlement, material compatibility, and NDT procedures without risk. - Standardised competence acquisition: Supports consistent interpretation of standards and other requirements for inspection tasks. - Upskilling and reskilling flexibility: Modular AR content allows adaptation to specific competence units	• Reduces resource consumption (materials, gas, consumables) during training. • Minimises CO₂ emissions linked to physical testing. • Aligns with EU Green Deal other strategies promoting hydrogen and low-carbon technologies.

2.3 Challenges and Barriers

While AR technologies present great potential, their integration into VET requires addressing several technical, pedagogical, and organisational barriers:

Technical Challenges

Infrastructure and hardware limitations: Many VET centres lack high-performance devices or stable connectivity for AR deployment.

Software interoperability: Integration with existing Learning Management Systems (LMS) and qualification frameworks is often complex.



Data management and cybersecurity: Use of industrial data or personal data in AR simulations requires compliance with GDPR and secure data handling.

Pedagogical Challenges

Trainer readiness: Many instructors have limited experience with immersive pedagogies and digital tools. As an institutional objective, centres may use DigCompEdu to define an appropriate progression pathway for trainers; however, the expected proficiency level should be justified and described in the trainer-development plan.

Curriculum alignment: AR scenarios must be mapped to learning outcomes, competence units, and assessment standards — not treated as add-ons.

Cognitive overload: Excessive visual or informational content can hinder comprehension if not well-structured.

Organisational and Systemic Barriers

High initial investment: The cost of AR hardware, software licences, and maintenance can be prohibitive for small or resource-limited VET centres.

Absence of institutional digital strategies: Many centres lack a clear roadmap or governance model for digital transformation, making AR initiatives isolated rather than systemic.

Insufficient quality assurance mechanisms: Centres may encounter gaps or variation in the guidance available for evaluating and accrediting AR-supported learning activities. Applicable national and awarding-body requirements should therefore be verified before implementation.

Resistance to change and cultural inertia: Educators and administrators may prefer traditional workshop-based training, slowing innovation and adoption of digital pedagogies.

Unequal access across regions: Variations in funding and infrastructure between countries or training centres can widen the digital divide within the VET system.



Addressing these barriers requires a systemic approach that combines institutional planning, adequate infrastructure, trainer professional development, pedagogical integration and continuous quality assurance. This approach is consistent with the Council Recommendation on vocational education and training for sustainable competitiveness, social fairness and resilience, which promotes adaptable, digitally enabled and high-quality VET systems that respond to changing labour-market and skills needs (Council of the European Union, 2020).

3. Technical Requirements for Implementation

The successful integration of Augmented Reality (AR) technologies in welding inspection training depends on careful planning of the technical infrastructure.

This section outlines the essential hardware, software, infrastructure, and data management requirements to ensure effective, safe, and sustainable implementation across VET centres.

3.1 Hardware Options

The effective deployment of Augmented Reality (AR) and Assisted Reality (aR) technologies in welding inspection training goes far beyond selecting a headset or tablet. In practice, the reliability and impact of these solutions are determined by the entire technical ecosystem: the optical and tracking capabilities of the device, the computational layer behind it, workshop environmental conditions, and the training flow in which the system is used.

3.1.1 AR/MR headsets with spatial AR

AR/MR headsets such as HoloLens 2 or Magic Leap 2 provide true spatial augmentation, enabling inspectors and trainees to see 3D overlays, defect markers, dimensional checks, and step-by-step procedures aligned directly to the physical weld. These devices support 6DoF tracking, environment mapping, and persistent anchors and enable precise, spatially aligned instructions.

Strengths	Considerations
• Hands-free operation, essential for inspections and NDT workflows • Stable 3D alignment of geometry, annotations, and guidance • Useful for immersive training and remote expert support • Applicable with modern industrial workflows	• Higher cost per trainee • Requires periodic calibration and careful handling • Reflective and curved weld surfaces may affect tracking performance • Compatibility with PPE (helmets, visors, gloves) must be verified • May require additional controller(s) or hand gestures as voice control is not robust • Weight may cause neck strain • Displays may increase the risk of dry eye syndrome • Compute pucks and cables may negatively impact user experience in industrial setting • Battery life limited to approx. 2 hours • No ATEX-certified devices • Narrow choice of devices (Microsoft has discontinued HoloLens 2 and Magic Leap 2 is difficult to procure)

3.1.2 Assisted Reality headsets

Traditional Assisted Reality devices (e.g., RealWear Navigator series) offer a monocular display that presents information *within* the user's field of view without anchoring it to real-world objects. Their role is typically limited to workflows, checklists, manuals, and remote support.

However, software component middleware platforms can extend the capabilities of assisted-reality hardware. Through server-side spatial processing and video-based SLAM, software of this kind can add the following to step-by-step workflows and remote collaboration:

- Spatial anchoring
- Environment understanding
- Object-linked annotations



- AR-style overlays rendered back onto the video stream

This bridges the gap between Assisted Reality and Augmented Reality, enabling spatially meaningful training even on devices that normally lack built-in environmental tracking. Assisted Reality headsets enable safe, hands-free training in realistic workshop conditions, with step-by-step guidance, collaborative teaching and learning and optionally with spatial cues that help trainees understand weld geometry, defect locations, and inspection sequences even on monocular devices.

