



care, judgment, dexterity

CRAEFT

Craft simulation and immersive craft training

Project Acronym	Craeft
Project Title	
Project Number	101094349
Deliverable Number	D4.1
Deliverable Title	Craft simulation and immersive craft training FORTH
Work Package	WP4
Authors	Nikolaos Partarakis and Xenophon Zabulis
Number of pages	53



This project has received funding from the European Commission, under the Horizon Europe research and innovation programme, Grant Agreement No 101094349.

<http://www.craeft.eu/>

Executive summary

This deliverable addresses the challenges of documenting, transmitting, and teaching traditional crafts by proposing and validating a comprehensive framework that integrates pedagogical theory, semantic knowledge representation, interactive simulation, and immersive learning environments. The deliverable focuses on craft simulation and immersive craft training as key mechanisms for supporting the preservation and transmission of intangible cultural heritage in contemporary educational contexts.

Traditional crafts represent complex forms of embodied knowledge that are typically transmitted through apprenticeship, observation, and hands-on practice. These forms of knowledge are deeply contextual, material-dependent, and often tacit, making them difficult to formalise and transfer through conventional digital learning approaches. At the same time, many craft practices face declining participation, limited access to expert training, economic constraints, and increasing competition from industrial production. This deliverable addresses these challenges by examining how eLearning platforms and immersive digital environments can be designed to support craft education without reducing it to abstract or decontextualised instruction.

Methodological Overview

The methodological foundation of this deliverable combines Cognitive Load Theory (CLT) with a layered technical framework for craft representation and simulation. CLT provides the pedagogical basis for structuring learning experiences in a way that manages the inherent complexity of craft processes. By explicitly addressing intrinsic, extraneous, and germane cognitive load, the framework supports the gradual acquisition of procedural, perceptual, and decision-making skills that characterise craft expertise.

Building on this pedagogical foundation, the deliverable presents a layered methodological approach comprising three tightly integrated components. The first component is a semantic layer that formalises craft knowledge in terms of processes, actions, tools, materials, and constraints. This layer enables the explicit representation of craft workflows and decision logic, providing a bridge between expert knowledge and computational systems. The second component is a simulation layer, which models material transformation and tool–material interaction using offline and real-time techniques adapted to the characteristics of different crafts. The third component is a visualisation and interaction layer, which delivers learner-facing experiences through interactive rendering, immersive environments, and feedback mechanisms designed to support embodied learning.

This integrated methodology underpins both conventional eLearning content and immersive training scenarios, ensuring consistency between pedagogical intent, computational behaviour, and learner experience.

Chapter Overview

Chapter 1 introduces the scope and objectives of the deliverable, situating the work within the broader context of the Craeft project. It outlines the motivation for focusing on craft simulation and immersive

training and clarifies the relationship between pedagogical theory, technological development, and cultural heritage preservation.

Chapter 2 presents background and related work, focusing on existing approaches to eLearning, craft documentation, and digital heritage. The chapter highlights the limitations of conventional online learning when applied to crafts, particularly the difficulty of conveying embodied interaction with materials and tools. It reviews prior work in simulation, immersive training, and craft-oriented educational platforms, identifying gaps that motivate the proposed framework.

Chapter 3 introduces Cognitive Load Theory in detail and examines its relevance to craft education. The chapter explains the main CLT effects and principles and translates them into practical instructional design guidelines tailored to craft learning. These guidelines address issues such as segmentation, modality, redundancy, worked examples, and scaffolding. The chapter also demonstrates how these guidelines can be operationalised through the design of eLearning content, using glassblowing as an illustrative case.

Chapter 4 focuses on the application of the CLT-based guidelines within Moodle-enhanced eLearning environments. It demonstrates how structured multimedia content, interactive elements, and assessment mechanisms can be designed to support craft learning while managing cognitive load. Although Moodle is used as a concrete implementation platform, the chapter emphasises the platform-agnostic nature of the guidelines and their applicability to other learning management systems.

Chapter 5 introduces the eLearning portal developed within the Craeft project as a foundational component for digital craft education. The portal provides structured access to learning material, theoretical background, process descriptions, and preparatory exercises that support the acquisition of craft knowledge. While immersive training environments play a central role in experiential learning, conventional eLearning platforms remain essential for introducing concepts, contextualising practice, and supporting reflection. The eLearning portal addresses these needs by offering an accessible, scalable, and pedagogically grounded entry point to craft education.

Chapter 6 details the implementation of the Apprentice Studio. It describes how semantically structured craft knowledge is interpreted at runtime, how simulation components are integrated to support different categories of craft processes, and how visualisation and interaction techniques are employed to provide meaningful feedback. The chapter also discusses how CLT principles are embedded into the execution logic to regulate guidance, task complexity, and learner progression.

Chapter 7 presents the Craft Studio, the complementary authoring environment within the Craeft ecosystem. This chapter explains how craft experts and educators can use the Craft Studio to formalise craft processes, define pedagogical structures, and configure simulation parameters. The Craft Studio enables the creation of reusable, semantically grounded training content that can be exported and executed within the Apprentice Studio.

Chapter 8 introduces the first immersive craft use case, focusing on glassblowing. This chapter demonstrates how the Craeft framework can be applied to a forming craft characterised by continuous material deformation, high temperatures, and strong sensory feedback. The use case illustrates the

integration of semantic process modelling, simulation, and visualisation within an immersive training scenario.

Chapter 9 presents a second use case centred on pin striping. This chapter focuses on fine motor skills, precision, and visual control, highlighting how the framework accommodates crafts that rely heavily on gesture, rhythm, and visual feedback rather than large-scale material transformation.

Chapter 10 introduces a use case on plaster model turning for porcelain slip-casting. This chapter addresses a subtractive craft process and demonstrates how geometrically constrained simulation can be combined with semantic process descriptions to support interactive training and documentation of workshop practice.

Chapter 11 presents a woodworking use case focusing on wood carving with chisels. This chapter explores the challenges of modelling anisotropic materials and directional constraints imposed by wood grain. It demonstrates how the Craeft framework supports subtractive carving processes, tool-material interaction, and pedagogical feedback tailored to embodied learning.

Chapter 12 concludes the deliverable by synthesising the pedagogical, methodological, and technological contributions. It reflects on the versatility of the proposed framework across diverse craft domains and outlines directions for future work, including richer sensory feedback, adaptive learning mechanisms, and tighter integration between semantic knowledge graphs and intelligent tutoring systems.

The content of this deliverable has been the basis for the following publication: Partarakis, N.; Zabulis, X. Applying Cognitive Load Theory to eLearning of Crafts. *Multimodal Technol. Interact.* 2024, 8, 2. <https://doi.org/10.3390/mti8010002>

Document history

Date	Author	Affiliation	Comment
1-6-2024	Nikolaos Partarakis and Xenophon Zabulis	FORTH	First version eLearning
1-7-2024	Nikolaos Partarakis and Xenophon Zabulis	FORTH	Updated version of Apprentice Studio and Craft Studio
1-9-2024	Nikolaos Partarakis and Xenophon Zabulis	FORTH	Final version for internal review
30-9-2024	Nikolaos Partarakis and Xenophon Zabulis	FORTH	Final version for M18 with integration of the internal review comments
30-1-2026	Nikolaos Partarakis and Xenophon Zabulis	FORTH	Updated version for M36
15-02-2026	Nikolaos Partarakis and Xenophon Zabulis	FORTH	Final version for M36 with integration of the internal review comments

Abbreviations

AR	Augmented Reality
3D	Three Dimensional
CH	Cultural Heritage
CERFAV	Centre for Research and Training in Glass Arts
CLT	Cognitive Load Theory
CMS	Content Management System
DIY	Do It Yourself
GA	Grant Agreement
G_WEE	Guideline Worked Example Effect
G_PCE	Guideline Problem Completion Effect
G_SAE	Guideline Split-Attention Effect
G_MDE	Guideline Modality Effect
G_RDE1	Guideline Redundancy Effect
G_ERE	Guideline Expertise Reversal Effect
G_GFE	Guideline Guidance Fading Effect
G_IME	Guideline Imagination Effect
G_SEE	Guideline Self-Explanation Effect
G_EIE	Guideline Element Interactivity Effect
G_HG	Guideline Horizontal Guidelines
H5P	HTML5 Package
VR	Virtual Reality

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1 Introduction

Crafts represent a valuable repository of cultural heritage, encapsulating the wisdom and craftsmanship passed down through generations. These crafts encompass a diverse array of artistic, functional, and cultural practices, ranging from woodworking and pottery to textiles and basket weaving [1]. With their intricate techniques, cultural significance, and historical context, crafts stand as a testament to human creativity, innovation, and cultural preservation. In a world marked by rapid technological transformations, the preservation of crafts is of significance for their safeguarding [2].

Training individuals in crafts poses various challenges. It is of paramount importance to understand these challenges when trying to produce digital learning solutions that aim to support such goals [3]. The main challenge lies in preserving the authenticity of these crafts [4], while adapting to contemporary teaching methods. Other challenges are related to the nature of craft concerning the modern globalised environment [5]. These crafts are typically transmitted orally from one generation to the next, lacking a structured, written format that facilitates systematic education [6]. The absence of written records poses a significant risk of knowledge loss [7]. The mastery of crafts is a labour-intensive and time-consuming endeavour, with a dwindling number of individuals showing interest in apprenticeships. This decreasing interest in crafts raises concerns about their preservation [8]. Furthermore, the economic viability of these crafts remains limited, as they generally offer low financial returns [9]. Challenges also include the procurement of appropriate materials, adaptation to cultural changes, and the effective transfer of skills from experienced artisans to younger generations. Ensuring consistency in quality, addressing competition from mass-produced alternatives, and preserving the authenticity of crafts further complicate the training process. Moreover, access to markets, government support, and the revitalisation of interest in crafts within communities are critical factors [10]. These multifaceted challenges underscore the need for comprehensive training approaches in crafts, whether technology-assisted or otherwise, to safeguard these invaluable cultural practices.

In this deliverable, a hypothesis is made that embracing eLearning and immersive training in crafts education can offer significant advantages. First and foremost, it introduces accessibility to craft education, breaking geographical boundaries. Learners from diverse locations can now access instructional materials and interact with instructors and peers, fostering a global exchange of craftsmanship. Moreover, eLearning platforms, such as Moodle, provide a centralised and scalable approach to education. They serve as a repository of knowledge, efficiently organised and catalogued for learners to explore. One of the most compelling benefits of eLearning is its ability to accommodate diverse learning paces [11]. Additionally, immersive training can support skills acquisition without the physical presence in a workshop or the physical presence of a tutor.

More specifically, concerning craft training, craft apprentices, often constrained by the rigidity of traditional settings, can now tailor their learning experiences to match their unique progress rates. eLearning ensures that learners are not overwhelmed by cognitive overload, offering ample time for the vital process of cognitive processing. This is particularly true when eLearning is designed to reduce intrinsic and extraneous cognitive loads [12]. Incorporating multimedia elements, interactive simulations, and self-assessment tools enhances the learning experience, keeping learners engaged and motivated [13]. At the same time, immersive interactive simulations can support free experimentation and practice without occupying a physical workshop and in a cost-effective way without the need for expensive material,



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electric power for running the workshop, or any other material sources that are required to physically practice a craft.

A critical issue in eLearning with a special application to craft is the management of cognitive load, a concept deeply rooted in cognitive psychology. Cognitive Load Theory (CLT) offers an intricate framework for understanding how the human cognitive system processes information and how the design of instructional materials [14] can shape the learning experience. eLearning platforms have been proven sufficient for the integration of principles from CLT, ensuring that instructional materials are thoughtfully designed to optimise the cognitive load of learners effectively [15–18].

This research work aims to bridge eLearning and immersive training on crafts with CLT, serving as a comprehensive guide for applying CLT effects in eLearning settings. eLearning platforms have revolutionised education, offering powerful tools and methods to enhance learning experiences [19,20]. It is argued that craft education can benefit from the principles of CLT. In the use cases described in this research work, the Moodle platform is employed [21], but any other e-learning platform can be suitable for applying the ergonomic knowledge developed by this research work. The rationale for selecting Moodle is the fact that it is an open-source, completely free eLearning platform that is currently used to implement more than 170k eLearning sites and more than 46M. courses. Of course, any other eLearning platform or CMS can be of use as a target system since the provided guidelines are platform-agnostic.

The innovation in providing guidelines to support training on traditional crafts lies in adopting a multifaceted approach that combines an established cognitive theory, such as CLT, with modern eLearning platforms. This fusion allows for a comprehensive understanding of cognitive processes while creating digital content for eLearning environments. These guidelines, rooted in cognitive phenomena, aim to optimise craft learning experiences. Both the guidelines and their application on a widely used eLearning platform are innovative dimensions in craft training. They offer a practical and scalable solution for crafting educational content in traditional crafts. This approach not only acknowledges the unique challenges of traditional craft education but also pioneers a new pathway for integrating cognitive theories into the digital landscape, enhancing the pedagogical strategies employed in training on traditional crafts.

2 Background and related work

Craft education and training are challenging since they introduce learners to a multifaceted world, where they must acquire skills, knowledge, and appreciation for cultural heritage. Balancing these learning objectives is a cognitive challenge. At the same time, the “low status” and “lack of prestige” of vocational options demotivate young people from following craft training [22]. In this work, we try to address the cognitive challenge, building on CLT, as conceptualised by John Sweller [14]. This theory offers guidance on how to structure instructional materials and virtual environments to optimise the learning process. Understanding and addressing the different facets of cognitive load when designing eLearning courses [15] can foster effective learning [16], reduce cognitive overload, and facilitate deep engagement with crafts.

The significance of integrating CLT within the realm of craft eLearning becomes evident as we consider the vast potential to enhance the educational experience. Tailoring eLearning materials and Moodle-based activities to accommodate the complexities of crafts and the distinct needs of learners can empower individuals to engage more deeply with these crafts. The successful application of CLT through Moodle stands as a bridge between tradition and innovation, safeguarding the preservation, appreciation, and continuation of crafts.

This section provides a comprehensive overview of the theoretical foundations and existing research in the domains of CLT, craft education, and eLearning platforms, with a particular focus on Moodle-based learning environments.

2.1 Cognitive Load Theory

CLT is a foundational framework in educational psychology that underpins our approach to designing effective eLearning experiences for crafts. CLT delves into the intricacies of how the human cognitive system processes information and how instructional materials’ design influences the learning experience. The framework identifies three distinct types of cognitive load: intrinsic, extraneous, and germane. Intrinsic cognitive load relates to the inherent complexity of the subject matter, extraneous cognitive load pertains to the load imposed by ineffective instructional design, and germane cognitive load concerns the cognitive effort that leads to meaningful learning.

The core effects associated with CLT have a close relevance in eLearning contexts and include the Split-Attention Effect, which underscores the significance of not overloading learners with disparate sources of information [23]. The Modality Effect highlights how presenting information through multiple sensory channels can enhance comprehension and retention [24]. The Redundancy Effect emphasises the negative impact of presenting the same information redundantly in different modalities [25]. In contrast, the Expertise Reversal Effect reminds us that what is effective for novices may not work for experts [26]. We will also consider the Guidance Fading Effect, which suggests that as learners gain proficiency, guidance should be gradually reduced, and the Imagination Effect, which underlines the power of mental imagery in learning [27]. The Self-Explanation Effect advocates for learners to articulate their understanding [28], and the Element Interactivity Effect [29] focuses on handling complex, interactive topics.

2.2 Knowledge Graphs in Education

Domain-specific KGs are important for understanding specialised fields. A review by Abu-Salih and Alotaibi (2024) stresses that KGs are knowledge representations for personalised learning, curriculum design, and content recommendations [30]. Weichselbraun et al. (2022) review the application of KGs in educational contexts [31]. Fan et al. (2024) studied knowledge mapping for KG development [32]. Beyond these foundations, recent comprehensive surveys show a significant increase in KG adoption within educational technology. Beyond these foundations, recent comprehensive surveys show a significant increase in KG adoption within educational technology. Qu et al. (2024) provide a large-scale review of KG-based educational systems, identifying common applications such as adaptive learning, resource recommendation, and curriculum sequencing, and highlighting challenges including data heterogeneity and ontology maintenance [33]. Similarly, a 2024 systematic review examines KG construction pipelines in education, discussing methods for ontology design, multimodal data integration, and evaluation criteria [34]. These studies reinforce the role of KGs as core infrastructure for personalised and semantically enriched learning technologies.

Additionally, modern approaches explore how KGs can serve as a structured context for LLM-based tutoring. For example, Abu-Rasheed et al. (2024) demonstrate that using KGs as factual scaffolds improves the accuracy and explainability of AI-generated learning recommendations [35]. This suggests a path for integrating KGs with intelligent craft-learning assistants.

2.3 Knowledge Graphs in Learning Crafting Skills

Abu-Rasheed et al. (20224) investigate knowledge management and transfer within arts and crafts organisations [36]. Handmade products rely on tacit knowledge, yet transfer methods lack standardisation. Improved codification, training, and dedicated repositories are crucial for preserving this knowledge. The construction of KGs using textual sources was proposed in [31]; however, this is insufficient for crafting education, where tacit knowledge and materiality require visual and physically informed learning sources.

Zabulis et al. (2023, 2024) describe a methodology for using KGs to document and preserve crafts using a dedicated ontology [37, 38]. The proposed methodology extends the CIDOC CRM model and is implemented via an online semantic representation system. This methodology uses semantic annotation to formalise craft concepts, linking knowledge to multimodal resources. It documents crafting entities: tools, materials, and movements. This is further extended in [39] by integrating ethnographic observations on crafting actions, products, tools, and materials. The representation links recordings to nominal and verbal descriptions, enabling inference, external links, and enrichment. The importance of well-structured and organised content to craft eLearning sources is underscored in [40]. [40] advocates that organising complex crafting processes in a KG ensures logical flow and meaningful connections between learning elements. The need for systematic, quantitative evaluation of 3D human movement using ground truth data, in real-world scenarios for traditional crafts, is emphasised in [41].

Recent work further expands the potential of KGs in traditional craft documentation and preservation. Wang et al. (2024) develop a cultural-heritage KG using graph-attention neural networks to unify diverse sources of heritage data, showing promising techniques for modelling heterogeneous material and process descriptions [42]. This is directly relevant to crafts where data may span artefacts, actions,



gestures, and practitioner knowledge. Similarly, Papadopoulou et al. (2025) propose a KG-based heritage modelling framework for 19th-century Greek bookbinding, capturing tools, binding styles, materials, and workshop practices through domain-specific ontologies [43]. This demonstrates that specialist craft domains can be semantically modelled for research, preservation, and training. Beyond KGs alone, digital knowledge-management systems have been introduced for traditional craft communities, enabling structured collection, semantic linking, and archiving craft processes. Huang & Chiou (2025) present such a system integrating multimedia, process steps, and expert annotations to support long-term preservation and transmission [44]. These approaches highlight the growing convergence between heritage preservation, knowledge engineering, and educational technology in craft domains. Finally, multimodal KG research provides methods suitable for integrating gestures, materials, and video exemplars, which are essential in craft education. Zhu et al. (2022) surveyed multimodal KG construction techniques capable of linking textual, visual, and motion data [45], offering a foundation for representing tacit craft knowledge that is difficult to capture through text alone.

2.4 Physics-Based Simulation and Interactive Training

The importance and applications of real-time simulation and training environments are increasing. Physics-based simulation uses numerical methods to approximate physical systems governed by fundamental laws like thermodynamics. FEMs are widely used for simulating deformable solids, fluids, and multi-phase interactions. Recent advances use GPU acceleration, allowing the coupling of mechanical and thermal events. Real-time simulation and training environments exhibit high utility in training environments. Replicating complex systems and scenarios with increasing fidelity and interactivity offers advantages for training across diverse disciplines [46–50]. A central theme is to replicate complex real-world scenarios for training [51, 52]. Key aspects include the need for realism and the integration of immersive technologies. Simulating realistic physical behaviour involves complex phenomena such as bending, cutting, or tearing of materials, enhances immersion and training effectiveness, and is a key challenge for enhancing realism [53].

In addition to these established foundations, recent surveys on real-time FEM simulation show increasing feasibility of interactive high-fidelity models due to model-order reduction, GPU-accelerated solvers, and hybrid explicit–implicit methods (Marinković et al., 2020; updated analyses in 2023–2024) [54]. These developments directly support craft-training contexts where soft material behaviour, deformation, and tool-material interaction must be simulated with both accuracy and responsiveness.

2.5 Physically Based Rendering in Educational Contexts

Physics-based simulation is crucial in computer graphics for the photorealistic animation of cloth, hair, translucent, and shiny objects. Computational methods for modelling and simulating traditional crafts have the potential to safeguard and ensure the transmission of crafting skills. The framework proposed in [55] simulates crafting actions using the FEM. Actions are classified into forming, subtractive, and additive based on their mechanics. In [56], their visualisation for documentation is demonstrated, using light transport simulation to handle challenging materials such as transparent and metallic.

In [57], an interactive model and simulation system address craft preservation using VR. The system implementation creates a knowledge base of materials, tools, and processes, enabling interactive



simulation for training. The digital model supports and enhances traditional craft training compared to purely physical methods.

Additional advances in Physically Based Rendering (PBR) research highlight how material-accurate shading models (microfacet BRDFs, subsurface-scattering models, and spectral rendering) enhance perceptual realism in educational and training applications. Modern PBR frameworks provide the computational basis for displaying fine-grained material cues — such as reflectance changes, tool marks, and deformation patterns — that are essential for evaluating craft outcomes [58]. Integrating such rendering approaches with KG-driven simulations enables precise visual feedback linked to semantically defined process states.

2.6 Craft Education via Online Social Platforms

Currently, there are several platforms dedicated to teaching crafts. For example, Craftsy is an online platform that offers video courses on a wide range of crafts, including knitting, quilting, sewing, and more [59]. Users can access pre-recorded classes taught by expert instructors. Udemy hosts a variety of online courses on crafts and DIY projects. Instructors from around the world create and offer these courses. While the quality and content can vary, it provides a diverse range of craft-related courses [60]. Skillshare is an e-learning platform that offers a wide range of courses, including those related to crafts and DIY. It is known for its creative and practical courses, with many focused on crafts. The Great Courses offers a selection of video courses, and they have offerings related to crafts. These courses are often taught by experts in their respective fields [61]. While not a dedicated eLearning platform, YouTube has a vast library of craft tutorials. Many artisans and crafters share their knowledge and skills through video tutorials [62]. This offers a wealth of free resources for those interested in crafts. Some craft schools and workshops have adopted e-learning and hybrid learning models. They offer both in-person and online classes, making craft education more accessible to a wider audience.

Moodle is a versatile open-source eLearning platform renowned for its rich feature set and widespread adoption in education and training [63]. Educators can seamlessly create and manage online courses, incorporating multimedia content, interactive assignments, and automated assessments. The user-friendly interface promotes easy navigation for instructors and learners alike. Moodle's flexible design allows for extensive customisation with themes and plugins, ensuring it can be tailored to diverse educational needs. Its comprehensive gradebook and analytics tools facilitate learner progress tracking and performance evaluation. Moodle's robust security measures prioritise data protection, and its mobile accessibility caters to various devices, making it an excellent choice for modern eLearning. With a supportive global community and seamless integration capabilities, Moodle remains a top choice for educational institutions, corporations, and organisations worldwide [64].

2.7 Extending Learning Paradigms in Craft Education

In craft education, focusing on digital transformation while preserving the essence of craftsmanship and cultural heritage is important. The landscape of learning paradigms in craft education currently includes or has the potential to include in the future several novel learning approaches, such as:

Blended Learning Models: craft education often thrives on hands-on learning, apprenticeships, and the transfer of practical skills from one generation to the next [65]. The fusion of practices with digital tools



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and platforms, such as Moodle, can create blended learning models that combine the tactile experience of crafting with digital resources.

Microlearning and Skill-Based Learning: As the educational landscape evolves, microlearning has gained prominence [66] in the context of crafts. Delivering skill-based modules in small, easily digestible segments through eLearning platforms is such a paradigm.

Gamification and Interactive Learning: Interactive and game-based learning approaches [67] can engage learners and make the process of acquiring craft skills more enjoyable. Gamified elements can encourage learners to explore the art of crafting while mastering skills in an immersive, enjoyable manner [68].

Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality(MR): New immersive technologies have a good track record in education and training and have been used in the field of Craft training [69–76]. eLearning as a digital form of education has the potential to support or be combined with immersive learning experiences, with the benefit of being able to emphasise its ability to simulate real craftwork environments.

Personalised Learning and Adaptive Platforms: Personalised learning experiences tailored to individual learners can be facilitated in contemporary education.

Lifelong Learning and Cultural Preservation: Craft education often extends beyond formal schooling, making lifelong learning essential.

3 CLT for Craft Practice Education and Training

Proposing craft-related guidelines for the application of the CLT effects in the eLearning context is the objective of this section. Although the proposed guidelines can be applied to other eLearning contexts too, in the context of this work, we are focusing strictly on how to enhance eLearning in traditional craft contexts.

To simplify the understanding and application of these guidelines, we have kept the same structure as in CLT, and thus, we are providing guidelines per effect. The consolidation of these guidelines resulted in the definition of a small set of guidelines that can be applied horizontally, and these are presented in a separate section. The validation of the usage of these guidelines is provided in Section 7 through a use case of implementing eLearning education and training material for a representative craft instance.

3.1 Effects of CLT Considered in this Work

This section provides a short introduction to the effects of CLT before moving forward to the definition of practical guidelines for their implementation in the eLearning context.

The Worked Example Effect refers to providing learners with worked examples or step-by-step solutions to problems before they attempt to solve similar problems. This effect aims to enhance learning and problem-solving skills by allowing learners to see how a task or problem is solved before they try it themselves and is applied by (a) the provision of exemplar solutions or models of how to solve a particular type of problem, (b) Scaffolding Learning by providing learners with guidance and support, and (c) Gradual Release of Responsibility by limiting over time the level of guidance provided.

The Problem-Completion Effect aims to ensure that learners pay sufficient attention to the worked examples to provide learners with completion problems [74]. A completion problem is a partially worked example where the learner has to complete some key solution steps. Sweller [77] asserted that completion problems are effective because they incorporate a problem-solving component, prompting learners to engage with the problem at a sufficient depth to grasp crucial information. This approach avoids overloading working memory by steering clear of complete problem-solving. In completing the problem, learners are required to focus on and process the pre-solved portion before responding to the unfinished steps. Essentially, completion problems represent a hybrid approach, combining aspects of both a worked example and a problem to be solved [78].

The Split-Attention Effect occurs when learners need to divide their focus between at least two sources of information that are intentionally separated either spatially or temporally [79]. Spatial split attention occurs when a learner is required to simultaneously focus on two or more spatially separated sources of information. This occurs when information that is essential for understanding a concept is presented in different locations or on different parts of a display. In such cases, the cognitive load increases as individuals need to split their attention between multiple sources, which can hinder comprehension and learning. Temporal split attention refers to the division of a learner's attention over time due to the presentation of information at separate points in time. It occurs when critical information is presented in a manner that requires individuals to remember and integrate information from an earlier point in time when processing subsequent information.



The Modality Effect refers to the idea that people learn more efficiently when information is presented in multiple modalities (e.g., text and spoken words). The rationale behind the Modality Effect is that by engaging both the visual and auditory processing systems, learners have more opportunities to encode and consolidate the information, resulting in better learning outcomes [80]. This effect is related to the broader field of multimedia learning theory, which explores how the presentation of information in multiple modalities can impact learning and memory.

The Redundancy Effect refers to the principle that presenting the same information through multiple modalities (typically, visual and auditory) can lead to cognitive overload and reduced learning effectiveness. In other words, when learners are presented with redundant information, where the same content is provided in both written text and spoken narration, it can hurt their ability to comprehend and remember the material [25]. The Redundancy Effect is the opposite of the Modality Effect, which suggests that presenting information in multiple modalities enhances learning. The key distinction is that while the Modality Effect advocates for using different modalities to convey complementary information (e.g., visuals and spoken explanations), the Redundancy Effect warns against presenting the same information in redundant ways (e.g., showing on-screen text and simultaneously reading it aloud). Both Modality and Redundancy Effects are subjects of constant research as new media and learning technologies arise [81–84].

The Expertise-Reversal Effect describes how the impact of instructional methods can change based on the level of expertise or prior knowledge of the learners. In essence, it suggests that what is an effective teaching strategy for novices may not be as effective for experts and vice versa [85].

The Guidance-Fading Effect involves gradually reducing the level of guidance provided to learners as they gain proficiency and expertise in solving problems or completing tasks. The key elements of the Guidance-Fading Effect include (a) guidance at the beginning of the learning process with detailed step-by-step guidance, such as fully worked examples or explicit instructions [86]; and (b) a gradual reduction in guidance so that learners become more familiar with the problem-solving or task-completion process and demonstrate proficiency, and the level of guidance is progressively reduced. Independence is the ultimate goal to empower learners to solve problems or complete tasks independently, relying on their own understanding and problem-solving skills.

The Imagination Effect is a cognitive phenomenon in which individuals tend to remember information or concepts more effectively when they actively engage their imagination to visualise or mentally simulate the content they are trying to learn [87]. By mentally creating vivid images or scenarios related to the material, learners can enhance their understanding and retention of the information. This effect suggests that imagination and visualisation can be powerful tools for encoding and recalling knowledge.

The Self-Explanation Effect is a learning and cognitive phenomenon that pertains to the practice of self-explanation. It involves learners explaining concepts, problems, or solutions to themselves in their own words as they engage with educational materials. When individuals actively articulate and clarify their understanding, they tend to learn and retain information more effectively [28]. Self-explanation helps learners identify gaps in their comprehension and reinforce their grasp of the subject matter, promoting deeper understanding.

The Element Interactivity Effect refers to the idea that the difficulty of learning and understanding a particular topic or subject is influenced by the degree of interactivity or complexity among the elements or components of that topic. This effect suggests that learning is more challenging when the subject

matter is highly interactive or when multiple elements must be understood relative to one another [29]. The complexity and interdependence of these elements can make it more difficult for learners to grasp the material, particularly for novices or learners with limited prior knowledge.

3.2. Guidelines per CLT effect

The proposed guidelines are the result of working with craft practitioners, craft communities, and craft training organisations in the context of the Horizon2020 project Mingei and the Horizon Europe project Craeft. In Mingei, a protocol for craft representation and presentation has been developed as the outcome of the interdisciplinary effort between heritage scientists, ethnographers, anthropologists, craft practitioners, digitisation experts, and experts on modern ICT [88]. This protocol sets the foundations for understanding traditional crafts and presenting them for information, education, and training.

Rooted in this protocol, in Craeft, the objective is to propose advanced ethnographic strategies for craft understanding and the application of modern technologies in craft training. Part of the scientific process was the analysis of current craft training curricula in collaboration with craft training institutes in Europe, such as the European Centre for Research and Training in Glass Arts (CERFAV). CLT was considered since it is well-suited for digital training methods. In collaboration with craft training organisations, we formulated the wireframes of exemplary courses that could bring part of the training process into an eLearning context. These wireframes were then studied in conjunction with the available digital material such as (a) ethnographic recordings from a glass workshop, photographic documentation, (c) 3D models of tools, machines, and the workshop itself, (d) rendered virtual representations of the workshop, (e) visual abstractions of fundamental glassblowing actions in the form of rendered 3D animations, (f) visual abstractions in the form of cartoonized images, and (g) educational material from textbooks regarding the glassblowing craft.

The next step was to study the facilities offered by modern eLearning systems in terms of authoring interactive and multimodal training material. This was important to identify the forms of training experiences that can be supported by the current state of the art in conjunction with the availability of the aforementioned digital material. During this study, the guidelines discussed in this section were authored to optimally bring together digital material and training experiences.

3.2.1 Worked Example Effect

The Worked Example Effect can be applied to the eLearning context through the application of the following guidelines:

- G_WEE1. Provide craft-specific worked examples in the form of step-by-step demonstrations of key techniques and processes;
- G_WEE2. Use high-quality visuals and depict the fine details of the craft, and use close-up shots and visualisation to help learners see intricate work.
- G_WEE3. Include narration and explanation alongside the visual demonstrations to explain the purpose and significance of each step, the tools and materials used, and any historical or cultural context.
- G_WEE4. Demonstrate variations in techniques and styles that are relevant to the specific craft, since different regions and cultures may have their unique approaches.



- G_WEE5. Incorporate hands-on interactive activities that allow learners to practice the techniques they have observed (through imitation), such as virtual workshops and simulations;
- G_WEE6. Provide progressive complexity on the worked examples and interactive activities, starting with basic techniques and gradually introducing more complex skills;
- G_WEE7. Offer information on the tools and materials used in the craft to explain their purposes, how to select them, and where to obtain them;
- G_WEE8. Emphasise safety guidelines and best practices, particularly for crafts that involve potentially hazardous tools or materials;
- G_WEE9. Organise field trips (including virtual trips) and invite guest artists and craftspeople to share their experiences and expertise with learners.

3.2.2 Problem Completion Effect

The following guidelines are proposed for applying the Problem-Completion Effect:

- G_PCE1. Introduce learners to craft projects that are partially completed, especially in the case of complex or multi-step tasks.
- G_PCE2. Ensure that the partially completed craft project represents the initial or starting state of the craft to help learners understand the project's context and how to proceed.
- G_PCE3. Accompany the partially completed project with explanations of the techniques and steps taken to reach that point to help learners understand the craft's methodology and thought process.
- G_PCE4. After presenting the partially completed project, encourage learners to actively engage with it. This can include asking them to complete the remaining steps, add intricate details, or identify areas for improvement.
- G_PCE5. Over time, gradually reduce the level of completion provided in the partially finished craft projects to align with learners' increasing proficiency and confidence in completing similar projects independently.
- G_PCE6. Offer constructive feedback on learners' attempts to complete the partially finished craft projects to reinforce correct techniques and address misconceptions.
- G_PCE7. Present a range of craft projects with varying levels of complexity, gradually increasing in difficulty;
- G_PCE8. Encourage meta-craftsmanship by motivating learners to think about their craft process and reflect on the techniques and strategies they use, thus helping them develop problem-solving skills specific to crafts.
- G_PCE9. Scaffold craft learning by providing more guidance for novice learners in the early stages of craft training and gradually reducing the level of support.
- G_PCE10. Consider the craft context by applying the Problem Completion Effect in a way that aligns with the specific craft context and objectives. Different crafts may require tailored approaches based on the craft's nature and cultural significance.
- G_PCE11. Encourage collaborative craftsmanship. Learners can work in pairs or groups to complete partially finished craft projects, fostering discussion, sharing traditional techniques, and peer learning within the craft community.

3.2.3 The Split-Attention Effect

When considering spatial split attention, the following guidelines come into use:



- G_SAE1. Organise eLearning content effectively to reduce the existence of spatially separated sources.
- G_SAE2. Use visuals such as images or videos that are closely aligned with the accompanying text or explanations to help learners integrate information from a single source more easily.
- G_SAE3. Minimise scrolling that may disrupt the flow of information and lead to spatial split attention. Ensure that content fits within a single screen or provides clear navigational cues.
- G_SAE4. Provide sequential learning by presenting information in a logical sequence and avoiding introducing concepts that depend on earlier content before providing the necessary foundation.
- G_SAE5. Maintain a consistent pace throughout a lesson and provide sufficient time for learners to absorb the content before moving on.
- G_SAE6. Segment instructions by dividing complex instructions into smaller, manageable steps or modules, allowing learners to focus on one step at a time and build their skills progressively.
- G_SAE7. Provide redundancy by using multiple formats. Combine text explanations with visuals or demonstrations, allowing learners to access the same information from different sources.
- G_SAE8. Ensure spatial contiguity by placing related information, such as written instructions and visual examples, nearby.
- G_SAE9. Ensure temporal contiguity by presenting information in a logical order, allowing learners to integrate it as they encounter it. Avoid jumping between past and present information.
- G_SAE10. Segment complex craft projects or techniques into smaller, manageable sections or modules to assist in the step-by-step understanding of crafts.
- G_SAE11. Facilitate signalling by using clear cues or markers to highlight relationships between different pieces of information, such as arrows, connectors, or highlighting to indicate connections between text instructions and accompanying visuals.
- G_SAE12. Provide a summary or an overview before or after presenting information on a specific craft technique to help learners understand the big picture and how different elements are related.
- G_SAE13. Incorporate interactive elements into the eLearning materials and offer activities that allow learners to actively practice craft techniques, fostering deeper understanding.

3.2.4 The Modality Effect

For the Modality Effect, the following guidelines come into play:

- G_MDE1. Accompany text with narration to enhance comprehension and retention.
- G_MDE2. Use relevant visuals such as images, diagrams, and animations, alongside text and narration, to illustrate craft techniques, materials, and finished products, making the content more engaging and memorable.
- G_MDE3. Maintain consistency and ensure that content is presented similarly across different modalities (text, narration, visuals) to prevent confusion and reinforce learning;
- G_MDE4. Organise information into smaller, manageable sections or modules to allow learners to focus on mastering one aspect of the craft at a time, making it easier to process information in different modalities.
- G_MDE5. Incorporate interactive elements that encourage active engagement with the craft material. Create interactive exercises, simulations, or crafting activities that enable learners to apply what they have learned;
- G_MDE6. Give learners control over the pace of their craft learning and enable them to review and revisit content presented in different modalities as needed.



- G_MDE7. Minimise unnecessary distractions that can interfere with the processing of craft-related information presented in different modalities.
- G_MDE8. Keep eLearning content engaging by using storytelling, real-life examples, and relevant craft scenarios. Create content that captivates learners' interest, motivating them to engage with multiple modalities.
- G_MDE9. Test on various devices to ensure that the eLearning course is compatible with various devices and screen sizes to accommodate different learning preferences and environments, including those of craft enthusiasts who may access the course on different devices.

3.2.5 The Redundancy Effect

For the appropriate use of redundancy, the following guidelines can be followed:

- G_RDE1. Use redundancy sparingly and avoid presenting the same information in both text and narration unless it is essential for clarity or accessibility reasons. In the craft learning context, redundancy should be used judiciously, such as when explaining complex techniques.
- G_RDE2. Prioritise complementary information and leverage different modalities to present complementary content. For example, use visuals (images or videos) to visually demonstrate craft techniques while the narration provides explanations;
- G_RDE3. Consider the diverse needs and preferences of your craft learners. Some may benefit from redundancy, while others may find it distracting. Consider offering options for learners to choose their preferred modality, such as providing text and audio options.
- G_RDE4. Emphasise key craft points by highlighting key craft techniques, important terminology, or critical information. Emphasise the most vital content rather than reiterating every detail.
- G_RDE5. Allow craft learners to control the pace of content delivery. They should have the option to skip or replay redundant information based on their understanding and needs, promoting a personalised learning experience.
- G_RDE6. Engage craft learners through interactive elements such as quizzes, discussions, and problem-solving exercises. Interactivity can reinforce learning without relying solely on redundancy, making the learning experience more engaging.

3.2.6 The Expertise Reversal Effect

To ensure that all learners get content that is sufficient for their level of learning and expertise, the following guidelines are suitable:

- G_ERE1. Begin by assessing the learners' prior knowledge and expertise in crafts. Use pre-assessments, quizzes, or self-assessments to understand their current skill level and familiarity with craft techniques.
- G_ERE2. For novice craft learners with little or no prior knowledge, provide explicit and structured instruction. Use clear explanations, step-by-step guidance, and scaffolded learning activities to build a solid foundation in craft techniques. Emphasise foundational concepts, tools, and terminology commonly used in the craft;
- G_ERE3. For learners with moderate expertise in crafts, offer a balanced approach that combines guidance with opportunities for independent thinking and problem-solving. Provide guided problem-solving activities that encourage critical thinking and the application of craft knowledge to practical



scenarios. Use real-world craft projects, case studies, and more advanced techniques to deepen their understanding and skills.

- G_ERE4. Highly knowledgeable craft practitioners should engage in open-ended, exploratory, and problem-based learning approaches. Encourage independent exploration, research, and self-directed learning, allowing experts to apply their advanced knowledge to real-world craft challenges and creative projects;
- G_ERE5. Utilise adaptive learning technologies or techniques that can adjust the level of instruction based on learners' responses and demonstrated expertise. This ensures that each craft learner receives content and activities appropriate to their skill level.
- G_ERE6. Provide options to mixed groups of craft learners with varying levels of expertise, consider offering multiple pathways or content modules that cater to different expertise levels within the same course. This allows craft learners to self-select the most suitable learning path.