The characteristics below vary by model and configuration and must be verified against current manufacturer specifications.

Strengths	Considerations
• Lower purchase cost • Rugged, industry-ready, heat-resistant – ideal for welding bays • 5–8 hours of battery life • Hot-swap of batteries • Some models offer a modular design allowing thermal cameras to be fitted • 4G or 5G connectivity built-in or available as accessories • Voice control in many languages, usable in ambient noise up to about 100 dB • Voice-control enables future integration with AI systems for conversational and multi-modal collaboration with AI agents • Fully hands-free and compatible with helmets, gloves, visors • Wide compatibility with PPE • Lightweight • Not obstructing field of view • Glanceable use lowers the risk of dry eye syndrome • Easier to use in confined spaces or unnatural body positions	• Limited field of view compared to optical AR/MR • Spatial accuracy depends on video quality, lighting, and network conditions • For spatial AR, requires backend processing on a SLAM server or an equivalent service



- Combined with suitable middleware, can provide AR-like functionality without optical see-through hardware
- Low maintenance and easy to scale across large training groups
- ATEX-certified models available (at extra price)
- Relatively wide choice of manufacturers (for example RealWear, Vuzix, MRTECH, CIMO) and models

3.1.3 Mobile devices/tablets

Tablets and smartphones provide a cost-effective entry point into AR training with strong camera systems and powerful processors (e.g., iPad Pro M-series). They work well in classrooms, training centres, and non-hazardous environments. They are useful for pre-inspection exercises, defect visualization, and introductory AR content. Not ideal for advanced, hands-on welding inspection tasks where both hands are required.

Strengths	Considerations
• Large, high-resolution screens • Excellent cameras for weld documentation and scanning • Good for blended learning scenarios (classroom + workshop) • Easy to use and widely available • Wide price range from entry-level to flagship devices • Industrial devices available (usually at higher price)	• Not hands-free; interrupts the workflow during inspection • Difficult to operate with gloves or PPE • Less suitable near hot metal or in constrained spaces • Entry-level device may negatively impact user experience and performance (low processing, poor remote collaboration or slow video encoding/decoding)



3.1.4 Desktop PCs / Laptops / cloud compute

While not used directly on the workbench, desktop systems form the computational backbone of AR-enhanced training. Such a stable backend ensures smooth overlays, real-time spatial understanding, or reliable remote collaboration among others.

Typical roles in the XR ecosystem include:

- Running backend services (e.g. SLAM workers, session orchestration)
- Processing high-resolution weld scans and defect models
- Creating step-by-step procedures and digital twins
- Managing trainee progress and analytics
- Training and running AI models for defect classification

3.1.5 Why the Hardware Layer Matters

Welding environments are uniquely challenging due to factors like: intense lighting contrasts, reflective metals, heat, dust, and fumes, protective gear limiting movement and visibility.

Therefore, successful AR integration requires a setup of priorities like:

- **hands-free operation** for safety
- **rugged devices** that tolerate workshop conditions
- **user experience** affected typically by device complexity, weight, battery life, interaction methods, configuration, adoption, maintenance, connectivity
- **backend processing** capable of handling video-based and/or voice-based pipelines (SLAM, AR overlays, visual inspections, AI agents etc.)
- **importance of robust tracking and spatial understanding** despite reflections
- **objective measurement tools** for assessment and certification



3.1.6 Choosing hardware: functional requirements to procure against

Rather than selecting a product, centres should define the functions the solution must perform and then test candidates against them. The requirements below have proved decisive in welding inspection settings and can be used directly in a tender or in a supplier demonstration.

- **Hands-free operation:** the learner must be able to hold a magnifier, a gauge, a torch or a probe while receiving guidance. A device that must be held in one hand interrupts the very task being taught.
- **PPE compatibility:** the device must be usable with the helmets, safety glasses, welding visors, hearing protection and gloves actually used in the centre. Verify this physically, on your own PPE, rather than accepting it from a datasheet.
- **Tolerance of the workshop environment:** high contrast between arc light and shadow, reflective and curved metal, dust, fumes, heat and noise. Ask the supplier to demonstrate on a real weld coupon in your own workshop, not on a matte printed marker.
- **Session endurance:** battery life must cover a realistic training block, or the device must support hot-swappable batteries. A two-hour battery in a three-hour session means an interrupted lesson.
- **Field of view and glanceability:** the display must not obstruct the learner's view of the workpiece. For inspection tasks a small, glanceable display is often preferable to a large immersive one.
- **Language and interaction:** voice control, where used, must work in the languages of the learner group and in the ambient noise of the workshop, and an alternative input method must exist for learners whose speech is not recognised reliably.
- **Cleaning and shared use:** devices will be worn by successive learners on the same day, so surfaces in contact with the face must be cleanable or replaceable.
- **Content portability:** scenarios authored for the device must be exportable in a documented format, so that they survive a change of supplier or device.