3.2.7 The Guidance Fading Effect

To ensure that the level of guidance is always optimal while moving forward on a learning path, the following guidelines can be used:

- G_GFE1. Provide explicit and highly guided instruction for novice craft learners, such as complete worked examples, detailed step-by-step solutions, or comprehensive instructions for craft projects. Clearly explain the concepts, techniques, and tools involved in crafts to build a strong foundation.
- G_GFE2. Continuously assess and monitor the progress of craft learners as they engage with the materials and complete projects, and look for signs of increased proficiency and understanding. Use formative assessments, quizzes, or skill checks to gauge when learners are ready for reduced guidance.
- G_GFE3. Gradually reduce the level of guidance provided as craft learners demonstrate growing competence and familiarity with craft techniques. Begin by omitting some steps, providing fewer hints, or requiring more independent problem-solving;
- G_GFE4. Scaffold the craft learning experience, maintaining a balance between support and independence and adjusting the level of guidance according to the evolving needs of craft learners. Consider individualised learning paths based on each craft learner's skill development.
- G_GFE5. Use prompts and hints instead of providing complete solutions to nudge craft learners in the right direction when they encounter difficulties. These prompts should encourage them to think critically and apply their craft knowledge effectively.
- G_GFE6. Challenge critical thinking for more proficient learners by introducing open-ended or complex craft projects that require critical thinking, analysis, and the synthesis of techniques. Encourage them to explore alternative craft techniques and creative problem-solving strategies.
- G_GFE7. Encourage reflection and metacognition by prompting craft learners to reflect on their craft projects and the techniques they have applied. Encourage metacognition to foster a deeper understanding of their craft learning process. Ask them to journal their progress and reflect on what they have learned.
- G_GFE8. Be responsive to individual craft learner needs and offer support when needed. If some learners are struggling with particular techniques or projects, be ready to provide additional guidance or support to prevent frustration and ensure successful learning.

3.2.8 The Imagination Effect

To ensure that imagination supports learning, the following guidelines are essential:

- G_IME1. Visualise complex concepts by encouraging learners to visualise intricate craft techniques or artistic processes by providing detailed, descriptive language in the eLearning content. Use analogies or metaphors to simplify complex concepts and stimulate learners' imagination. Complement textual information with visuals, diagrams, and multimedia that help learners create mental images;
- G_IME2. Incorporate storytelling elements in your eLearning materials. Craft narratives and scenarios that depict the historical context or cultural significance of crafts. Engage learners' imagination by creating relatable situations that illustrate the key concepts and the creative journey of craftsmen.
- G_IME3. Utilise interactive simulations or virtual environments to immerse learners in the world of crafts. This hands-on experience allows them to apply their knowledge in realistic scenarios, making abstract concepts more tangible. Provide opportunities for learners to experiment with craft techniques in a safe, virtual space.
- G_IME4. Develop creative assignments that require learners to produce craftwork or understand other people's craftwork. These assignments can encourage imaginative thinking, problem-solving, and a deeper connection to the craft.

3.2.9 The Self-Explanation Effect

Developing critical thinking can be facilitated through the following guidelines.

- G_SEE1. Incorporate self-questioning by encouraging learners to ask themselves questions as they study, such as "How is this craft technique applied?" or "Why is this design element important?" Self-questioning prompts active engagement and self-explanation, helping learners articulate their understanding.
- G_SEE2. Provide prompts within the eLearning content that guide learners in self-explaining craft concepts. For example, include questions like, "Can you explain the significance of this craft tradition in your own words?" These prompts serve as cues for learners to engage in self-explanation.
- G_SEE3. Reflect and summarise by encouraging learners to periodically pause and reflect on what they have learned in the context of crafts. They can create summaries, mind maps, or written reflections to consolidate their understanding and explore how craft techniques connect with cultural heritage.
- G_SEE4. Incorporate opportunities for peer review and feedback on craft projects and explanations. When learners explain craft concepts to their peers, it reinforces their understanding and allows them to learn from one another.
- G_SEE5. Provide feedback on learners' self-explanations to reinforce correct explanations and offer guidance in areas where learners may need further clarification. Feedback promotes self-improvement and the development of nuanced understandings of crafts.
- G_SEE6. Integrate active learning activities that require learners to solve problems, complete craft exercises, and explain their thought processes as they work through the material. Active participation enhances self-explanation and hands-on craft learning.
- G_SEE7. Teach metacognitive skills that help learners monitor their understanding of crafts. Encourage them to reflect on their learning strategies and adjust their approaches as needed. Metacognition is closely tied to the self-explanation effect and can lead to more effective self-regulated learning.

3.2.10 The Element Interactivity Effect

For the Element Interactivity Effect, the following guidelines can be considered.

- G_EIE1. Assess the learner’s prior knowledge before designing your eLearning course on crafts. Gauge the appropriate level of complexity and interactivity based on the learners’ expertise;
- G_EIE2. Break down complex topics related to crafts into smaller, manageable chunks of information. Present these chunks in a logical sequence or order, ensuring that learners grasp one concept before moving on to the next.
- G_EIE3. Use visual aids, diagrams, charts, and graphs to represent the relationships and interactions between elements of crafts. Visuals can make complex content more accessible and understandable, especially when explaining intricate crafting techniques or designs.
- G_EIE4. Provide explanations and examples that accompany the presentation of complex concepts in crafts. Use real-world examples or scenarios to illustrate how various elements interact within craft processes.
- G_EIE5. Incorporate interactive simulations or scenarios specific to crafts that allow learners to explore the interactivity of complex crafting systems. This hands-on experience can deepen their understanding of crafting techniques and artistic processes.
- G_EIE6. Offer structured guidance and scaffolding as learners work through complex craft topics. Provide hints, prompts, or step-by-step instructions to help them navigate intricate crafting methods and cultural contexts.
- G_EIE7. Encourage peer collaboration and discussion among learners studying crafts. Learners can benefit from sharing their understanding of crafting traditions, artistic interpretations, and techniques, providing different perspectives, and helping each other navigate the interactivity of crafts.
- G_EIE8. Offer opportunities for learners to pause and reflect. Encourage them to think critically about how the various elements of craft-making and cultural significance interact and how their understanding of crafts has evolved.
- G_EIE9. Implement frequent assessments and quizzes that focus on the interactivity of elements within the subject matter of crafts. Assess learners’ ability to apply crafting techniques and understand the cultural context of crafts;
- G_EIE10. Provide feedback on assessments and encourage learners to review and revisit complex topics in crafts as needed. Feedback can help clarify misunderstandings about crafting processes and the historical background of crafts.
- G_EIE11. Teach metacognitive skills that help learners monitor and adjust their learning strategies, especially when dealing with highly interactive content related to crafts. Encourage learners to reflect on their learning experiences.
- G_EIE12. Encourage critical thinking and problem-solving skills, especially in the context of crafts. Complex and interactive subjects often require learners to think analytically, creatively interpret crafting techniques, and apply their knowledge in culturally meaningful ways.

3.2.11 Horizontal Guidelines

In general, the following horizontal guidelines can be applied when creating educational material in eLearning contexts:



- G_HG1. Regularly review and revise your eLearning craft content and adapt your eLearning materials on crafts based on learner feedback, performance data, and evolving needs. Keep the course content up-to-date and aligned with best practices in instructional design for craft education.
- G_HG2. Receive and offer feedback.
 - Gather feedback from craft learners to understand their preferences;
 - Provide timely and constructive feedback on learners' craft projects and techniques. Highlight what they did correctly and suggest improvements to enhance their craftsmanship.
 - Encourage learners to critique each other's work constructively, fostering improvement.
 - Encourage learners to take ownership of their craft learning journey.
- G_HG3. Encourage discussion, sharing, and peer learning. Create forums or discussion boards where learners can share their imaginative interpretations and associations related to crafts. Encourage learners to discuss their creative ideas, inspirations, and the emotional connections they form with the craft. Encourage peer collaboration and discussion within the craft learning community. More experienced craft learners can assist those with less expertise, creating a valuable learning experience for all participants.
- G_HG4. Be mindful of accessibility. Make the eLearning course content accessible to individuals with various learning needs, including those who may rely more on one modality than another. In certain cases, redundancy may be necessary to accommodate individuals with different learning needs, such as those with visual or auditory impairments. Ensure your craft eLearning course is accessible to all learners by providing alternative formats and options. Achieving such compatibility would require that web content be authored following the web content accessibility guidelines [89], which, of course, requires expertise, time, and resources. More analysis on adhering to these guidelines is out of the scope of this research work; however, we provide here some basic guidelines that would enhance the accessibility and usability of eLearning content and are easy to apply and integrate into your eLearning authoring workflow.
 - Make sure that standard web-based content complies with basic accessibility guidelines. Use headings, provide alternative texts for all visual elements, avoid using tables for layouts, use simple language, etc. Facilitate accessibility checkers embedded in HTML editors and check your content before publishing.
 - Make sure that your web-based content is easily located within a page. Use a screen reader to evaluate the accessibility of your navigation and whether users can easily locate eLearning content.
 - Provide audio-only alternatives for eLearning content by facilitating online text-to-speech facilities.
 - Provide descriptions of what is presented in video elements, and author subtitles for videos. Use video transcript tools to simplify authoring and provide access to the text of the transcript.
 - Provide users with control over the size of text and contrast settings to enhance visibility for users with reduced visual acuity.
 - Support text translations in multiple languages, including translations of audio-visual content, subtitles, alternative texts, and media element descriptions;
 - Ensure that eLearning site navigation is seamlessly and consistently presented across different languages.
 - Follow the guidelines presented in the previous sections to enhance the usability of web content. This will happen automatically since usability is strongly bound to the reduction of cognitive load.



- G_HG5. Evaluate learning outcomes. Assess the effectiveness of the instructional approach by measuring learning outcomes and learner satisfaction. Use feedback and data to make continuous improvements to the eLearning experience for crafts.
- G_HG6. Do not disregard the context.
 - Include case studies and craft history context to showcase the significance of crafts from a cultural or historical perspective.
 - Highlight the importance of preserving and documenting crafts. Discuss the role of contemporary technology in documenting and promoting these crafts.
 - Promote respect for tradition and cultural sensitivity, and encourage learners to appreciate the heritage and significance of crafts.
- G_HG7. Celebrate independence. When craft learners reach the point of completing projects independently and mastering craft techniques, celebrate their achievements and emphasise the value of self-directed craft learning.

3.3 Good Practice Guide on Applying the Provided Ergonomic Knowledge

Guidelines, serving as directives for individuals to perform specific tasks effectively and efficiently, can provide a framework guiding designers and developers in making appropriate decisions [90]. For many years, guidelines have constituted an inexpensive and widely used tool. However, despite the indisputable value and importance of such knowledge, several studies investigating the use of guidelines and standards by designers and developers have concluded that they are frequently ignored. This is partly attributed to the challenging exploitability of such knowledge and partly due to the medium of its embodiment, which often gives rise to issues of ineffectiveness and a lack of user-friendliness [91].

To combat this issue, we have followed a dual approach in this research work. The first is to provide, in this section, a good practice guide that provides the basic principles for reusing these guidelines. The second is to provide use-case examples of their application in actual circumstances, which is the subject of the next section. Use-case examples fall in the category of the Worked Example Effect discussed in the previous section.

3.3.1 Familiarisation and Preparation

The first step in applying these guidelines would require the designer to achieve a basic understanding of the concepts of the effects of CLT through a one-page introduction, such as the one provided in Section 3. This introduction aims at providing basic orientation and be capable of following the guidelines provided per effect. The second step is to become familiar with the guidelines by simply studying them to understand how each effect should be considered during the design of the eLearning content.

Having achieved a familiarity with the concepts described by the guidelines, the next issue to be considered is the availability of instructional content or the capacity to develop different forms of instructional content. This is essential to define the basic tool set that will be used during authoring instructional content.

The next issue to be considered is the end users of the educational content and how these can be grouped based on their knowledge and expertise. This grouping will support the scaffolding of the training courses.



Next, how progress should be evaluated, and the forms of exercises, assignments, and projects that are of interest for the specific eLearning content should be considered. A generic understanding of what is expected to be evaluated is sufficient for this phase of the design.

3.3.2 Design of Educational Content

Based on the aforementioned information, the designer of the eLearning course can start by defining an appropriate categorisation. The category structure will provide the basic principles of scaffolding, will define the basic educational sections, and will guide the selection of modalities. At the same time, it will support the visualisation of the type of assessment that will support the evaluation of the learning outcomes for each category. This will act as a good starting point for the creation of actual educational content.

Regarding the creation of such content, it is highly advised that the examples provided in Section 6.3 be studied. These examples do not cover exhaustively all the types of courses that can be authored by following these guidelines, but are considered a good starting point. Studying these examples provides information on how to apply most of the effects presented in the previous section, except for the Expertise-Reversal Effect and the Guidance-Fading Effect, which are most efficiently covered through scaffolding learning.

Regarding the evaluation of educational outcomes, studying the examples of Section 6.4 can provide useful ideas on different forms of assignments that can support different effects and achieve various educational goals.

3.3.3 Creativity in the Design of Educational Content

Although the application of the aforementioned guidelines is considered important in this research work, it cannot guarantee the success of the authored courses. As in any human activity, creativity plays a significant role in the authoring of craft educational content and can influence both the design and delivery of content. Crafting, by its nature, is a creative endeavour, and incorporating creativity into educational materials aligns with the hands-on and expressive aspects of traditional crafts. Creative authoring involves not only presenting factual information but also engaging learners' imaginations and fostering a deep connection to the craft. By infusing creativity into content creation, educators can employ diverse and innovative teaching methods that resonate with learners, making the educational experience more engaging and memorable. Creative instructional materials, such as visually compelling presentations, interactive simulations, and imaginative scenarios, capture learners' attention and facilitate a deeper understanding of craft concepts. Most of these aspects fall under the Modality Effect and cannot be simply dealt with by adhering to the provided guidelines. In this context, creativity can promote a dynamic and adaptive approach to content delivery, ensuring that educational materials remain vibrant and responsive to the evolving needs of learners.

3.3.4 Enhance Acceptability through a User-Centred Design Approach

Incorporating a user-centred design approach, involving a small set of users from all targeted user groups in all stages of the design process, can greatly enhance the effectiveness of educational materials. Seeking feedback in the initial phases becomes a fundamental step in ensuring that the content is not only relevant



D4.1 Craft simulation and immersive craft training



but also aligns with the preferences and needs of the intended audience. Early involvement of users allows for the identification of potential challenges, misconceptions, or areas that require improvement, promoting a collaborative and learner-centric development process. This iterative feedback loop, integral to user-centred design, ensures that the final educational materials resonate well with users, enhancing engagement and overall effectiveness. By actively involving learners from the outset, educators and instructional designers can create content that is not only accurate and informative but also tailored to the specific requirements and expectations of the target audience.

4 Methodology

The methodology proposed by this work is organised into three interconnected layers that structure how craft knowledge is modelled, simulated, and delivered to learners (see Figure 1). At the top, the Semantic Layer encodes craft knowledge in a formal, machine-interpretable form, including process steps, materials, constraints, decision points, and expert exemplars. This layer provides the conceptual grounding for the entire pipeline, ensuring interoperability through CIDOC-CRM-aligned models and enabling the system to reason about actions and their intended outcomes.

Building on this foundation, the Offline Simulation Layer translates semantic descriptions into executable physical scenarios. Here, the FEM engine computes material deformation, tool-material interaction, and predictive behaviour, while an environment-instantiation module reconstructs the workspace, tools, and task objectives directly from the knowledge graph.

Finally, the Visualisation and Feedback Layer presents simulated craft processes to learners through interactive, high-fidelity environments. Physically based rendering provides realistic material appearance and surface detail, while the Apprentice Studio and eLearning portal deliver scenario execution, theory, and examples. Learners interact through virtual tools and input devices, receiving perceptually rich, action-linked feedback that supports procedural understanding and reflective learning.

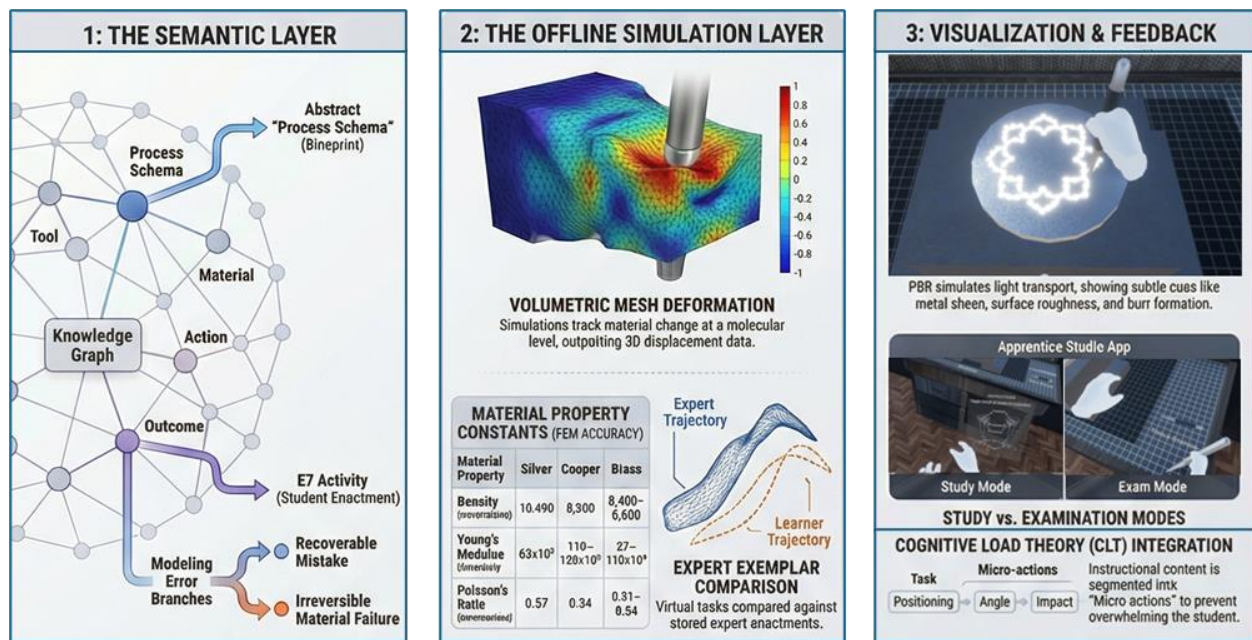


Figure 1. Methodology followed by this research work

4.1 Semantic layer

The Semantic layer formalises craft knowledge in a machine-interpretable form. It captures not only the physical entities involved in a craft process but also the actions performed, the agents responsible, and the procedural knowledge that governs execution. Craft processes are modelled as Knowledge Graphs

aligned with CIDOC-CRM. These graphs encode process schemas, action sequences, decision points, and error pathways, while explicitly linking action execution parameters to expected physical outcomes.

4.1.1 Process Schema

In modelling traditional craft processes, it is essential to distinguish between the physical entities involved, the actions performed, the agents responsible, and the underlying procedural knowledge that guides activity. A process schema, derived from ethnographic studies and authored by ethnographers and information scientists, outlines foreseen temporal, causal, or conditional relationships, action sequences, and decision-based divergences. This schema is a graph where nodes are steps and edges define relationships. Errors and corrective actions are modelled as branches. Visualised in UML, the graph shows step inputs and outputs. Enacting this schema generates a process, comprising physical interventions, observations, and judgments, all characterised as actions. Figure 2 illustrates the KG structure of a craft Process Schema.