- **Measurement output:** if the solution is to contribute to assessment, it must export what the learner did in a form a trainer can review and archive, not only a pass or fail score.
- **Service, warranty and spares:** confirm repair turnaround, availability of spare parts, and the supplier's commitment to the product line over the expected life of the investment.
- **Certification where required:** if any part of the training takes place in a classified area, only devices with the corresponding ATEX or equivalent certification may be used. Most immersive devices do not carry it.

A practical approach is to score two or three candidate solutions against these requirements together with the trainers who will use them, and to run that scoring with the centre's own PPE, own lighting and own weld samples. A device that performs well in a supplier's showroom may fail in a welding bay.

3.2 Software Platforms

The software layer determines whether an AR investment becomes part of the training programme or remains a demonstration. Two distinct components are normally needed: an authoring environment in which trainers create and maintain scenarios, and a delivery and management environment that distributes content to devices and records what learners did. Some suppliers provide both; others provide only one, and the missing part has to be procured separately.

The following functional requirements should be confirmed before any commitment is made:

- **Trainer authoring without programming:** a trainer who is competent in welding inspection but not in software development must be able to create and edit a scenario. If every change requires the supplier, the content will not be maintained.
- **Mapping to learning outcomes:** scenarios must be describable in terms of the competence unit and learning outcome they address, so that they can be audited against the qualification rather than existing alongside it.
- **Standards-based integration:** export of learner activity to the centre's Learning Management System using an established specification such as



SCORM, xAPI or cmi5. Without this, AR results sit in a separate silo and cannot be used for progression or reporting.

- **Multi-language content:** the same scenario should be deliverable in the languages of the centre without being rebuilt.
- **Offline or degraded-network operation:** workshops are frequently shielded by metal structures, so the solution should continue to function, at least in a reduced mode, when connectivity drops.
- **Multi-user sessions:** a trainer and one or more learners must be able to share a session, for demonstration, supervision and remote moderation.
- **Version and content management:** scenarios must be versioned, so that it is always clear which version a learner was assessed against.
- **Accessibility features:** adjustable text size and contrast, captions for any audio content, and alternatives to gesture-only interaction.
- **Data location and export:** where learner data is stored, in which jurisdiction, and how the centre can extract it in full at any time.
- **Licensing model and total cost:** per device, per user or per site; what happens to existing content if the licence lapses; and the cost of renewals over the planned life of the system.
- **Content ownership:** the contract should state explicitly that scenarios authored by the centre remain the property of the centre and can be exported.

Supplier lock-in is the most common cause of abandoned immersive-learning investments. A centre that has authored fifty scenarios in a proprietary format, on a device that has been discontinued, under a licence it can no longer afford, has lost the investment entirely. The requirements on portability, ownership and standards-based export exist to prevent that outcome and should not be traded away for a lower purchase price.



3.3 Infrastructure Needs

The successful implementation of AR-based training depends not only on the selected devices and software but also on the infrastructure available in the environment where the training takes place. Before implementation, centres should assess the following requirements:

- **Reliable internet and network connectivity:** AR applications may depend on network access for content distribution, user authentication, remote collaboration, data synchronisation or cloud-based processing. Centres should identify which functions require continuous connectivity and which can operate offline or under degraded network conditions. A temporary loss of connectivity should not create a safety risk or result in the loss of learner progress.
- **Suitable training spaces:** AR training should take place in an area with adequate lighting, sufficient space for learners to move safely and appropriate separation from live welding or other hazardous activities. The training space should support the intended tasks, accommodate the required equipment and allow trainers to supervise all learners effectively.
- **Secure servers and storage for AR content:** Centres should provide an appropriate environment for storing training scenarios, device configurations, learner records and assessment evidence. Access should be restricted according to defined roles, and backup, retention and deletion arrangements should be established in accordance with the data governance requirements described in Section 3.4.
- **Network coverage where the training actually happens:** welding bays are often metal-clad and shielded. Wi-Fi coverage must be surveyed and, where necessary, extended into the bay itself rather than assumed from the office.
- **Bandwidth and latency:** video-based spatial processing and remote collaboration are sensitive to latency as well as bandwidth. Agree measurable figures with the supplier and test them under load, with the expected number of simultaneous devices.
- **Server location:** decide deliberately whether processing runs on the centre's own hardware or in the supplier's cloud. This choice determines both resilience and the data protection analysis in Section 3.4.
- **A defined training space:** controlled and adjustable lighting, a stable bench for weld coupons, room to move safely while wearing a head-mounted device, and adequate separation from live welding.



- **Charging, storage and hygiene:** a lockable, ventilated cabinet with charging for every device, a documented cleaning routine between users, and consumables such as replaceable face pads.
- **Named technical support:** one identified person responsible for updates, device configuration, account management and first-line troubleshooting. Immersive training fails quickly when nobody owns the equipment.
- **Spare capacity:** Where resources allow, centres should maintain spare capacity or define an alternative delivery plan so that a single device failure does not cancel the session.