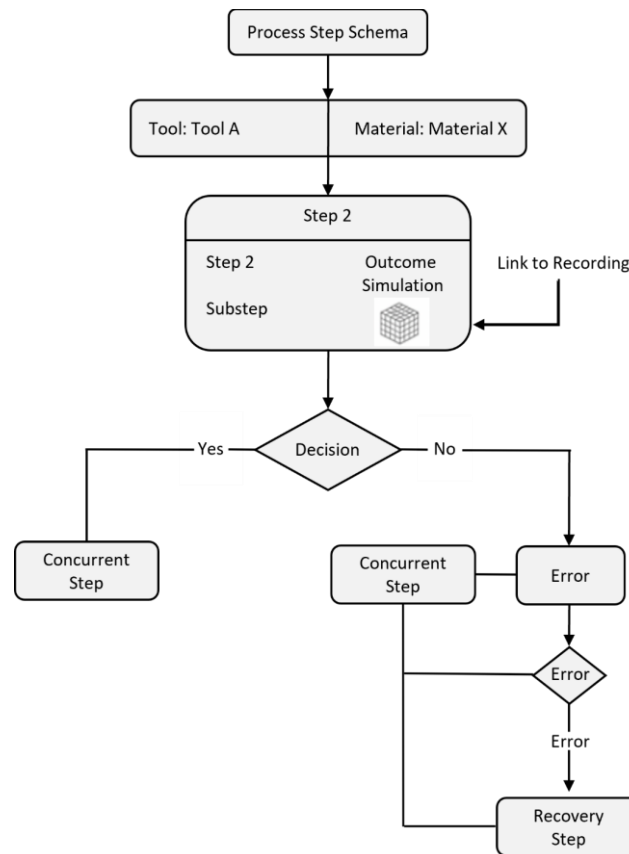


Figure 2. Knowledge Graph Structure of a Craft Process Schema

Each node references the (a) tools and workpieces employed, (b) their material properties, (c) prerequisite conditions, and (d) a set of associations between action execution parameters and action outcomes. The knowledge elements in (a), (b), and (c) are described geometrically and physically, as well as the execution parameters in (d). The action outcomes in (d) are the states of the affected entities during and after the action, encoded as FEM volumetric mesh animations. These knowledge elements are represented

physically and semantically. Physical properties and parameters are numerical, and their values are in the International System of Units (SI). These are the values of geometrical and material properties over time. Objects and actions are knowledge elements registered to a knowledge structure used as a lexicon. Each elementary representation contains a link to its thesaurus entry and its recording [39]; 3D for objects and 4D for actions.

4.1.2 Process Semantic Model

The model represents workpieces as the primary entities that transform a crafting process. Whether originating as raw material or as the output of a previous production stage, each workpiece is consistently modelled as an instance of the CIDOC-CRM entity *E18 Physical Thing*. This intentionally broad classification encompasses any tangible object with a persistent physical identity that can participate in crafting operations. Treating all workpieces as E18 entities enables their uniform identification, tracking, and management across process stages.

For workpieces resulting from intentional human manufacturing activity, the model applies an additional classification as *E24 Physical Man-Made Thing*. This dual classification supports tracing the evolving status and provenance of physical objects as they progress through successive transformations. By distinguishing between generic physical entities (E18) and manufactured artefacts (E24), the model preserves information about prior production steps, supporting provenance tracking, quality control, and the analysis of multi-stage manufacturing workflows. The CIDOC Conceptual Reference Model (CIDOC-CRM) provides the semantic foundation for expressing these distinctions, as summarised in Table 1.

Table 1. CIDOC CRM-Based Ontological Mapping of Craft Concepts.

CRM Class	Concept	Description in CRM Context	Role in Craft Model
<i>E18 Physical Thing</i>	Material or workpiece	Any persistent item with physical identity.	Represents all workpieces, whether raw or already transformed.
<i>E24 Physical Man-Made Thing</i>	Product of the previous step	A physical object intentionally created or modified by humans; subclass of E18.	Used for products of previous steps in the crafting process.
<i>E5 Event</i>	General Event	Any phenomenon occurring over time.	Superclass of E7, models the general event structure of processes.
<i>E7 Activity</i>	Actions	A deliberate action performed by an actor to achieve a goal, with a start and end time.	Represents individual craft actions, such as shaping or hammering.
<i>E52 Time-Span</i>	Temporal context	A defined period with a beginning and an end.	Specifies when a crafting action takes place.

<i>E53 Place</i>	Spatial context	A location in which something occurred or existed.	Specifies where the action is performed.
<i>E39 Actor</i>	Practitioner	A person or group that performs activities or bears responsibility.	Represents the craft practitioner or team responsible for the action.
<i>E29 Design or Procedure</i>	Process schema	A plan, workflow, or design describing how something should be done.	Encodes process structures including steps, decisions, and error handling.

Crafting Actions and Events. In craft processes, individual actions are modelled as instances of E7 Activity, a subclass of E5 Event, which denotes any phenomenon with a defined temporal extent. E7 Activity captures deliberate human interventions aimed at transforming materials or achieving specific outcomes and encompasses the operational steps of a craft process, such as shaping, joining, decorating, or refining materials. Each activity is situated within a spatiotemporal context: temporal extent is represented using E52 Time-Span, while location is captured through E53 Place. Together, these elements enable precise documentation, analysis, and reproducibility of crafting actions.

Agents. Entities responsible for executing activities are represented as instances of E39 Actor, a class encompassing both individuals and collective groups. This broad categorisation covers solitary craftsmen, collaborative teams, and supporting agents involved in decision-making, supervision, or resource provision. Modelling practitioners as Actors establishes explicit links between agents and actions, supporting accountability, provenance tracking, stakeholder identification, and analysis of human agency within production processes. Figure 3 illustrates the core classes and relationships employed in the proposed knowledge representation model.

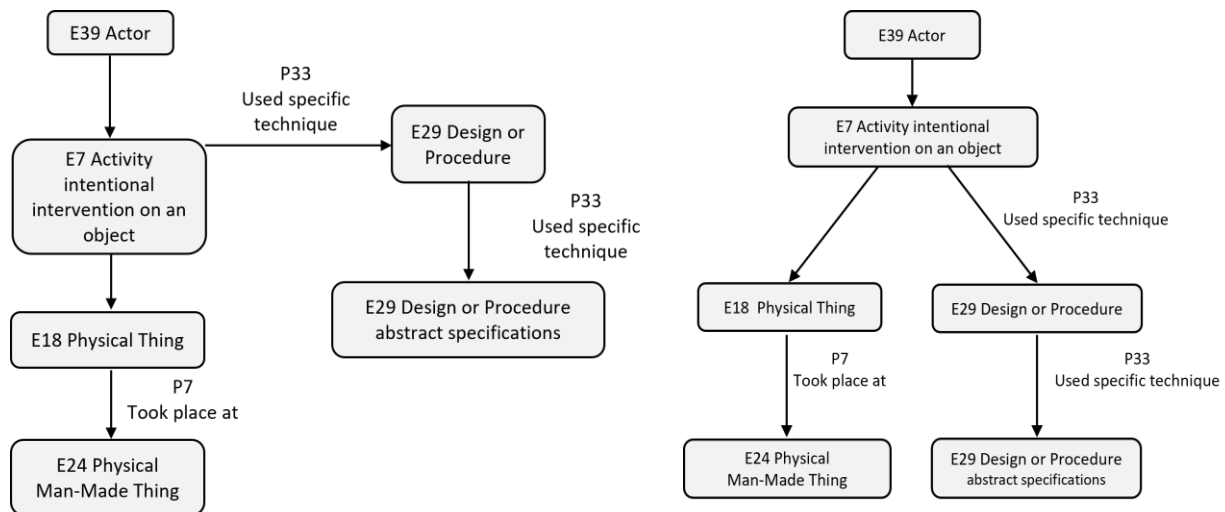


Figure 3. Knowledge Representation Classes and Relations.

Process Schemas. Execution of crafting actions is underpinned by the concept of a Process Schema, which is modelled as an instance of 'E29 Design or Procedure'. This classification situates Process Schemas under categories of E28 Conceptual Object and E90 Symbolic Object. These classes encompass the realm of non-



physical entities, representing artefacts of thought, meaning, and codified knowledge. An E29 Design or Procedure is defined as a specification detailing a course of action that is formulated to achieve an anticipated result. It does not describe or refer to a past or ongoing event; instead, it exists as a blueprint, a conceptual design, or a structured set of instructions that is interpreted and enacted by an agent. We stress the distinction between the Process Schema and the concrete E7 Activity that informs and directs. An Activity denotes an actual, situated event that unfolds in time and space, invariably involving some physical change. In contrast, an E29 Design or Procedure is a model of such events, existing in the realm of abstract concepts, providing a template for potential actions.

4.1.3 Semantic to FEM Knowledge Representation

Each step is associated with at least a set of action execution parameters and its action outcome. The parameters are the numerical values required to represent the action physically and are the same as those simulated in the Finite Elements Analysis (FEA) presented later in this work. They represent physical quantities pertinent to environmental conditions and practitioner actions, such as temperature, gripping tool posture, and induced motion for tools. The state of affected entities during the action is computed in the simulation. In this way, an ostensive representation of actions and their results is achieved.

The presentation of action outcomes is not limited to the exemplary performance of the action. They contain alternative workflows per the outcomes of branching nodes. Common mistakes, e.g., incorrect tool angles or inappropriate material or condition choices, are also represented as diverging paths. These branches terminate in either recovery paths, showing how the mistake can be corrected, or in failure nodes, used to indicate irreversible outcomes. This enables the system to offer predictive guidance and real-time feedback during the simulation.

4.1.4 Multimodal Craft knowledge

Craft knowledge encoded in the graph is multimodal. Each action node is linked to exemplars, including video recordings, verbal descriptions, and semantic annotations. These links facilitate a comprehensive and media-rich learning experience, allowing learners to review expert demonstrations in tandem with procedural simulation. A multilingual and hierarchically structured thesaurus ensures semantic consistency and interoperability across linguistic and cultural contexts. This procedural, material, and contextual organisation of knowledge enables dynamic simulation scenarios that adapt to learner behaviour while preserving the epistemic integrity of traditional craft practices.

4.2 Offline Simulation layer

Finite Element Method (FEM) functionality within the system is directly driven by the structured information encoded in the knowledge graph. The process schema supplies the simulator with all required inputs, such as tool and material geometries, material properties, and boundary conditions, allowing the FEM module to instantiate a physically meaningful simulation setup without manual configuration. Once initialised, FEM provides a sequence of physically grounded simulations that reveal how the workpiece responds under the forces and constraints defined by the craft action.

The primary objective of these simulations is to visualise the material transformations that occur as the virtual procedure unfolds. The simulation produces time-dependent deformation data, expressing how

the 3D workpiece changes as each action is executed (see Figure 4). These object-state sequences constitute the core outputs of the FEM engine, including volumetric deformation fields (e.g., STEP format), updated surface meshes (e.g., OBJ/PLY), and stress–strain time series corresponding to each interaction event, as reflected in the figure.

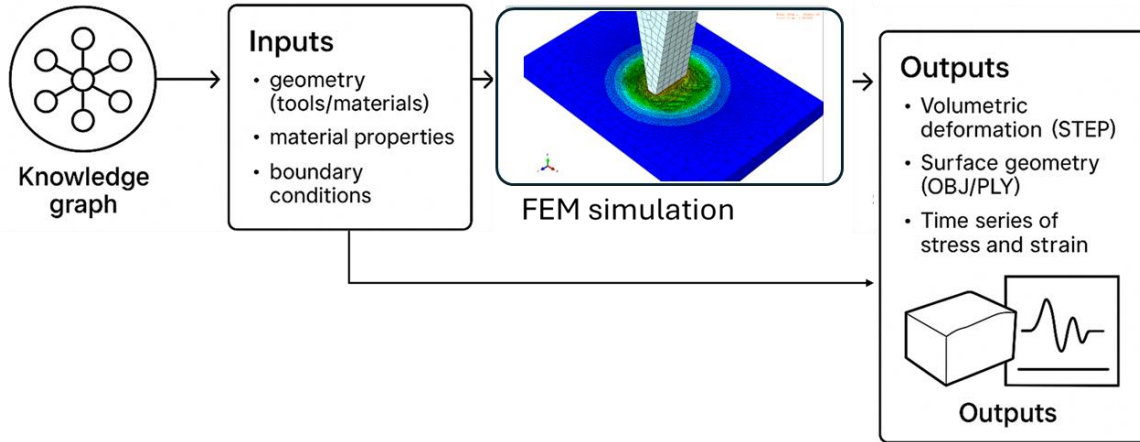


Figure 4. Knowledge Graph-based simulation workflow

To maximise instructional value, the FEM outputs are passed directly into the physically based rendering (PBR) module presented later in the methodology. Rendering operates on the deformation-updated geometry produced by the FEM engine, ensuring consistency between the simulated physical behaviour and the visual appearance of the workpiece. The PBR system uses a light-transport model informed by FEM-derived surface evolution, enabling realistic visualisation of damage, compression, warping, or subtle surface changes. Material models parameterised by measurable attributes, such as roughness, metallicity, and index of refraction, allow the rendered appearance to reflect variations in tool pressure, speed, or technique.

Following the approach detailed in [56], the renderer simulates key optical effects such as subsurface scattering, anisotropic reflection, and refraction, all of which are essential for accurately presenting complex craft materials like metal, polished wood, glass, or ceramics. These effects provide learners with perceptually rich cues about material state and surface quality, which are critical for understanding how craft actions influence the outcome. Mesh-based visualisation is achieved by applying the FEM displacement field to morph the base mesh while preserving its topology. The resulting geometry is shaded using a physically based bidirectional scattering distribution function, ensuring consistency between simulated physical changes and their visual manifestation.

Finally, the photorealistic depiction of tool–material interaction creates a perceptually grounded feedback loop. Learners can visually detect inaccuracies, inconsistencies, or undesirable deformation patterns that arise from improper technique. This perceptual feedback supports reasoning about cause-and-effect relationships, reinforcing the link between procedural execution, physical behaviour, and resulting material appearance, an essential component of effective craft education.

4.3 Visualisation and Feedback Layer

The Visualisation and Feedback Layer operationalises the outputs of semantic modelling and physical simulation by presenting them to learners through interactive, perceptually grounded environments. Its primary role is to transform simulated craft processes and material responses into visual and interactive experiences. Feedback is delivered continuously through visual, kinematic, and semantic signals, enabling learners to recognise errors, understand their causes, and explore corrective actions.

4.3.1 Craft-Studio, Implementation of Learning Scenarios

An application called 'Craft Studio' is a suite of tools for authoring immersive educational and training materials. The Craft Studio is an interactive authoring application implemented in Unity. It provides features for authoring and executing both interactive simulations. The Craft Studio renders the simulation outputs within the Unity game engine. Course authoring involves linking these sources to lessons, as shown in Figure 5. The lesson execution environment is called Apprentice Studio and is used to present lessons to apprentices.

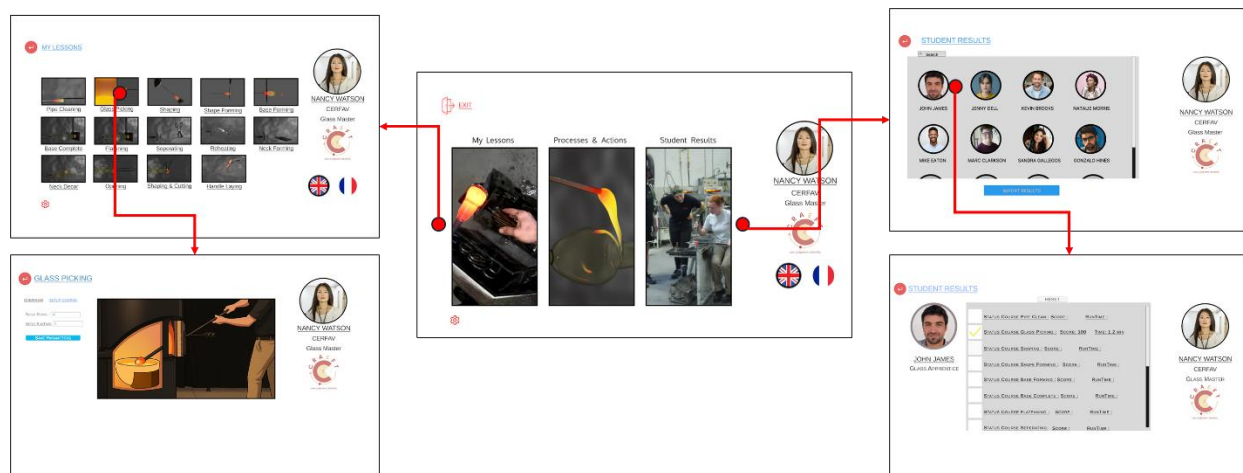


Figure 5. Course authoring in Craft-Studio.

The process schema is converted to a simulator input. A lesson is compiled into a Lesson Specification File, in JSON format, which is exported and uploaded to the eLearning portal. The theoretical components of the lesson are authored directly within the e-learning portal, containing all necessary material except for the execution aspects. This includes details such as tools, materials, and transformation mechanisms, all designed to appropriately introduce students to the lesson. The execution file for the lesson is the one previously uploaded from the Craft Studio and is linked as a resource within the lesson. Subsequently, the lesson is assigned to apprentices. Apprentices then download the Lesson Specification File and load it into the Apprentice Studio to undertake the lesson.

Workshops, tools, and machines are derived from the KG for craft or processes. The Craft Studio provides a graphical user interface (GUI) for authoring these lessons, making use of these digital assets and renderers. Lesson scenarios are set within a virtual workshop environment. Authoring a Lesson scenario

also includes defining its input/output interfaces. Student inputs come from the keyboard, mouse, and haptic devices. System outputs are delivered in 2D, 3D, XR (Extended Reality), and haptic rendering.

The VR assets and behaviours are integrated into the pedagogical framework described earlier. Craft Studio uses PBR/PhysX Action Animators to define lessons, sequencing them through semantic prerequisites and CLT-aligned scaffolding. PhysX enables objective assessment, such as: (a) detecting angle deviation beyond semantic thresholds, (b) measuring stroke smoothness, contact stability, or timing, and (c) capturing force patterns for comparison against model performance. Apprentice Studio executes these lessons in two modes: (a) Study Mode, where visual and physical cues are enhanced, and (b) Examination Mode, where prompts are minimised, and correctness depends on tool angle, applied force, contact duration, and resulting surface cues (see Figure 6).

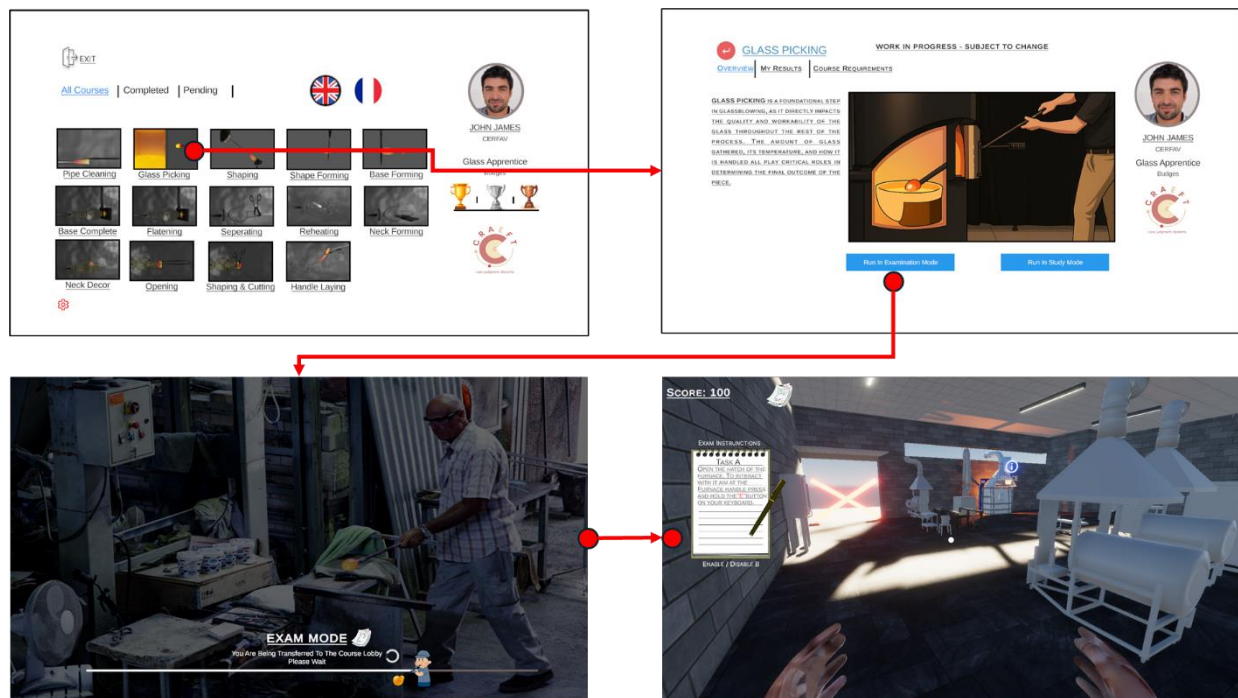


Figure 6. Executing craft training simulations via the Craft Studio.

4.3.2 eLearning portal – Theory and practice exemplars

Having established the semantic representation of craft processes and the structuring of domain knowledge through the ontology, the next methodological step involves operationalising this representation within the Craeft eLearning Platform, a Moodle-based environment designed specifically for the transmission of traditional craft knowledge. The Craeft eLearning Portal serves as the central access point for all Craeft users. It provides a wide array of functionalities designed to support and guide individuals through their craft education journey. The Craeft eLearning platform provided training courses required to master a particular craft. Its landing page is presented in Figure 7.

Courses can be either educational, focusing on theoretical knowledge, or training, providing practical skills through hands-on practice. Lessons can be either online or offline and draw from diverse training materials, craft demonstrations, action visualisations, and action simulations. This platform extends the

previously presented modelling approach by providing a technical and pedagogical layer through which semantically structured content is transformed into instructional sequences that support online training. The Craeft platform was designed to align closely with the principles of Cognitive Load Theory (CLT) presented earlier in the paper. The segmentation of processes, the formalisation of dependencies, and the explicit representation of perceptual cues in the semantic model enable the platform to generate instructional units that minimise extraneous load and support schema formation. Rather than creating learning material manually, the semantic structure acts as a guiding blueprint for organising Moodle course elements and determining how content should be sequenced, scaffolded, and delivered.

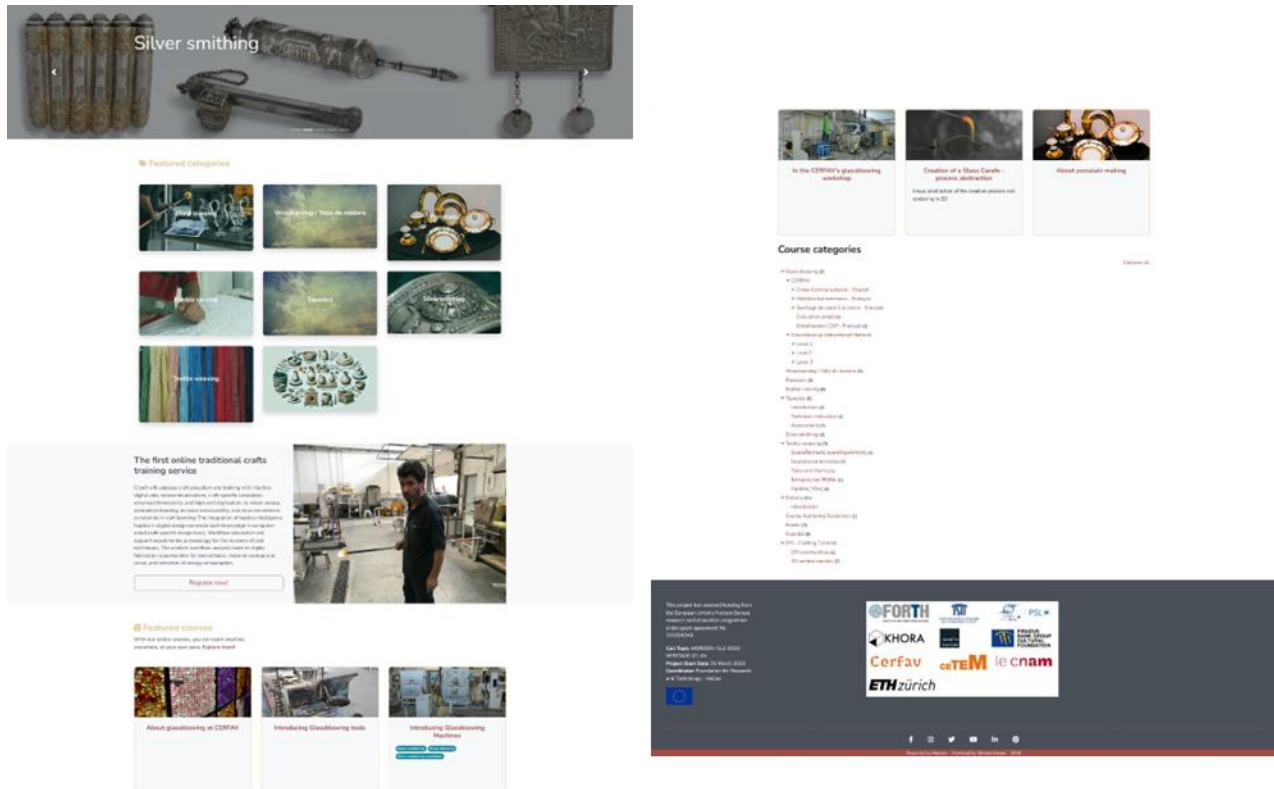


Figure 7. The Craeft eLearning portal.

From Semantic Units to Instructional Components

The methodology presented above already demonstrates how processes, actions, materials, and tool relations are captured semantically. Craeft uses these representations to determine the granularity and organisation of instructional components within Moodle. This integration ensures that the structure of the course mirrors the internal logic of the craft itself, rather than following an arbitrary or teacher-dependent layout. The mapping employed is presented in Table 2.

Table 2. From Semantic Units to Moodle Instructional Components.

Semantic Entity Type	Description (Craft Domain)	Corresponding Moodle Element(s)	Purpose in the Course
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Process	Craft workflow composed of sequential actions and decisions	Course, Topic/Section	High-level course structure; each process becomes a main module or topic.
Sub-process	A coherent group of related actions (e.g., clay preparation)	Lesson, Book, or H5P Course Presentation	Breaks the process into structured, teachable units.
Action	A discrete step performed by the craftsperson	Lesson Page, H5P Interactive Video, Page Resource	Instructional explanation of each step using text, images, or video.
Micro-action / Technique	Fine-grained motor or perceptual element of an action	H5P Hotspots, H5P Image Annotation, Glossary Entry	Highlights details, subtle movements, and focal points of attention.
Tool	Instrument or equipment used in a step	Glossary (Tool Category), Database Activity	Presents tool knowledge, tool constraints, and safe operation.
Material	Raw or transformed material states	Page, Glossary Entry, H5P Image Set	Presents material properties, transformation stages, and quality references.
Material State	Specific state of the material during the process	Quiz with Images, H5P Branching Scenario	Helps learners recognise correct/incorrect material conditions.
Constraint	Limitations related to timing, technique, or material behaviour	Quiz Question, Assignment Instructions, Lesson Warning Boxes	Ensure learners understand what must and must not happen at specific stages.
Required Conditions	Preconditions for performing an action	Restrict Access Rules, Prerequisite Activities, Competency Conditions	Enforces adaptive sequencing in Moodle based on semantic prerequisites.
Outcome / Intermediate Product State	The expected result of one or more actions	Assignment (Upload Photo), H5P Image Comparison	Allow learners to check progress or submit evidence of learning.
Skill / Competency	Knowledge or ability needed to perform an action	Moodle Competencies, Learning Plans	Enables tracking of proficiency and automated course-level progression.
Decision Point	A choice between alternative actions based on material behaviour	H5P Branching Scenario, Lesson Branch Table, Quiz (MCQ)	Supports training on conditional reasoning and craft-specific judgments.
Error / Risk Factor	Common mistakes or hazards	H5P Interactive Video, Label, Warning Boxes in Lessons	Enhances learner awareness of safety and quality risks.
Contextual Knowledge	Cultural, historical, or symbolic meaning	Page Resource, URL Resource, Book Introduction	Provides heritage, context, and reasoning behind craft practices.
Annotation / Observation	Notes on key perceptual features	H5P Mark the Hotspot, Database Activity, Feedback Tool	Supports perception training and expert noticing skills.

Embedding CLT Principles into Craeft Course Design

In this transformation process, there is a need to support novice learners with worked examples, segmentation, variability, and progressive fading of guidance, especially in domains such as crafts, where actions are interdependent, perceptually complex, and physically demanding. Craeft incorporates these principles operationally:

Segmentation is implemented through short, focused Lesson pages, each corresponding to a semantically defined action or perceptual cue.

Worked examples are generated by embedding complete demonstrations—often derived from Multiview video or annotated imagery—before learners engage in tasks.

Variability is achieved by linking each semantic action to multiple examples under different material states, tool conditions, or stylistic variations.

Guidance fading is enabled by the semantic prerequisite structure: once foundational actions are completed, Moodle automatically reveals more open-ended tasks and assessments.

The semantic model, therefore, not only defines the knowledge but also enables an instructional strategy grounded in CLT. The Mapping of CLT Principles to Course Design is presented in Table 3.

Table 3. Mapping CLT Principles to Craeft Course Design.

CLT Principle	Description (Pedagogical Intent)	Moodle Implementation	How It Supports Learning
Managing Intrinsic Load	Control the complexity of information by sequencing it appropriately	Lesson with short pages, Book chapters, Topic-based modularisation	Breaks processes into manageable units aligned with semantic action granularity.
Reducing Extraneous Load	Eliminate unnecessary cognitive effort (clutter, redundancy, split attention)	H5P Interactive Video with text and markers; Resources with aligned media; No multi-window navigation	Integrates explanation and visuals in one place; removes unnecessary clicks or page switching.
Worked Examples Effect	Provide fully guided demonstrations before problem-solving	Pages with examples, H5P step-by-step sequences, Embedded annotated videos	Helps novices build mental schemas before attempting tasks independently.
Completion Task Effect	Partially complete problems to scaffold learners	Quiz (embedded answers); Drag-and-drop ordering tasks; Assignment templates	Encourages active processing while avoiding overload from fully open-ended tasks.
Modality Effect	Combine visual and auditory channels effectively	Narrated video demonstrations: Audio	Utilises dual channels to reduce visual overload and enhance retention.

		commentary with diagrammatic visuals	
Split-Attention Effect (Reduction)	Integrate information that would otherwise require shifting attention	H5P hotspots, In-video labels, Combined text-image blocks	Enables learners to process related information simultaneously and coherently.
Signaling Effect	Highlight key information or transitions.	Lesson highlights, H5P colored markers, Glossary links, Labels inside topics	Directs attention to critical steps, reducing cognitive search effort.
Segmentation Effect	Break content into meaningful segments.	H5P course presentation slides, Short Lesson pages, and Topic-based sequencing	Prevents overload by pacing information delivery, especially for complex craft actions.
Expertise Reversal Effect	Adapt instruction based on learner expertise.	Restrict Access rules, Competency-based progression, and Conditional activity release.	Allows novices to receive more guidance while advanced learners skip redundant explanations.
Self-Explanation Effect	Encourage learners to justify their reasoning or reflect	Assignment (short reflections); Forum prompts; Quiz open responses	Strengthens deep understanding of craft decision-making and procedural logic.
Variability Effect	Provide variation in examples to build flexible schemas	Multiple video examples, Gallery of material states, H5P comparisons	Learners generalise skills and recognise variations in materials and outcomes.
Goal-Free Effect	Remove specific goals to encourage exploration and schema formation	Exploration activities inside Lessons, Non-graded H5P interactivities	Reduces pressure and encourages intuitive understanding of craft behaviours.
Fading Guidance	Gradually reduce support as learners gain expertise	Lesson ↔ Quiz ↔ Assignment progression; Removing hints in later modules	Supports transition from guided practice to autonomous performance.

Technical Realisation

Semantic entities are mapped to Moodle components according to the schema defined previously. This methodology is a systematic procedure for turning semantic knowledge into a fully navigable and pedagogically coherent course, as shown in Table 4.

Table 4. Mapping semantic entities to Moodle facilities.

Semantic entity	Moodle
<i>Craft process</i>	The course structure, while subprocesses define the major sections.

<i>Prerequisite relations encoded in the semantic model</i>	Implemented using Moodle’s Restrict Access and Activity Completion features, ensuring that learners progress in cognitively appropriate steps.
<i>Videos, diagrams, annotations, and perceptual cues</i>	Are placed in the appropriate Lesson pages or H5P activities in alignment with CLT recommendations to avoid split attention.
<i>Semantic descriptions of correct intermediate states, constraints, and expected outcomes</i>	Used to define quiz items, assignment rubrics, and competency-linked achievements within Moodle.
<i>Expert–novice differentiation in the semantic structure</i>	Adjust learning pathways by reducing guidance once sufficient competency is demonstrated.

4.3.3 Interactive Simulation – Physical-Based Rendering

The real-time simulation of manipulating deformable objects uses the NVIDIA PhysX simulator [Error! Reference source not found.] that simulates complex physics interactions, including soft body dynamics, by leveraging the parallel processing capabilities of GPUs. In our case, it is used for simulating real-time tool interactions, rigid-body behaviour, collision response, mass and inertia handling, and material-dependent contact conditions. Together, PBR and PhysX provide an interactive VR environment where learners can observe and perform craft actions under conditions that approximate the sensory experience of working with real materials. The interaction loop is presented in Figure 8.

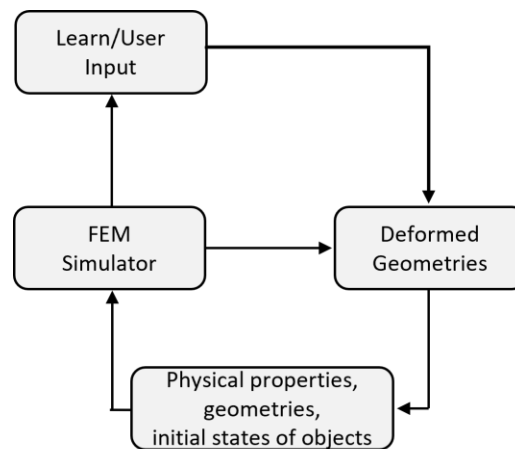


Figure 8. An illustration showing the interaction loop.

The methodology for interactive simulation comprises four steps:

Step 1: Semantic–PBR–PhysX Integration Framework. The methodology begins with a semantic representation of tools, materials, actions, micro-actions, and constraints. This representation defines what is manipulated (tool metadata, material states), how it appears (surface qualities, roughness, reflectance, wear), how it behaves physically (mass, friction, constraints, permissible motion ranges), and which perceptual cues are relevant (specular highlights, texture, compression marks). These semantic attributes are mapped to two complementary VR subsystems: a PBR asset-generation pipeline governing appearance and a PhysX-based interaction pipeline governing behaviour. As a result, VR objects are both



visually grounded and physically coherent, allowing learners to interpret cues such as tool angle, applied pressure, and frictional response with realism.

Step 2: PBR Pipeline for Craft VR. The PBR workflow ensures realistic light–material interaction for tools, workpieces, intermediate states, and environmental elements. This is critical in training scenarios where subtle visual cues—such as surface roughness, moisture, burnishing, cutting sheen, or grain direction—carry instructional meaning. Each semantic material state is realised as a dedicated PBR texture set comprising albedo, roughness, normal or height, metallic, and ambient-occlusion maps. This mapping ensures that all semantically defined state transitions are visually reflected in the VR environment. Blender is used to model assets with high geometric fidelity, sculpt surface modifications caused by craft actions, and bake high-resolution details into PBR-compatible textures. Textures are optimised (e.g., BC7 compression), and level-of-detail meshes are generated to maintain performance during close inspection.

Step 3: PhysX-Based Physical Interaction Layer. While PBR governs appearance, NVIDIA PhysX provides physically consistent real-time interaction. The simulator is implemented directly using the PhysX SDK, enabling fine-grained control over manipulation behaviour. Physical properties, geometries, and initial object states are defined in configuration files, with separate parameter sets for rigid bodies (tools) and soft or deformable materials. Object geometries are imported using the Wavefront format, and resulting deformed meshes are forwarded to the rendering pipeline for interactive visualisation. Simulation parameters are recorded in JSON and loaded at runtime. To support real-time execution, the simulation core is exported as a DLL and integrated into a Unity3D application, where scene components become accessible through Unity interfaces and scripts. Manipulators support constrained translation and rotation, enabling repetitive practice and incremental action sequences. Each tool and material object is assigned collision meshes, rigid-body properties, and PhysX material definitions, including friction, restitution, density, and damping, derived from semantic metadata such as tool hardness or material consistency. Action constraints are enforced through PhysX joints (hinge, slider, configurable) and kinematic bodies for guided demonstrations, directly corresponding to semantically defined action parameters. PhysX manages real-time effects including contact forces, surface friction, momentum transfer, and collision events. Although PhysX does not perform volumetric deformation, visual deformation cues—such as decals, normal-map blending, and texture swapping—are triggered based on semantic and collision data.

Step 4: Runtime Integration in Unity. Unity serves as the runtime environment, integrating PBR and PhysX. PBR rendering is implemented using HDRP or URP with microfacet BRDF shaders, reflection probes, HDRI lighting, and screen-space ambient occlusion to ensure lighting realism. Custom C# components map PhysX events to semantic actions, including collision events mapped to micro-actions, force and velocity sampling for performance assessment, detection of valid tool orientations, and real-time classification of tool–material contact modes (e.g., scraping, pressing, gliding). Textures and normal maps are blended dynamically to reflect state changes, such as surface smoothing after trimming. These elements are encapsulated in reusable Action Animator prefabs that integrate PBR-rendered assets, PhysX-based interaction and state transitions, semantic parameter constraints, and assessment triggers, forming a modular component for executable craft actions.

4.3.4 Learner Interaction

Learner interaction supports active, embodied engagement with craft processes through semantically constrained and physically grounded virtual environments. Learner inputs are interpreted as semantically



D4.1 Craft simulation and immersive craft training



defined micro-actions—such as tool positioning, orientation, force application, and motion execution—ensuring device-independent interaction while preserving domain-specific meaning. Interaction is supported via desktop, controller-based, and immersive XR interfaces. User inputs are continuously evaluated against semantic execution parameters defining acceptable ranges for tool angle, contact duration, applied force, and movement trajectories. Correct actions advance the process normally, while deviations trigger semantic branches representing recoverable errors or irreversible failures.

During execution, physical behaviour is computed using PhysX-based interaction dynamics and FEM-based or proxy deformation models. Material responses are rendered through physically based rendering, providing immediate visual feedback on surface deformation and material-state transitions. Feedback is delivered through integrated visual and semantic cues, with enhanced guidance in Study Mode and reduced cues in Examination Mode to approximate real workshop conditions. A key objective is the development of perceptual discrimination and error awareness. Subtle visual cues are linked to semantically defined outcomes, while process-aware feedback activates recovery or failure paths encoded in the process schema. Learner progression and assessment are governed by semantic prerequisites and competency definitions, enabling continuous formative assessment and adaptive learning trajectories with diminishing guidance as expertise increases.

5 Authoring eLearning

This section presents the Craeft eLearning platform and demonstrates the usage of the aforementioned eLearning guidelines for the implementation of an eLearning course.

5.1 eLearning platform

5.2 Data sources

In the presented use case, the craft of glassblowing will be examined. In this use case, the material used for creating eLearning material is composed of:

- Ethnographic recordings from a glass workshop utilising various methods such as mobile phones, cameras mounted on a tripod, and close-up views with handheld cameras.
- Photographic documentation of the workshop tools, machines, and layout, including photographic documentation acquired during the creation process to capture key moments of the object's creation;
- 3D models of tools, machines, and the workshop itself;
- Rendered virtual representations of the workshop;
- Visual abstractions of fundamental glassblowing actions in the form of rendered 3D animations;
- Visual abstractions in the form of cartoonized images, composed in the form of a comic book, present the creation process.
- Educational material from textbooks regarding the glassblowing craft.

5.3 Using Guidelines to Structure an eLearning Course

The application of the developed guidelines started by creating an appropriate category structure for structuring the eLearning courses. During this process, several guidelines were followed to provide a clear picture to the learners of what to expect in terms of educational units. The analysis of the category structure and some exemplary course structures per category are presented in Figure 1. Figure 1 also provides a mapping of the guidelines followed to visually demonstrate how an appropriate category structure can act as the point of departure for a successful eLearning course on glassblowing.

Throughout this section, inline codes within the screenshots and textual descriptions are used to provide information on the conformance with specific guidelines.



Figure 9. The proposed category structure.

As shown in Figure 1, for the glassblowing case, we provided a scaffolding strategy decomposed into three levels, each one corresponding to a different expertise level in terms of craft education. The first level is introductory to the craft instance and contains lessons on the social and historical context (contextual information) and also introduces the tools, materials, and glassblowing machines. The knowledge acquired is reinforced through critical thinking and problem-solving assignments. Each level is completed through student evaluation tests and an open round of discussion and feedback that allows the learners to provide feedback on the course and the course editors to provide feedback on the learners based on the performed assignments and evaluation tests. The completion of this level provided a generic yet clear understanding of the craft instance to be studied.