A minimum viable configuration is worth defining explicitly, because it allows centres with limited resources to begin. One head-mounted device, one authoring licence, one prepared trainer and one scenario mapped to a single learning outcome is enough to run a meaningful pilot, and a tablet-based configuration is a legitimate and considerably cheaper starting point for the classroom phase. Scaling should follow evidence from that pilot rather than precede it.

3.4 Data Protection and GDPR Compliance

The use of AR technologies in VET environments often involves the collection and processing of personal information, such as learner profiles, performance analytics, and image data from real or simulated training sessions. As such, institutions must ensure full compliance with the General Data Protection Regulation (GDPR) (Regulation (EU) 2016/679) and related national data protection frameworks.

Each VET centre should establish a clear data governance framework defining responsibilities for data management, protection, and storage. This includes identifying what types of data are collected, who has access to them, and how they are retained or deleted after use. Institutions must also guarantee transparency and accountability in data handling processes.

Institutions implementing AR-based learning environments must ensure that all personal and performance-related data are processed in full compliance with GDPR. This requires establishing clear data retention policies that specify how long user data will be stored and under what conditions it will be deleted. Learners and trainers should be fully informed about data collection and usage, and their explicit consent must be obtained prior to participation.



To guarantee confidentiality and integrity, all platforms should use appropriately secured servers and current encryption protocols for data in transit and at rest. Furthermore, personal data processing must be strictly limited to what is necessary for the intended learning and assessment purposes, avoiding unnecessary collection or storage of sensitive information.

Two further steps are required in practice. First, immersive systems typically involve systematic monitoring of learners' behaviour, and where they do, a Data Protection Impact Assessment under Article 35 GDPR should be carried out and documented before the first session rather than after the pilot. Second, where the supplier processes data on the centre's behalf (which is the case for any cloud-hosted platform or remote processing service) a written data processing agreement under Article 28 is mandatory, specifying purposes, sub-processors, data location, retention periods and deletion on termination.

Head-mounted devices raise two specific issues that generic e-learning policies do not cover. The outward-facing camera records whatever is in front of the learner, which in a shared workshop includes colleagues who have not consented to being filmed; camera use, recording and storage must therefore be governed by a rule communicated to everyone working in the space, not only to the learners. Features such as eye tracking, hand tracking or voice capture may constitute biometric data, which attracts a higher standard of protection; where these features are not needed for the learning objective, the safest course is to disable them.

Finally, consent obtained from a learner as a condition of participating in their own training is not freely given in the sense intended by the Regulation. Where AR forms a mandatory part of a programme, the centre should identify a lawful basis other than consent for the processing that is strictly necessary, and reserve consent for genuinely optional elements such as recording a session for promotional use.

3.5 Health, Safety and Ergonomics of Head-Mounted Devices

Placing a display on a learner's head, in a workshop containing hot metal, moving equipment and welding arcs, introduces hazards that are absent from a classroom. They are manageable, but they must be assessed and controlled explicitly. This section is the minimum a centre should have in place before the first learner puts on a device.



- **Risk assessment first:** the centre's existing workshop risk assessment must be extended to cover the use of head-mounted displays and reviewed by whoever is responsible for health and safety. The centre should verify applicable national occupational health and safety requirements and formally extend its workshop risk assessment to cover head-mounted devices.
- **Restricted awareness:** any head-mounted display narrows or partly occludes the field of view and reduces attention to the surroundings. Devices must not be worn while walking through the workshop, while carrying loads, on stairs or platforms, or near moving machinery.
- **No use during live welding:** AR devices are not eye protection. They must never be worn as a substitute for a welding filter, and they should not be used within the arc-flash zone of live welding. Inspection tasks are performed on cooled coupons, and that separation should be maintained deliberately.
- **Heat and hot surfaces:** most immersive devices are not rated for the temperatures found near freshly welded material. Confirm the manufacturer's operating range and keep devices away from hot work.
- **Session length and breaks:** limit continuous wear, schedule breaks, and treat reports of eye strain, headache, neck discomfort or nausea as a reason to stop rather than something to work through. A common practical rule is a short break every twenty to thirty minutes, adjusted to the device and the task.
- **Visually induced discomfort:** a minority of users experience nausea or disorientation. Learners must know before the session that they may stop at any time without consequence for their assessment, and an alternative route to the same learning outcome must exist.
- **Photosensitivity:** learners with a history of epilepsy or photosensitive seizures should be informed about the technology in advance and offered the alternative route. The centre should not require a medical disclosure, only make the alternative available.
- **Fit, weight and eyewear:** check that the device can be worn over prescription glasses, that the fit is adjustable, and that weight distribution does not load the neck. Devices with an external compute unit and cable introduce a trip hazard that must be managed.
- **Hygiene:** shared devices in contact with the face require a documented cleaning procedure between users and, where available, replaceable hygiene pads.