Levels 2 and 3 are consistent in terms of structure and are formulated under the perspective of sequential learning, allowing learners to keep their own pace but at the same time follow a well-defined learning path. This distinction remains throughout the levels, maintaining the same scaffolding strategy. For simplicity, we will analyse level 2, having in mind that the same information stands true for level 3.

Level 2 starts with an introduction to the techniques that will be studied, which, in the case of Level 2, are the fundamental techniques of glassblowing. Then, the techniques are presented in the form of visual abstraction, which in our case is a 3D representation of the techniques in the form of an animated scene that presents only the tools and their interaction with the material. This form of presentation provides craft-specific worked examples and, at the same time, minimises the distractions from the environment. When these visualisations are studied, we continue by presenting the same techniques as executed in the



environment through audiovisual recording in a glassblowing workshop in which a glass master is performing the same techniques in the context of creating a glass artefact. These demonstrations enrich the previously studied visual abstractions and complement them through additional sources of information. The course continues with immersive training on basic techniques, which inevitably should happen outside the eLearning platform by using some form of immersion. In the context of the Craeft research project, 3D and VR 3D are to be integrated for immersive training, complemented with haptic devices for transferring information from the digital world to the learner and vice versa.

After this first round of training, the course proceeds to combine basic techniques to formulate complete glassblowing examples. These are presented in the form of both visual abstractions and recordings in the same way as presented above. Then, a second round of immersive training is to take place, where the learners are required to imitate what they learned previously in a virtual environment. The level continues with critical thinking and problem-solving exercises. These are both assignments that can be executed offline and assignments that can be integrated with workshop study lessons on-site. In both cases, these result in the submission of assignments by students. The level is completed with the evaluation tests and the open two-way feedback round.

Already for the creation of the structure, we have applied or foreseen the application of more than 30 of the aforementioned guidelines. The following example will delve even more into the formulation of specific courses.

5.4 Exemplars Courses

5.4.1 Course in the form of a Multimodal Document

In this example, the basic structure of a simple course will be presented and authored in the form of a multimodal document (see Figure 2). The objective of the example is to emphasise key craft points by presenting the basic glassblowing techniques. The course is composed of several topics, each focusing on a single subject—in this case, a fundamental glassblowing technique—minimising the need for the learners to split their attention between simultaneously presented techniques.

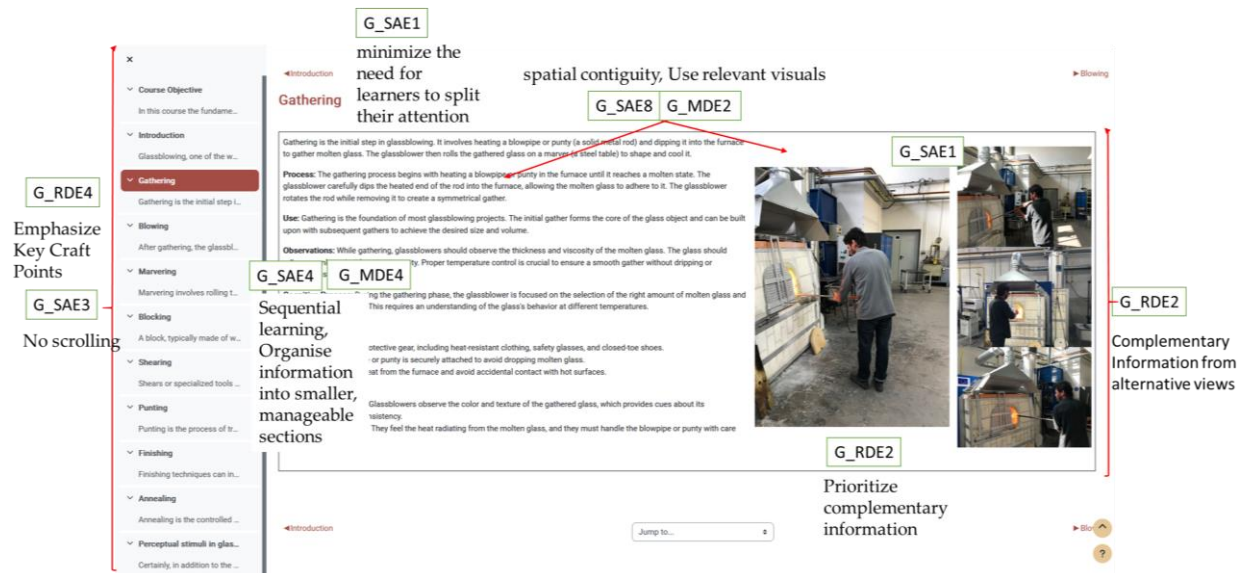


Figure 10. An example of a course authored in the form of a multimodal document.

Furthermore, the course is configured so that only one topic is presented on each page to organise information in small, manageable sections and minimise the need for scrolling throughout the content. Following these guidelines, we have achieved the specific course to eliminate the need for scrolling. Navigation between topics is provided both on the left side of the course, where the course structure is presented, and inline, where navigation to the previous and the next topic is provided, both on top and after the content of the topic (see Figure 2).

Moving to the content of the course, as seen in Figure 2, the course is a collection of well-defined textual information organised based on its subject (Process, Use, Observations, cognitive processes, etc.). This offers a well-defined sequential flow of information and provides the ability for learners to study each subject separately. Furthermore, by integrating cognitive and perceptual information into the description of techniques, we create mental information that is stored in long-term memory. This information is retrieved in the working memory when actually performing the techniques in a physical setting.

To ensure spatial contiguity, visual information is presented right next to textual information to be studied in parallel. Regarding the use of visuals, complementary information is prioritised. The objective, in this case, is to provide alternative views of the same process from different viewpoints, thus ensuring that the same actions of the practitioner can be studied from complementary views, which is extremely important when studying gestural information.

5.4.2 Courses Embedding Audio-Visual Components

In this example, a course that presents visual abstractions of glassblowing processes is studied. A visual abstraction can be thought of as a 3D scene that contains only the tools and materials and employs animation to mimic the events of a crafting process. By abstracting the process from the context, we can focus only on its essential parts.

An example of the blocking process in glassblowing is presented in Figure 3. To enhance the understanding of the content to be presented, the techniques and the steps followed are introduced shortly before the presentation of visual abstractions and shortly after to enhance self-questioning on the presented information. To further simplify the presentation of the technique, visual content is split into three steps, each presented individually, and the learner can control playback to study each step again and again. After completion, the student is prompted to confirm whether he has acquired the subject and wishes to move forward to the next subject or whether he wishes to be transferred to the next course in which the same technique is shown as practised by actual practitioners. In this way, the learners can control the pace of their learning and information provision and define alternative ways of browsing information by navigating between courses. General considerations in eLearning craft courses are maintained in this lesson too by keeping the same course structure and a consistent pace through the presentation of the course content, eliminating distractions and scrolling.

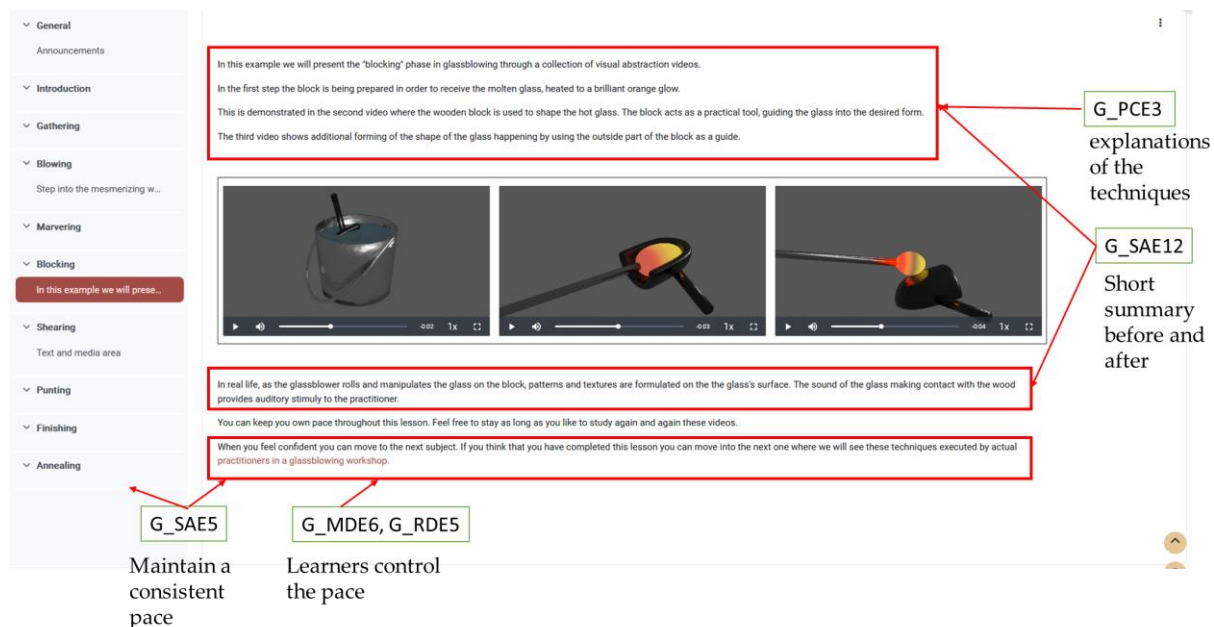


Figure 11. Example of a course embedding audio-visual components.

5.4.3 Course in the form of an Interactive Book

In this example, we are building on the H5P content compatibility of the eLearning platform to create two paradigms of interactive books.

The first paradigm is authored following principles of visual abstraction (see Figure 4). To do so, key frames from a glassblowing process are used as a summary of each action. To make content more interesting, the key frames are simplified using a cartoonification filter. The results are combined to author a comic book. Action sequences are complemented using inline textual descriptions following standard comic book principles. Using the capabilities offered by H5P content, we use the images illustrating each page of the comic to author an interactive book. To ensure that complex concepts are segmented into smaller and more manageable parts, each page of the interactive book has been authored in a way to present only one step of the process. The placement of images follows the logical sequence of the steps. Inline visual annotations are used to highlight important parts of each action and the interaction between the

craftmaster, tools, materials, and workshop. The textual descriptions act as narrations of the visual information. Key locations are also enhanced by linking to the source audiovisual captures of the process to further study important steps.

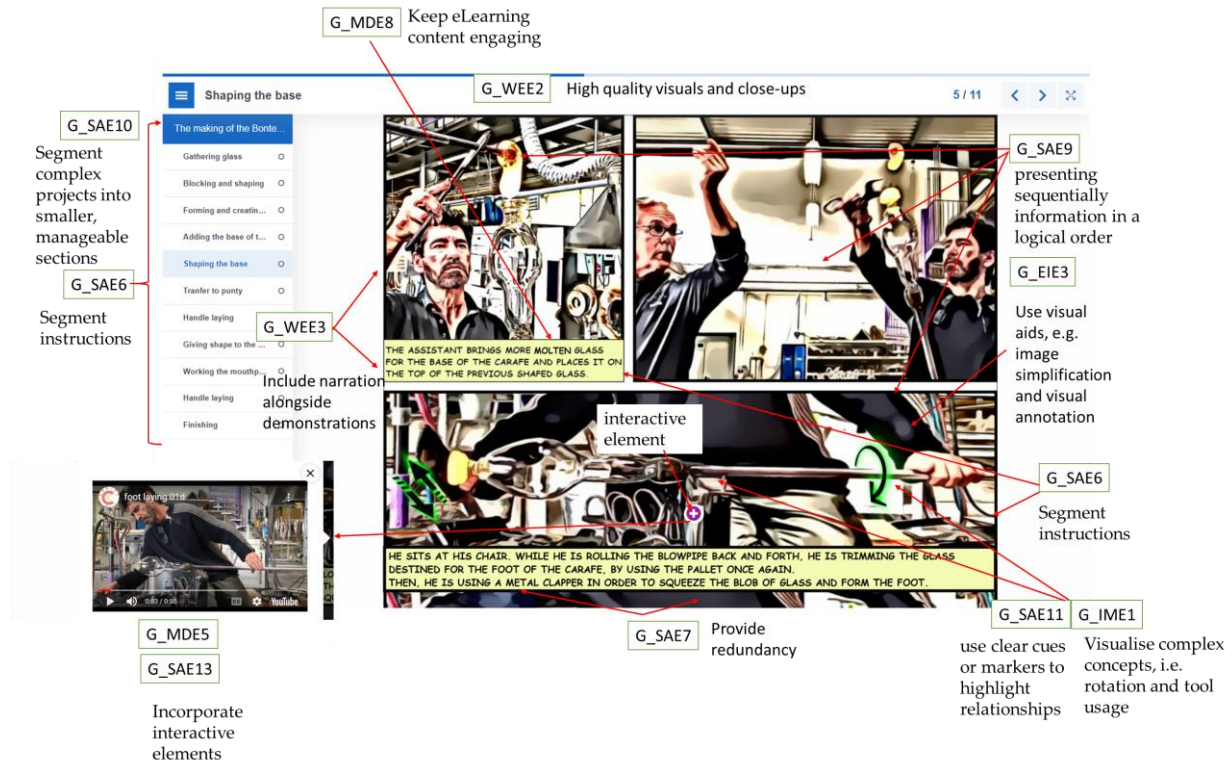


Figure 12. An example of a course in the form of an interactive comic book.

The second example builds on the same visual abstractions used for teaching individual glassblowing techniques, now combined in a completely worked example that presents from the beginning to the end the implementation of a complex glass object, which in this use case, is a glass carafe. The same principles of organisation in steps and of the provision of information sequentially are maintained in this example, too. An indicative screenshot from this interactive book authored in the H5P format [92] is presented in Figure 5.

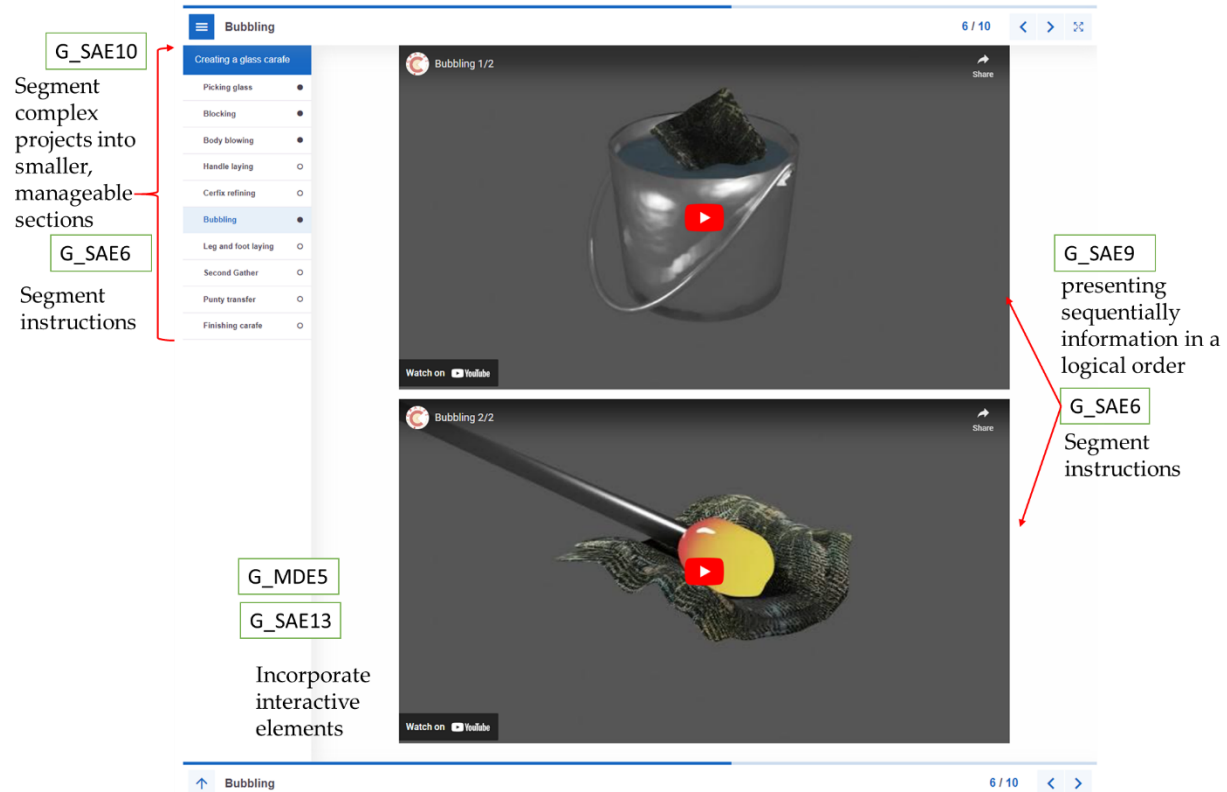


Figure 13. Example of a course that presents a complete worked example as a visual abstraction of steps.

5.5 Assignments and Student Evaluation

Student evaluation follows the method of assignments and tests enhanced through digital media to make them more engaging. In this section, examples of alternative evaluation means will be presented, starting from plain old-fashioned multiple-choice quizzes and moving to more creative forms such as interactive video quizzes, problem-solving exercises, and creative assignments.

5.5.1 Multiple-Choice Quizzes and Interactive Video Quizzes

Multiple-choice quizzes are not the target of this research work and have been thoroughly studied by previous research works (e.g., [93–95]). In this work, we focused on providing, through interactive quizzes, various levels of feedback during the test to provide real-time information to the learners regarding their selections and thus transform the test into yet another form of learning. Several guidelines are easy to apply here, too, such as maintaining a consistent pace in the presentation of questions, ensuring that no scrolling is required, using simple and consistent wording, providing incremental difficulty, etc.

Conversely, interactive video quizzes are considered a more innovative alternative to this research work since much of the craft training depends on observation, understanding, and mimicking. Such tests were created as part of this work using footage from actual practitioners, and in our example, the creation of a glass carafe is studied. The footage used regards the demonstration of its creation process in the workshop by a glassmaster and his assistant. The video is interactive, employing pausing at several

keyframes to allow the student to be prompted with a question that is based on their understanding of the glassblowing process (see Figure 6). Thus, pausing by itself introduces a partially completed problem that allows the learner to exercise knowledge and critical thinking. Questions are formulated in the form of asking for a justification from the learner, and questions provide several justifications of a phenomenon. In the case of success, the interactive video continues, while in the case of failure, feedback is provided to the learner to enhance their understanding of the phenomenon under study and the question itself.

G_PCE1
Introduce learners to partially completed problems

G_PCE2 Show a video of the process and pause on a key frame

G_PCE4
Ask for step justification

G_PCE6
Constructive feedback

Figure 14. A video quiz and the relevant guidelines were conformed to.

5.5.2 Problem Completion Assignments

In this example, we mainly study the Problem Completion Effect, in which the learners are introduced to a partially completed problem and prompted to practice their capabilities to fill in the missing pieces of information (see Figure 7). The presentation of the problem starts with a description of the context that the learners should focus on and a short description of the assignment. Then, explicit instructions on how to proceed with the assignment are provided alongside information on how their assignment will be assessed. The partially completed project is provided in the form of a partially filled answer template that the students should use as a starting point for their assignment. Furthermore, learners are strongly advised to work in groups to practice interpersonal collaboration and problem-solving skills. The structure of the aforementioned assignment is designed to support scaffolding learning by deactivating parts of the assignment based on the learner’s level. Thus, for novice learners, the assignment has the exact structure and content as shown in Figure 7, while for moderate users, only the instructions and an empty template are provided. For experts, only the objective of the assignment and an empty template are provided.

G_SEE6. Provide active learning activities

G_PCE10
Consider Craft Context

G_GFE1
Explicit instructions for novice learners

G_PCE3
Method to reach the initial stage and how to proceed

G_PCE2
Initial stage

G_PCE1
Partially completed project

G_PCE11
Encourage collaborative craftsmanship

G_GFE3
G_GFE4
G_PCE5
For moderate users only instructions and empty template

G_GFE3
G_GFE4
G_PCE5
For expert users only objective and empty template

Assignment Guidelines:

- 1. Period:** Your assignment focuses on the contemporary period, spanning from the late 20th century to the present day, emphasizing the developments and innovations in glass blowing during this time.
- 2. Research:** Each student or group is responsible for researching and identifying key innovations, artists, and influential figures in contemporary glass blowing. You should explore the techniques, styles, and artistic movements that have shaped the field.
- 3. Timeline Sections:** Your assignment will contribute to a larger class timeline, which is divided into sections covering different historical periods. Your section is "Contemporary Glass Blowing Innovations."
- 4. Fill in the Gaps:** Using the provided timeline template, fill in the gaps with information on important developments in contemporary glass blowing. Ensure that your entries are in chronological order to create a coherent narrative of the field's evolution.
- 5. Descriptions:** For each innovation, artist, or event you include, provide a concise description that explains its significance in the world of contemporary glass blowing. Discuss how it has contributed to the field's development and artistic expression.
- 6. Visual Elements:** Enhance your timeline by including relevant visual elements. Incorporate images of contemporary glass art pieces, influential artists, or studio setups that reflect the innovations and trends you're highlighting. Provide proper citations for visuals used.