- **Supervision:** a learner wearing a device is less aware of their surroundings and should not be left unattended in a workshop. A trainer supervising several device users needs a clear line of sight to all of them.
- **Emergency procedure:** learners must be able to remove the device instantly and must know the evacuation route without needing the display. Device audio must not mask alarms.

None of the above prevents the use of AR in welding inspection training. It was piloted successfully within INSPIRE precisely because the tasks chosen safety induction, visual testing and penetrant testing are performed on cooled material, away from the arc, with the learner standing at a bench. Selecting tasks with that profile is itself a safety control.

3.6 Accessibility, Inclusion and Equivalent Alternatives

Immersive technology is often described as inherently inclusive because it addresses different learning preferences. That is only half the picture: the same technology also excludes learners for reasons that have nothing to do with their competence as inspectors. A guide intended for public use has to say so, and has to say what to do about it.

- **Vision:** stereoscopic AR depends on binocular vision. Learners with monocular vision, significant amblyopia, or an interpupillary distance outside the device's adjustment range may be unable to perceive the overlay correctly. Monocular assisted-reality displays are frequently the more inclusive option.
- **Prescription eyewear:** verify that the device accommodates glasses, or budget for prescription inserts. Asking learners to remove their glasses is not acceptable.
- **Colour vision:** because some learners may have colour-vision deficiencies, defect markers, accept/reject indicators and heat maps must not rely on colour alone. Shape, labels or patterns should convey the same information.
- **Hearing:** any spoken instruction must also be available as on-screen text. The workshop is noisy in any case.
- **Speech and language:** voice control fails for learners with a strong accent, a speech difference, or a language the device supports poorly. An alternative input must always be available.



- **Motor function:** gesture-based interaction assumes fine hand control and a full range of arm movement. Provide an alternative for learners who cannot perform the gestures reliably, including while wearing gloves.
- **Digital confidence:** some learners, particularly experienced inspectors returning for upskilling, will be uncomfortable with the technology itself. Allow a short familiarisation session that does not count towards assessment.

The controlling principle is that an equivalent alternative route to every learning outcome must exist and must be documented in the programme. No learner may be prevented from completing the qualification, or disadvantaged in assessment, because they cannot use a particular device. In practice this means that for every AR activity the centre should be able to state how the same outcome is achieved conventionally, with a physical weld coupon, a printed radiograph, a classroom demonstration, and that both routes lead to the same assessment standard. Centres in the public sector should also check their obligations under national implementations of the Web Accessibility Directive and the European Accessibility Act, which may apply to digital learning material.

4. Pedagogical Integration

4.1 Curriculum Alignment and Theoretical Knowledge Delivery

Integrating AR into the European Welding Inspector (EWI) qualification requires a coherent alignment between curriculum design, competence units, and learning outcomes. Within the INSPIRE project, this alignment builds upon the modular structure defined under WP3T1 and WP3T2, which established the competence-based framework and the additional training content for hydrogen pipeline inspection.

AR tools are then integrated and validated in WP4, ensuring pedagogical consistency and quality.

In the theoretical phase of training, AR can enhance knowledge transfer by transforming abstract inspection principles into visual, interactive concepts. For instance, modules explaining hydrogen embrittlement mechanisms, weld defect typologies, or inspection sequences (topics that correspond to the INSPIRE competence units CU-H2-01 , on material integrity and safety, and CU-H2-02, on

inspection and testing for hydrogen pipelines, with the scenario types prepared against them listed in Section 4.2) can be delivered through AR overlays.

This approach supports multimodal learning by combining visual, auditory and kinaesthetic forms of representation and is consistent with the European Framework for the Digital Competence of Educators, DigCompEdu (Redecker, 2017).

The use of AR in the EWI curriculum may:

- make theoretical modules more accessible and engaging;
- enable trainers to demonstrate dynamic phenomena that are difficult to observe directly;
- strengthen institutional capacity for digital pedagogy.

AR thus acts as a pedagogical bridge between knowledge and application—preparing learners for practical tasks while reinforcing core theoretical foundations.



Figure 2 - Bridging knowledge and application through AR-enhanced training. Source: developed by the INSPIRE consortium with AI-assisted illustration, 2026.

4.2 AR for Practical and Simulation-Based Training

The use of AR in the practical component of the EWI curriculum represents a key innovation under WP4 (Development of AR training materials and implementation of pilot courses). By combining real equipment with digital overlays, AR allows trainees to practise inspection tasks safely, efficiently, and with immediate feedback.



Typical use cases include:

- **Safety induction to the training environment:** a guided walkthrough of the workshop, the hazards present, the location of emergency equipment and the required PPE, delivered in the space itself rather than as a classroom briefing. This was the first scenario piloted in INSPIRE and proved the most straightforward to implement, because it carries no measurement requirement.
- **Visual testing (VT):** step-by-step guidance through a visual examination of a weld (surface condition, profile, undercut, misalignment, spatter) with reference images and acceptance criteria displayed alongside the actual coupon in front of the learner. Piloted in INSPIRE.
- **Penetrant testing (PT):** the full sequence of pre-cleaning, penetrant application, dwell time, removal of excess, developer application and interpretation, with timings and acceptance criteria presented in the field of view. Piloted in INSPIRE. Because the sequence is time-dependent and easy to get wrong, guided practice is particularly valuable here.
- **Magnetic particle and ultrasonic familiarisation:** orientation to the equipment, the procedure and the interpretation of indications, as preparation for supervised practice with the real instrument.
- **Hydrogen-specific inspection scenarios:** delayed inspection intervals, hardness survey locations, and the difference between an imperfection that is acceptable in natural gas service and one that is not acceptable in hydrogen service, the subject matter of the INSPIRE competence units.
- **Documentation review:** overlaying a welding procedure specification, a procedure qualification record or an inspection and test plan onto the joint being inspected, so that the learner practises checking the weld against the document rather than in isolation.
- **Remote expert support and moderation:** a trainer or external assessor observing the learner's view in real time, for supervision, a second opinion, or standardisation between centres.

Two observations from the INSPIRE pilots are worth passing on. First, the scenarios that worked best were those in which the learner had to do something physical with their hands while the guidance remained visible; scenarios consisting mainly of reading text through a display added little over a printed procedure. Second, the



effort is heavily front-loaded: authoring and validating a single scenario took considerably longer than delivering it, which argues for starting with a small number of well-made scenarios rather than broad coverage.

Centres implementing this guide with a different toolset should read the list above as a set of task types rather than as a list of products. Any AR or assisted-reality solution capable of presenting a sequenced procedure, an acceptance criterion and a reference image at the point of work can deliver these scenarios.

When appropriately designed and evaluated, simulation-based training may reduce material consumption, support safer practice and contribute to lower waste and emissions.

4.3 Assessment and Validation Using AR Tools

Assessment in AR-enhanced environments must remain competence-based, ensuring that learners meet the required learning outcomes for each module or competence unit. AR can provide new opportunities for capturing user interactions, task completion time, and accuracy through embedded analytics.

Key assessment principles include formative assessment, with real-time feedback during training sessions enabling continuous improvement and self-correction.

Furthermore, AR facilitates peer and self-assessment, allowing learners to replay simulations, reflect on decisions, and compare outcomes.

One boundary has to be stated plainly, because it determines whether AR can be used at all within a certified pathway. AR-based activity supplements assessment; it does not replace the examinations and practical demonstrations required by the qualification. Under the IIW and EWF systems, and for the qualification and certification of non-destructive testing personnel under ISO 9712:2021, assessment requirements are established by the applicable qualification or certification framework rather than by the training centre (ISO, 2021). No centre may substitute an AR simulation for a required examination element without the prior agreement of its Authorised National Body and, where relevant, of EWF or IIW. Where AR is used to prepare learners for those assessments, or to gather formative evidence alongside them, no such approval is needed.



Within that boundary, three principles keep AR-based assessment defensible:

- **Validity before analytics:** the fact that a system can record completion time, gaze direction and error count does not make those measures evidence of competence. Each metric used must be shown to relate to the learning outcome it is claimed to assess. Speed in particular is a poor proxy for inspection quality and can actively reward the wrong behaviour.
- **Reliability and standardisation:** if two learners perform the same scenario, they must be scored the same way. That requires a written marking scheme, a defined scenario version, and moderation between trainers, exactly as for any other practical assessment.
- **Fairness and transparency:** learners must know in advance what is recorded, what counts towards assessment and what does not. Data captured for the trainer's convenience must not silently become assessment evidence, and there must be an appeals route that does not depend on the learner's ability to operate the device.

Used in this way, the strongest contribution of AR to assessment is formative rather than summative: it lets a learner attempt an inspection sequence, see immediately where they deviated from the procedure, and repeat it. That is difficult to organise with physical resources alone, and it improves performance in the formal assessment that follows.

4.4 Enhancing Learner Engagement and Attractiveness of VET

One of the INSPIRE goals is to increase the attractiveness of VET pathways, especially in technical and industrial profiles.

AR supports this by turning complex, abstract learning content into immersive, interactive experiences and may increase the appeal of technical training for learners who value interactive and digitally supported learning experiences.

This experiential dimension helps bridge the skills perception gap, making VET more visible, modern, and relevant to the green and digital transition.



Key pedagogical impacts include:

Motivation and curiosity: AR promotes active discovery and exploration rather than passive absorption of information.

Retention and comprehension: Well-designed interactive 3D representations may support conceptual understanding and retention, particularly when they are aligned with clearly defined learning outcomes.

Inclusiveness: AR supports learners with different backgrounds and learning preferences, improving accessibility and equity.

Professional identity: Exposure to high-tech training environments strengthens learners' connection to modern industry standards and technologies, promoting long-term engagement in the welding sector.

By making learning more immersive and relevant, AR technologies enhance both the attractiveness and responsiveness of vocational education and training. These technologies embody the principles of the EU's VET Modernisation Agenda and concretely promote the Erasmus+ priorities of digital transformation and labour market alignment, helping VET become a driver of Europe's green and digital transition.