Method:

- 1. Research:** Start by conducting in-depth research on contemporary glass blowing, focusing on innovations and artistic movements from the late 20th century to the present. Use reputable sources, contemporary art journals, and online resources to gather your information.
- 2. Chronological Order:** Organize your researched innovations, artists, and events in chronological order to construct a cohesive timeline. Pay close attention to the progression of techniques and styles.
- 3. Descriptions:** Craft informative and concise descriptions for each entry on the timeline. Explain the significance of the innovation or artist and how it has influenced the contemporary glass blowing landscape.
- 4. Visual Elements:** Select relevant visuals that support and complement your entries. These visuals should reflect the contemporary period and the topics you're covering, helping to visually represent the innovations and artists in question.
- 5. Presentation:** Compile your timeline in a digital format using software or a digital tool of your choice. The final timeline should be visually engaging, well-organized, and easy for your peers to follow. You will present your section to the class.

Assessment:

Your assignment will be assessed based on the accuracy and depth of the contemporary glass blowing information, the quality and appropriateness of visual elements, and the clarity and engagement of your presentation. This assignment encourages peer learning and a comprehensive exploration of contemporary glass blowing innovations.

Please note that in this assignment we provide a prefilled timeline template so as to provide the rationale of your search. The template has some parts that you should fill in the predefined filled and open to complete fields to complement with your research outcomes.

Prefilled Template (provided also as a docx file):

Contemporary Glass Blowing Innovations Timeline

- 2012: Dale Chihuly's "Flux" Series**
Description: In 2012, the renowned glass artist Dale Chihuly introduced his "Flux" series, characterized by vibrant, organic shapes and intricate details. This series marked a departure from his previous works and highlighted the fusion of traditional glassblowing techniques with bold contemporary designs.
Visual: [Insert an image of a piece from the "Flux" series.]
- 2015: Lino Tagliapietra's "Concerto" Series**
Description: Glass maestro Lino Tagliapietra launched the "Concerto" series in 2015, showcasing his mastery of complex forms and color manipulation. This series is celebrated for its harmonious use of color and balance, pushing the boundaries of contemporary glass art.
Visual: [Insert an image from the "Concerto" series.]
- 2017: Kin Glass Innovations**
Description: In 2017, the field of glass art saw significant developments in kin-formed glass techniques. Artists like Bullseye Glass Company introduced new types of glass and firing methods, enabling artists to create intricate kin-formed artworks with a wide range of colors and textures.
Visual: [Insert an image representing kin-formed glass innovations.]
- 2019: Collaboration: Jonah McElherny and Thaddeus Wolfe**
Description: Glass artist Jonah McElherny collaborated with designer Thaddeus Wolfe in 2019 to create a series of captivating glass sculptures. This partnership exemplified the synergy between artistic vision and craftsmanship, resulting in unique pieces that blur the lines between art and design.
Visual: [Insert an image from the McElherny-Wolfe collaboration.]
- 2021: 3D Printing in Glass Art**
Description: 3D printing technology made its mark in the world of glass art in 2021. Artists and studios began experimenting with 3D-printed glass, pushing the boundaries of what was previously thought possible. This innovation opened new avenues for creating intricate, sculptural glass works.
Visual: [Insert an image showcasing 3D-printed glass art.]
- 2022: Emerging Glass Artists**
Description: The contemporary glass art scene continues to thrive with a new generation of emerging artists. In 2022, artists like [Artist Name] and [Artist Name] gained recognition for their innovative approaches, infusing traditional glassblowing techniques with fresh perspectives.
Visual: [Insert images of artworks by emerging artists.]

[Students should continue with additional entries or add entries between key dates as needed.]
Assignment by [Your Name]

View all submissions | Grade

Grading summary

Hidden from students	No
Participants	0
Drafts	0
Submitted	0
Needs grading	0

Add submission

Figure 15. An example of an assignment focusing on the application of the Problem Completion Effect in craft eLearning.

5.5.3 Creative Assignments

In this example, we study the creative assignments that develop critical thinking and analytical skills. The structure of the assignment, as shown in Figure 8, is divided into two sections. The first presents the objective of the assignment, while the second presents instructions in the form of a step-by-step walkthrough of how to execute the assignment. These step-by-step instructions allow the authors of the assignment to integrate strategic sub-tasks that, through their execution, can assist in the development of critical thinking and analytical skills rather than expecting this to magically happen. For example, the assignment provides specific instructions on what should be researched for each art artifact and the research itself is a way of transferring knowledge to the learner, not only on this subject but in general on how to establish a new paradigm of collecting and evaluating knowledge from external sources. At the same time, it guides the learner with further instructions to focus on things that are considered essential, such as the artistic intent and the design elements, which can assist in cultivating creative thinking when composing works of art and in general creativity by identifying creative elements and their contribution to the composition. These instructions further provide incentives to the learners to search deeper into artistic creation and provide time for self-questioning, since understanding and judging what you see is essential while gathering information on what to see. Combining inner beliefs with external knowledge

can become a generator of new ideas, designs, and creative concepts. Of course, the learners are strongly advised to discuss with their peers since, through discussion, research, and consolidation, a more holistic understanding can be achieved.

The assessment of such an exercise is a reflective essay in which the learners are asked to summarise their analysis of the selected artefact, highlighting key points focused by following the instructions and new creative directions generated throughout their research. The creative essay acts as a form of self-explanation, inviting the learners to explain to themselves, while preparing the essay, the path, the focal points, and the decisions made during their research.

G_IME4 Promote Creative Assignments

G_EIE7 Peer Collaboration

G_HG3 Encourage Discussion, Sharing and Peer Learning

G_HG5 Evaluate Learning Outcomes

G_EIE8 Provide Opportunities for Reflection

G_SEE1 Self-Questioning

G_EIE7 Peer Collaboration

G_SEE2 Explicitly Prompt Self-Explanation

Exercise Title: Analyzing Glass Art Design

Objective: Welcome to the "Analyzing Glass Art Design" exercise. In this activity, you will have the opportunity to **develop your critical thinking and analytical skills** by examining an existing glass art piece. By closely analyzing the design and artistic elements of the artwork, you will gain a deeper understanding of the creative choices made by glass artists and how these choices influence the viewer's perception.

Instructions:

- Selection of Glass Art Pieces:** You are presented with high-resolution images of different glass art pieces (see right hand pane). Your task is to choose **one of these pieces for analysis**. Each piece represents a different style, technique, and artistic theme.
- Initial Observations:** Begin by making initial observations about your chosen piece. Consider the following aspects:
 - Size and dimensions
 - Color palette
 - Shape and form
 - Texture and surface treatment
 - Any unique or eye-catching features
- Context Research:** Dive into the context of the glass art piece you've chosen. Can you research information about the artist, the time period when the piece was created, and any historical or cultural influences that may have shaped the artwork?
- Artistic Intent:** Think about the artistic intent behind the chosen piece. What emotions or messages might the artist have been trying to convey? Consider the overall mood of the artwork.
- Design Elements:** Analyze the design elements present in the chosen piece. This includes:
 - **Composition:** How is the artwork arranged, and what is the focal point?
 - **Color:** How do color choices impact the viewer's perception?
 - **Form:** How does the shape and form of the glass contribute to the piece's overall design?
 - **Texture:** How does texture enhance or detract from the viewer's experience?
 - **Balance:** Is the composition balanced or asymmetrical, and how does this affect the piece?
- Discussion:** Engage in a discussion with your fellow students. Share your findings and analyses of the glass art piece you've chosen. Listen to your classmates' insights and provide feedback on their analyses.
- Reflective Essay (Homework):** As a follow-up to this exercise, you will be required to write a reflective essay (500-800 words) summarizing your analysis of the glass art piece you chose. In your essay, discuss the historical context, artistic intent, and the impact of design elements on the viewer. This essay will help you articulate your insights in a more structured format.

Figure 16. An example of a creative assignment.

6 Applying Guidelines for Immersive Craft Training

6.1 The Apprentice Studio – Design

This section provides the current version of the Apprentice studio, currently under design using the Figma collaborative UI design tool (<https://www.figma.com/>).

6.1.1 Introduction

The Apprentice Studio is an advanced, immersive training platform designed to facilitate the learning and mastering of traditional crafts. It is part of a comprehensive ecosystem that includes the Craft Studio, which authors and exports lessons that are then imported and executed within the Apprentice Studio. This innovative application is geared towards providing apprentices with a personalised, interactive, and hands-on learning experience, utilising cutting-edge technology to replicate real-world crafting processes.

To ensure that everything is recorded per user, a sign-in functionality has been designed. All users start their training by logging in to the apprentice studio using their assigned credentials are shown in Figure 17.

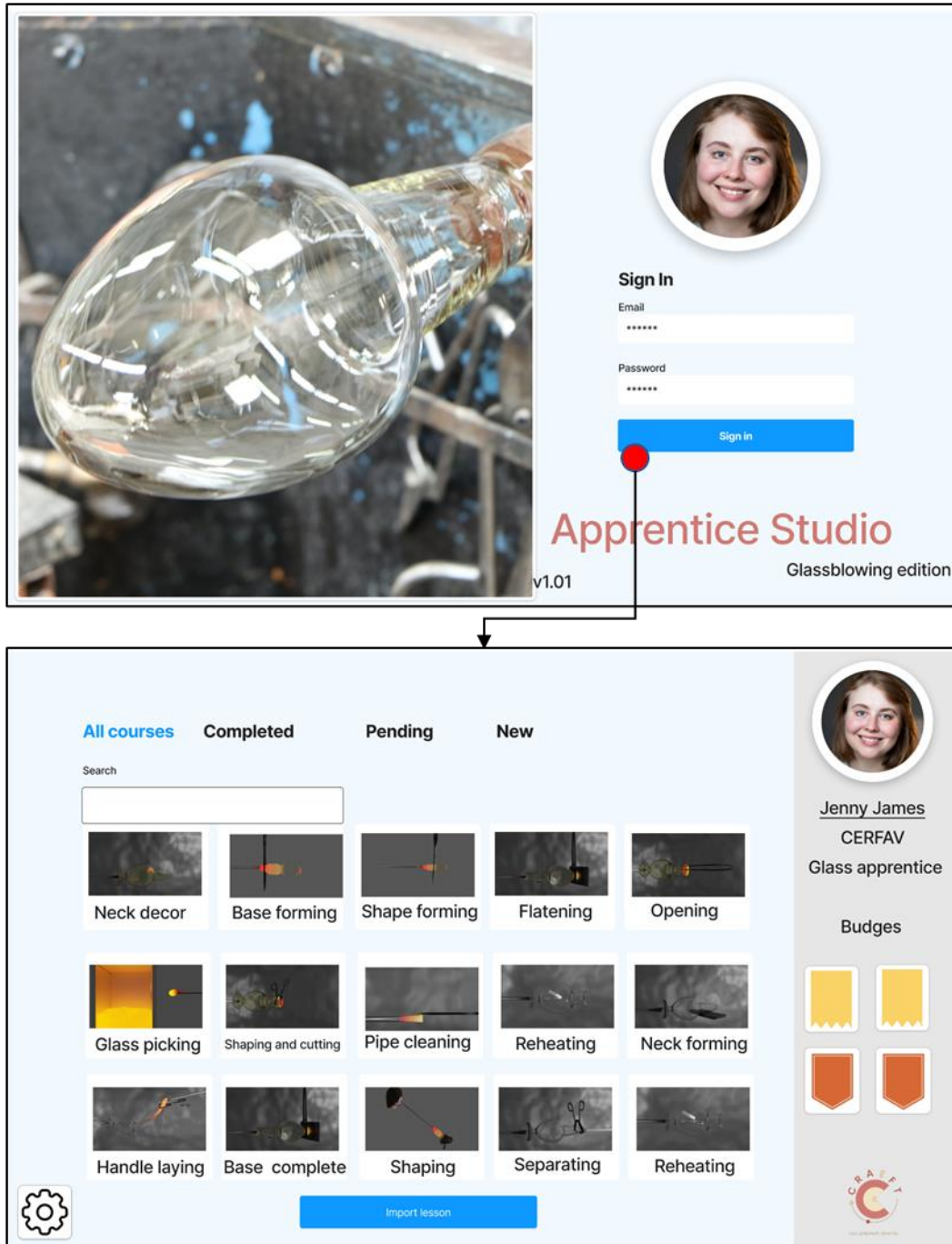


Figure 17. Signing in to the apprentice studio

When entering the Apprentices Studio, the splash screen contains the collection of courses assigned to the specific student. Initially, this is empty and waits for students to download courses from the eLearning portal and assign them to their instance of the Apprentices Studio. Courses are categorised in the following ways. All courses are on the list of courses assigned. Completed are the ones that have been completed by the apprentice, while pending are the ones assigned and pending examination.

From the home page, apprentices can also set up their full profile by entering their personal information, as shown in Figure 18. This allows for a customised learning experience tailored to each apprentice’s skills and development needs.

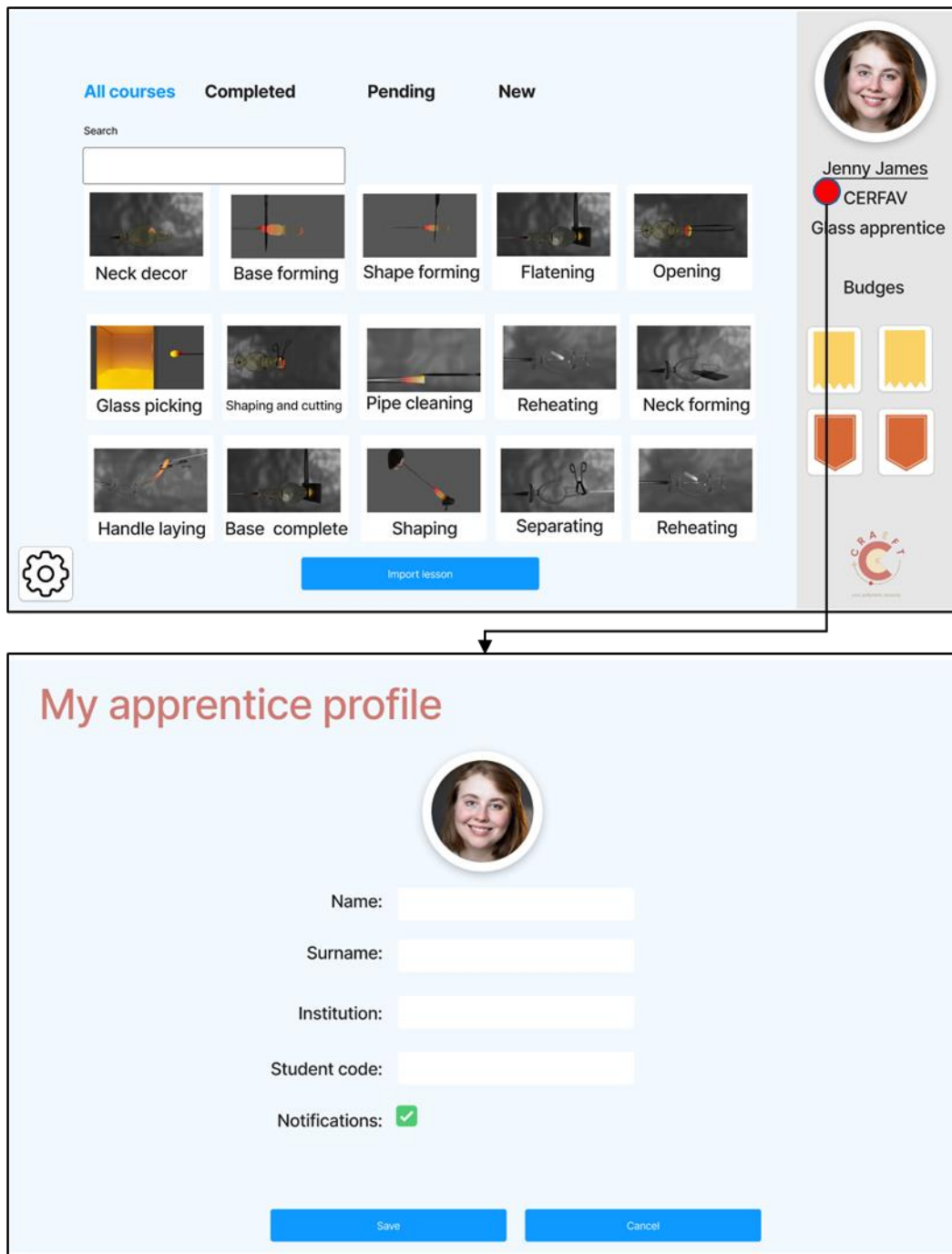


Figure 18. Editing the profile information of the apprentice



The system keeps detailed records of each apprentice's activities, completed lessons, practice sessions, and examination results. This data helps both apprentices and instructors monitor progress and identify areas needing improvement.

6.1.2 Lesson Integration

Importing Lessons: Lessons authored in the Craft Studio are exported and imported by the tutors in the eLearning portal. In the eLearning portal, Lessons are organised into a structured curriculum that guides apprentices through progressively more complex skills and techniques. This curriculum is designed to build a solid foundation before advancing to more intricate and challenging tasks. Part of this curriculum is the interactive training lessons executed by the Apprentice Studio.

Students who are taking a lesson can download the lesson specification from the eLearning portal and then integrate it into their instance of the Apprentice Studio, then import it into the Apprentice Studio. This seamless integration ensures that the content is consistent and aligned with the training objectives. The process of importing a lesson is presented in Figure 19.

When importing, the lesson information is also provided on the supported lesson modalities. This regards the input and output devices that can be used for training, such as haptic controllers, VR headsets, etc.

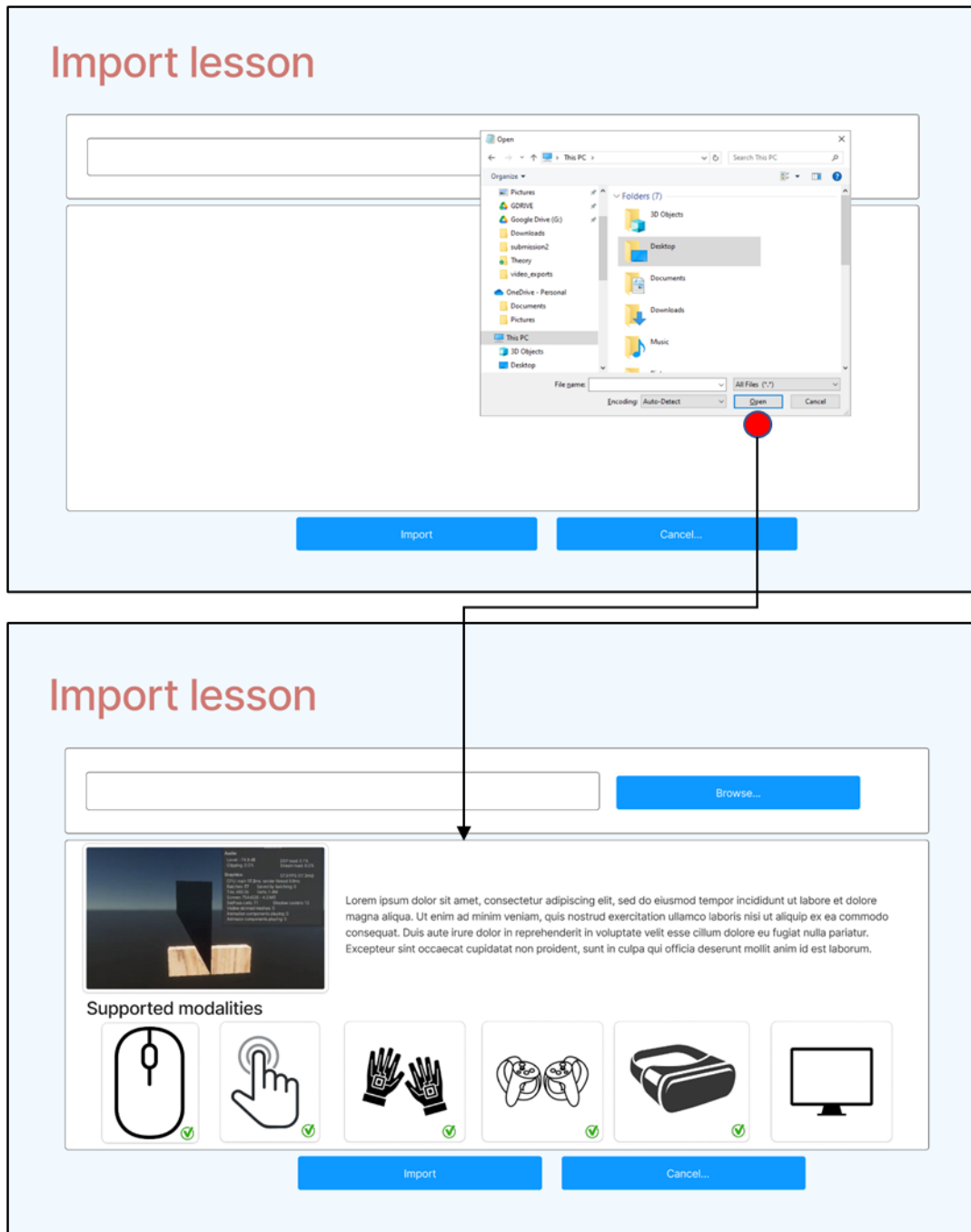


Figure 19. Importing a lesson

6.1.3 Device Compatibility

The Apprentice Studio is compatible with a wide range of devices, from standard desktop computers to advanced VR setups. This flexibility ensures that apprentices can access the training regardless of their hardware capabilities. By offering multiple modalities, the platform caters to different learning styles and preferences, ensuring that all apprentices can engage with the material in a way that suits them best.