4.5 Preparing Trainers

Trainer readiness is identified in Section 2.3 as a barrier. It is also the single factor that most reliably determines whether an AR investment is still in use after the first term: a device a trainer is not confident with stays in its case. Preparation should therefore be planned and resourced from the outset rather than treated as a by-product of the equipment purchase.

A workable minimum, based on the INSPIRE train-the-trainer sessions, comprises:

- hands-on familiarisation with the device itself, including fitting it, cleaning it, charging it, and recovering from the three or four failures that occur most often.



- the ability to author, or at least edit, one scenario, so that the trainer is not dependent on the supplier for every change.
- explicit pedagogical framing: when AR adds value over a physical coupon and when it does not. Trainers who have thought this through use the technology selectively and to better effect than those who use it because it is available.
- the safety and accessibility provisions in Sections 3.5 and 3.6, including how to offer the alternative route without making it feel like a lesser option.
- a named colleague to ask. Peer support within the centre, or across an EWF network, matters more than a one-off course.

Trainer development can be positioned against the DigCompEdu framework, which provides a common vocabulary for describing progression and is already used in many national VET systems. Reaching the level at which a trainer designs rather than merely delivers digital learning activity is a realistic target over one or two training cycles, and is worth recording as an institutional indicator alongside the learner metrics in Section 5.4.

5. Implementation Roadmap and Institutional Readiness

The successful integration of Augmented Reality (AR) in Vocational Education and Training requires a structured and quality-assured implementation process.

This roadmap provides VET institutions with a phased approach to plan, pilot, and scale AR-based training, ensuring alignment with European frameworks for digital maturity, quality assurance, and continuous improvement.

5.1 Phase 1 – Diagnosis and Institutional Planning

The first phase involves an in-depth diagnosis of institutional readiness, including the centre's digital capacity, human resources and pedagogical practices. Centres may use SELFIE for Schools, a European self-reflection tool that supports schools in examining how digital technologies are used for teaching and learning, to inform institutional discussion and improvement planning (European Commission, n.d.).



Trainer development may be considered separately using DigCompEdu or SELFIE for Teachers (Economou, 2023; Redecker, 2017).

Based on this diagnosis, centres should develop a Digital Transformation Plan defining goals, timelines, and responsible roles for AR implementation.

The plan should include:

- A clear pedagogical rationale for AR adoption (e.g., improving visualisation of inspection processes, reducing material use).
- Resource allocation (equipment, human resources, budget).
- Risk assessment covering safety, privacy, and technological obsolescence.

5.2 Phase 2 – Pilot Implementation

Once planning is complete, institutions should begin a pilot phase with a small, controlled group of trainers and learners.

This stage is intended to test the AR applications, refine the pedagogical approach, and validate their alignment with learning outcomes and competence units.

Key steps include:

- Selecting a limited number of pilot scenarios and mapping each scenario to a defined competence unit and learning outcome.
- Training instructors in AR pedagogy and safety protocols.
- Collecting qualitative and quantitative data on usability, engagement, and learning outcomes.
- Applying quality indicators (e.g., learner satisfaction, achievement rate, trainer feedback) to evaluate pilot performance.

Feedback loops are essential: trainers and learners should report on difficulties, technical constraints, and perceived learning benefits.

This iterative process supports continuous improvement and ensures the eventual scalability of AR tools.

5.3 Phase 3 – Scaling and Integration



Following successful pilots, institutions can move to the scale-up phase, gradually extending AR use to additional modules, trainers, and learner groups.

Scaling should follow quality assurance principles focusing on planning, implementation, evaluation, and review.

Actions include:

- Embedding AR activities within the official training programmes and curricula.
- Expanding technical infrastructure (dedicated AR labs, network capacity).
- Establishing peer learning communities for trainers to exchange resources and best practices.
- Integrating AR content into Learning Management Systems (LMS) and institutional repositories for accessibility and version control.

At this stage, sustainability and cost-effectiveness become key priorities.

Institutions should adopt blended training models, combining AR simulations with physical practice, and explore partnerships with industry for content co-development or equipment sponsorship.

5.4 Continuous Quality Assurance and Evaluation

Throughout all phases, institutions should apply a quality cycle—Planning → Implementation → Evaluation → Review—to ensure that AR integration remains effective, measurable, and aligned with sectoral standards.

Monitoring indicators may include:

- Learner satisfaction and engagement metrics
- Trainer digital competence development (based on DigCompEdu levels)
- Learning outcomes achievement rates
- Technical performance and uptime of AR tools



- Consumables used per learner, compared before and after the introduction of an AR module. This can be taken from existing purchasing records and does not require a new measurement system

Regular reporting and peer review within networks such as EWF Members or national VET alliances help ensure consistency and cross-border comparability, promoting a culture of organisational learning.

5.5 Institutional Readiness and Sustainability

Institutional readiness goes beyond technology; it encompasses leadership vision, staff engagement, and long-term sustainability planning.

To embed AR innovation successfully, VET centres should:

- Develop leadership capacity in digital and pedagogical innovation.
- Foster a collaborative culture among trainers, IT staff, and management.
- Ensure financial sustainability through cost-benefit analysis, reuse of digital assets, and partnerships with industry.
- Maintain ethical and inclusive practices, ensuring that all learners have equitable access to digital training opportunities.

This holistic approach ensures that AR integration is not treated as a one-off technological experiment but as a strategic component of institutional excellence and pedagogical modernisation.

5.6 Cost, Procurement and Continuity

Cost is identified as a barrier in Section 2.3 but becomes manageable once it is broken down. The business case should consider the total cost of ownership rather than the purchase price alone. The following should be built into the business case before funding is sought:

- Devices, plus at least one spare, plus replacement batteries and hygiene consumables.



- Software licences and their renewal, costed for the full planned period rather than the first year.
- Content authoring effort, counted in trainer days, normally the largest hidden cost.
- Network and server provision, including any upgrade to workshop connectivity.
- Trainer preparation, and substitute cover during it.
- Technical support, whether internal staff time or a support contract.
- Device replacement should be planned according to manufacturer support, warranty conditions, usage intensity and the expected service life established during procurement

Continuity deserves particular attention, because immersive hardware has a short commercial life. One of the devices referred to in Section 3.1.1 has already been discontinued by its manufacturer and a second is difficult to procure. A centre that has built its programme around a single device and a single proprietary platform is exposed. The mitigations are straightforward and should be contractual rather than aspirational: content in an exportable format, ownership of authored scenarios retained by the centre, learner data extractable in full, and a documented fallback to conventional delivery for every scenario, so that a supplier failure interrupts the technology but not the qualification.

Funding routes worth exploring include Erasmus+ and national VET modernisation programmes, regional smart-specialisation and digitalisation funds, shared procurement between centres in the same network, and industry partnership through equipment sponsorship or co-development of scenarios with a company that has a direct interest in the competence of the inspectors being trained. Sharing scenarios between centres, rather than each authoring its own, is the most effective single cost reduction available, and is one of the reasons for the portability requirements in Section 3.2.



6. Conclusions

The INSPIRE experience shows that AR can support welding inspection training when it is aligned with defined learning outcomes, introduced through a controlled pilot and supported by trained staff, appropriate infrastructure and robust quality assurance. Its value lies primarily in guided practice, visualisation and formative feedback, while formal assessment remains governed by the applicable qualification and certification frameworks. Sustainable implementation also requires attention to safety, accessibility, data protection, content portability and total cost of ownership. By addressing these conditions, VET centres can adopt AR selectively and responsibly, while ensuring that every learner retains access to an equivalent route to the same competence and assessment standards.



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Annex A – Implementation Checklist

The checklist below condenses this guide into the sequence a centre actually follows. It is intended to be copied into a project plan and worked through; the reference after each item points to the relevant section.

Before deciding

- Readiness diagnosis completed across the seven dimensions, and the results discussed by management (5.1).
- Pedagogical rationale written down: which competence units and learning outcomes AR is expected to serve, and why AR rather than existing methods (4.1).
- Functional requirements defined and candidate solutions scored against them, with trainers involved, using the centre's own PPE, lighting and weld samples (3.1.6, 3.2).
- Total cost of ownership estimated over five years, including authoring effort and licence renewal (5.6).
- Data Protection Impact Assessment carried out, lawful basis identified, and a processing agreement with the supplier in place (3.4).
- Workshop risk assessment extended to head-mounted devices and signed off by the person responsible for health and safety (3.5).
- Equivalent alternative route documented for every planned AR activity (3.6).

Before the first learner

- Trainers prepared: device handling, one scenario authored or edited, safety and accessibility provisions understood (4.5, 3.5, 3.6).
- Training space prepared: lighting, bench, separation from live welding, charging and lockable storage (3.3).
- Network tested under load with the expected number of simultaneous devices (3.3).
- Cleaning routine between users defined and materials available (3.5).
- Learner briefing prepared, covering what is recorded, the right to stop, and the alternative route (3.4, 3.5, 3.6).



- Marking scheme written for any activity contributing to assessment, and the boundary with the formal examination confirmed with the Authorised National Body (4.3).

During the pilot

- Small group, defined scenarios, defined duration (5.2).
- Usability, engagement and learning outcome data collected from learners and trainers (5.2, 5.4).
- Technical incidents logged, including downtime and its cause (5.4).
- Authoring effort recorded per scenario, for future planning (5.6).

Before scaling

- Pilot evaluated against the indicators, and the decision to scale or stop taken on that evidence (5.3, 5.4).
- Scenarios versioned and stored in the institutional repository in an exportable format (3.2, 5.3).
- AR activity embedded in the official programme documentation rather than annexed to it (5.3).
- Device replacement and licence renewal entered in the centre's budget cycle (5.6).
- Fallback to conventional delivery tested at least once (5.6).