The apprentice studio can be configured based on the availability of input and output devices per apprentice. To do so, each apprentice used the configuration interface, where different devices can be activated and deactivated. The selected configurations are propagated to all the lessons that will be imported by the apprentice. Lessons that require special devices that are not available will appear as deactivated until an appropriate device is acquired and configured. The configuration process is shown in Figure 20.

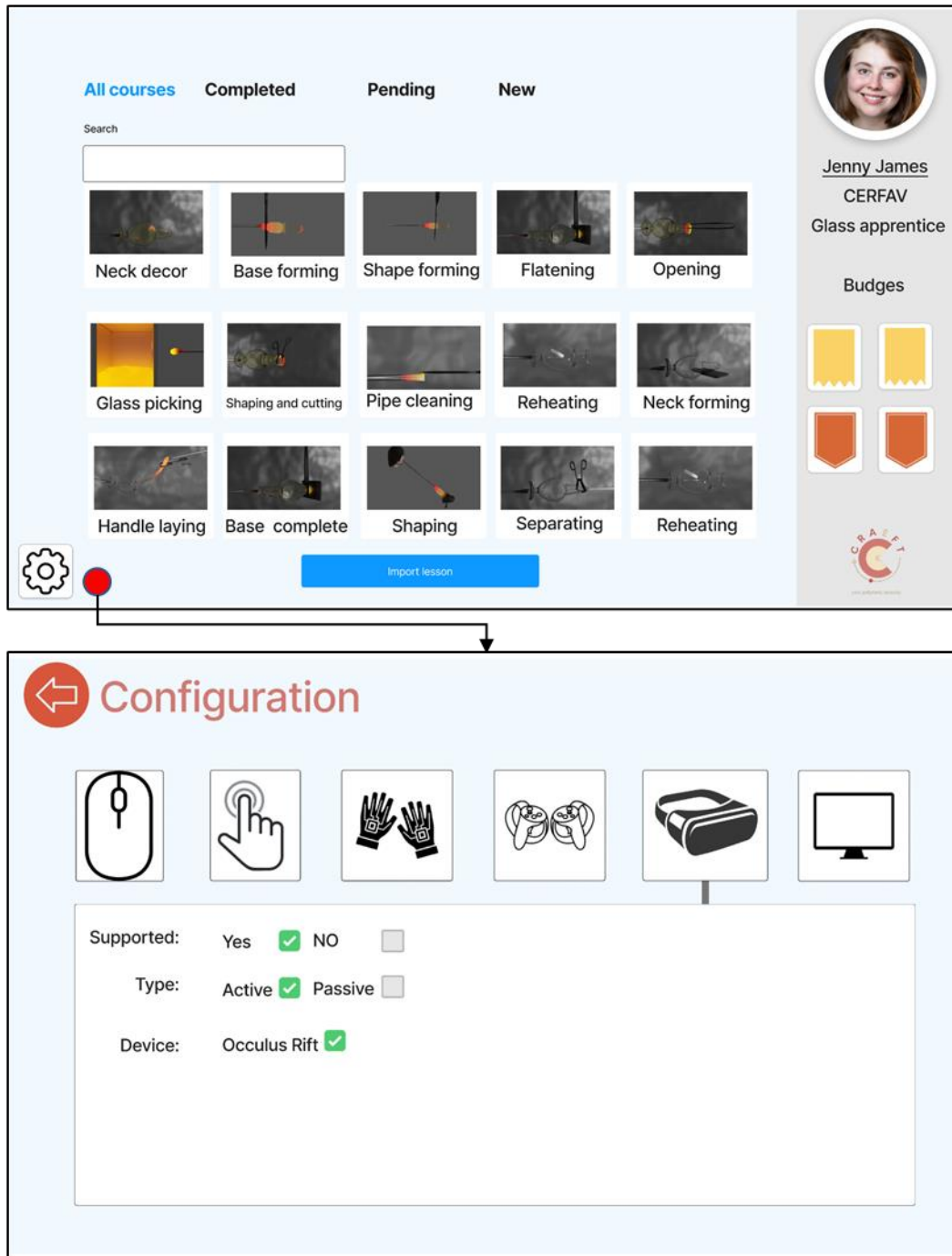


Figure 20. Configuring the apprentice studio

6.1.4 Lesson configuration

Lessons can be experienced in alternative forms based on the availability of input and output devices. The main supported modes of operation are the following:

- **3D Mode:** The lessons can be experienced in 3D on a standard computer screen, providing a detailed and interactive view of the crafting process. This mode includes interactive elements that allow apprentices to manipulate virtual tools and materials.
- **3D VR Mode:** For a more immersive experience, lessons can be experienced in Virtual Reality (VR). This mode uses VR headsets to place apprentices in a virtual workshop, providing a lifelike environment where they can practice their craft as if they were in a real studio.
- **3D VR with Haptic Devices:** To further enhance realism, the Apprentice Studio supports the use of haptic devices in VR mode. These devices provide tactile feedback, simulating the physical sensations of handling tools and materials. This helps apprentices develop a more intuitive understanding of the craft.

Figure 21 presents an example of a lesson home page. A description of the lesson is presented together with information on what devices and modes are supported.

Before selecting the preferred mode, the apprentice needs to select whether the lesson will be executed in practice or examination mode, as shown in Figure 21, bottom.

- **Practice Mode:** In practice mode, apprentices can freely explore the crafting processes without the pressure of formal assessment. This mode is designed to build confidence and competence through repetitive practice and exploration.
- **Examination Mode:** This mode evaluates the apprentice's skills and knowledge under simulated exam conditions. It is designed to test proficiency and ensure that apprentices meet the required standards for each craft.

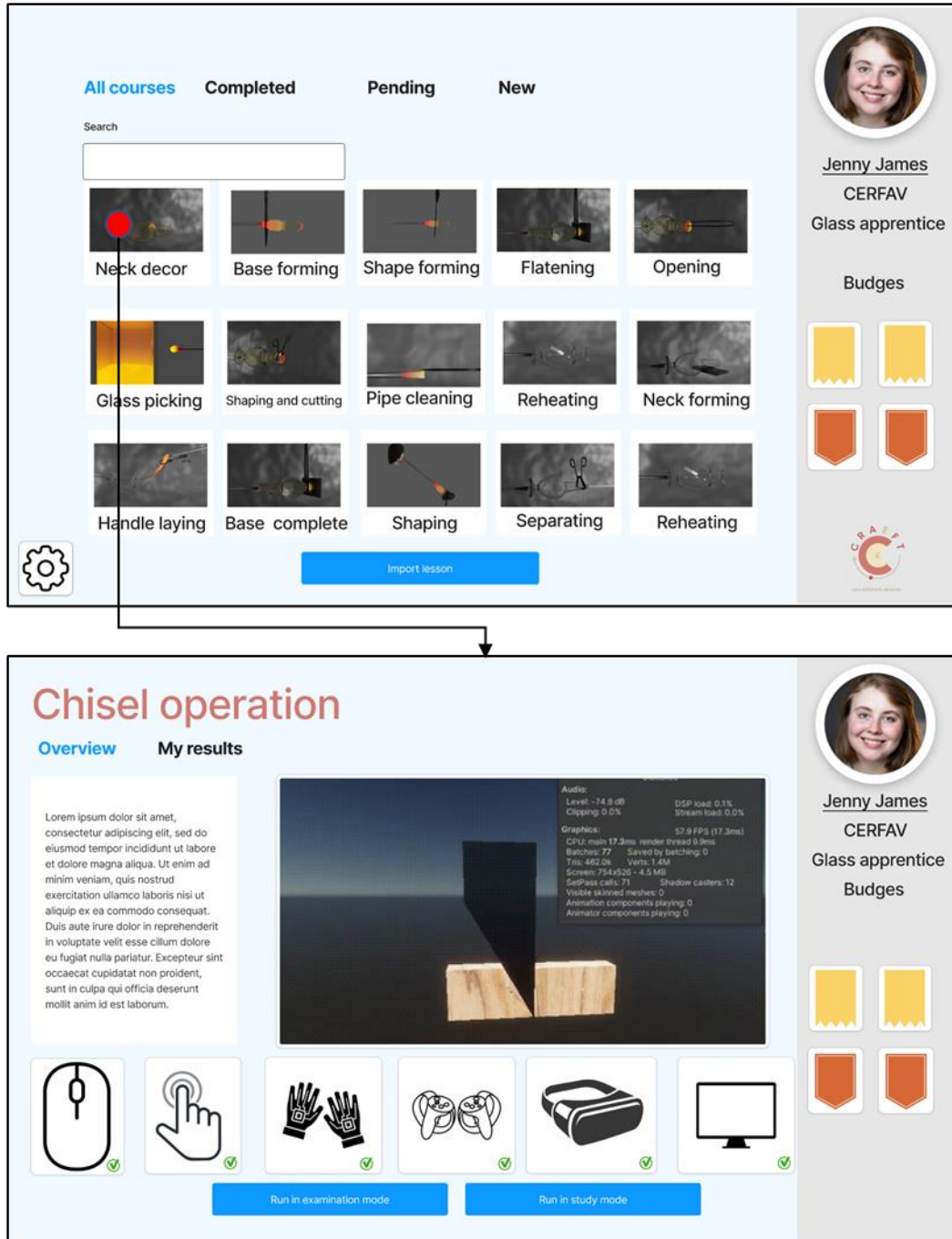


Figure 21. An example of a lesson's home page

When selecting to run a lesson in study mode, first, the apprentice is requested to decide upon the available modalities for the execution. From there, the devices to be used for rendering the lesson can be selected before executing it, as shown in Figure 22.

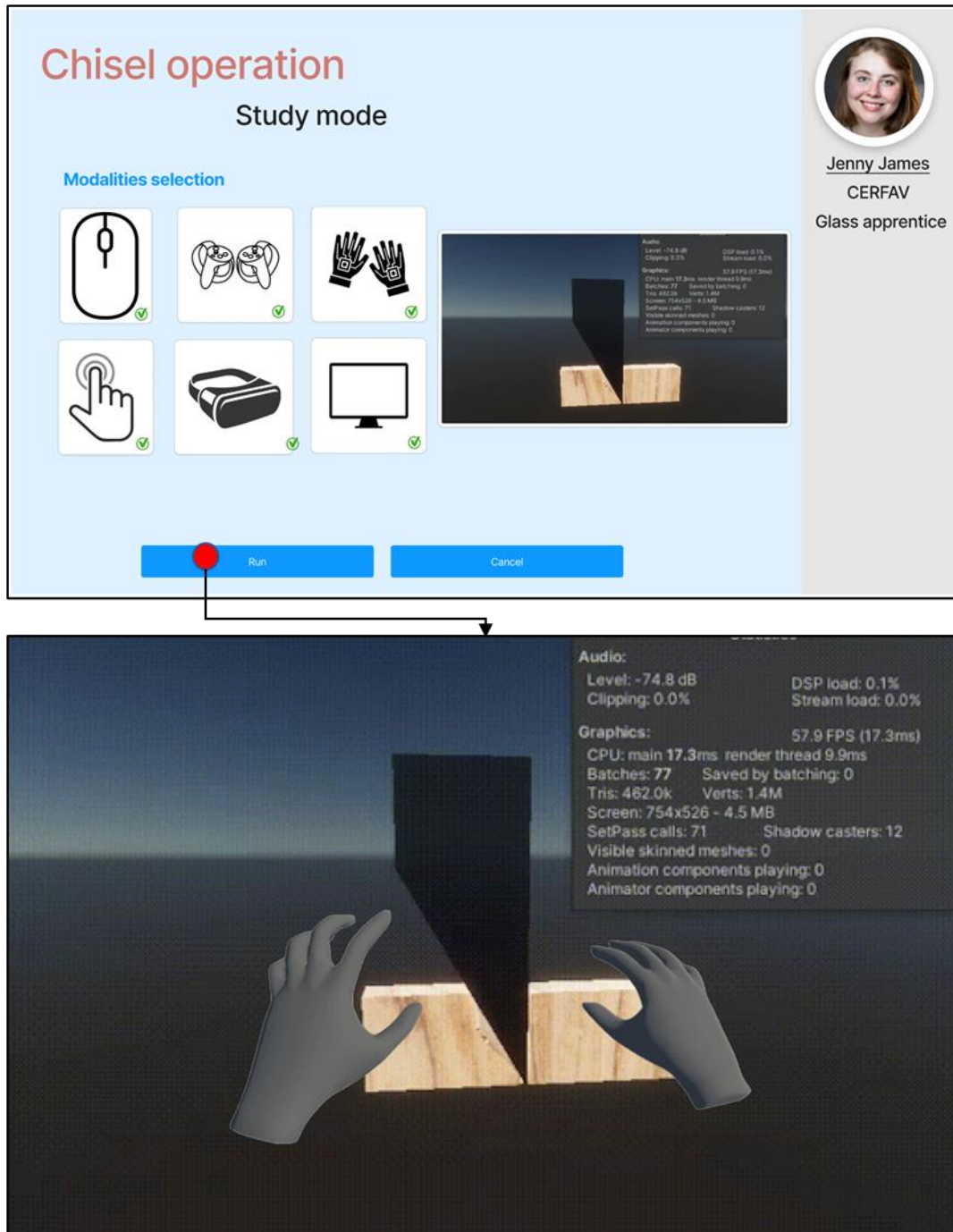


Figure 22. Running a lesson in practice mode

When selecting to run a lesson in examination mode, stricter rules apply. More specifically, there is a limitation on the devices that can be used for the examination since all apprentices should undertake the exams under the same conditions, which are the ones defined by the tutor. Thus, the selection of modalities is locked in examination mode; the exams can be taken only if the appropriate devices are available and configured on the apprentice's side. Furthermore, information is provided on the conditions that should be met for the exam to be considered successful. All are shown in Figure 23.

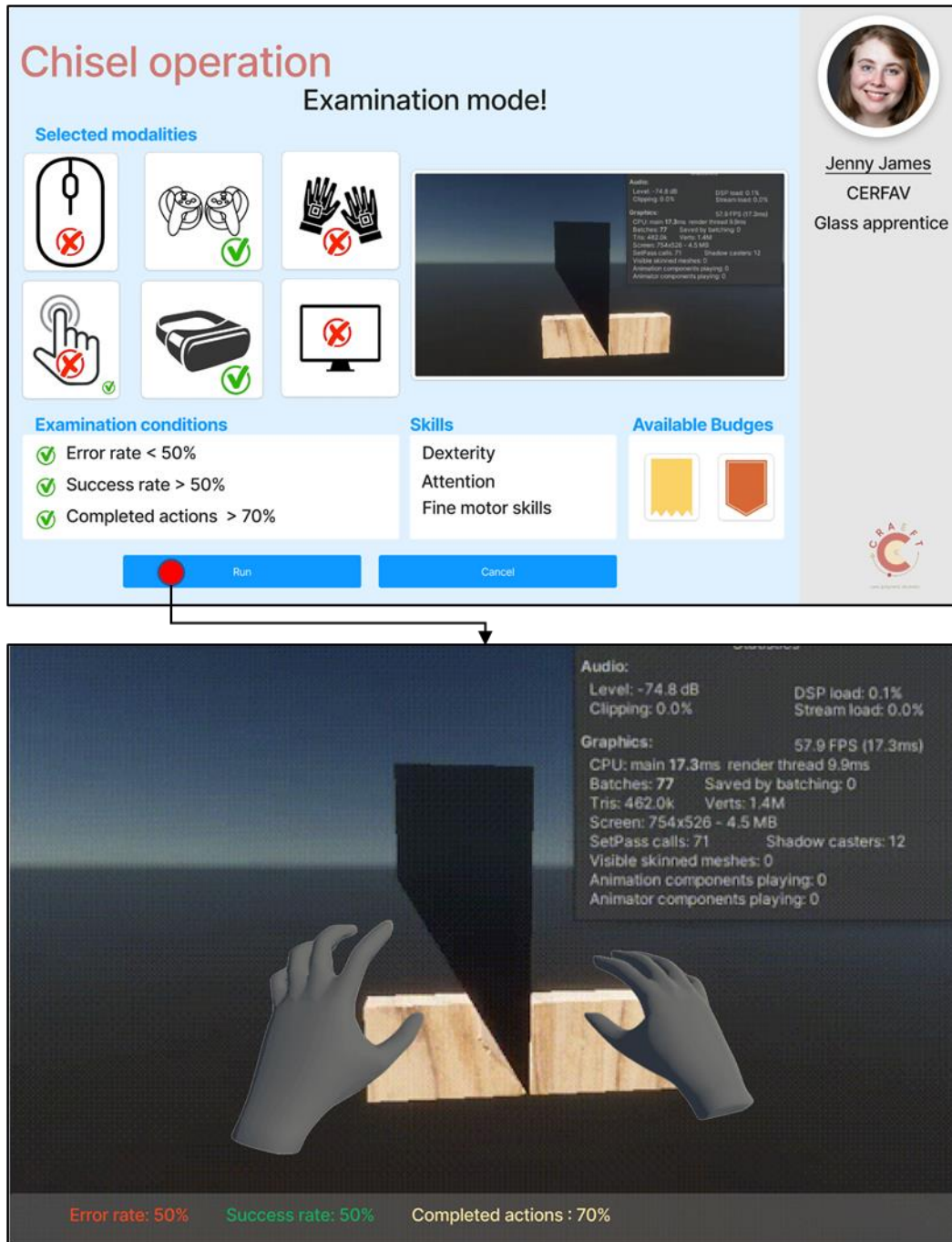


Figure 23. Running a lesson in examination mode

6.1.5 Real-World Applications

The platform's immersive capabilities simulate real-world crafting scenarios, helping apprentices develop practical skills that are directly applicable in real-world settings. The detailed and interactive nature of the lessons ensures that the skills learned in the virtual environment transfer effectively to real-world applications, making the training both practical and impactful.

6.2. The Apprentice Studio – Implementation

The Apprentice Studio is implemented as an immersive execution environment for craft training scenarios authored in the Craft Studio. Its primary role is to deliver interactive learning experiences that allow learners to observe, rehearse, and practice craft processes in a controlled digital setting. The implementation of the Apprentice Studio reflects the layered methodological approach introduced in this deliverable, integrating semantic process descriptions, simulation engines, visualisation components, and pedagogical logic into a unified runtime system.

At runtime, the Apprentice Studio interprets semantically structured learning content produced in the Craft Studio. Process descriptions, actions, tools, and constraints are instantiated as executable scenarios that govern learner interaction. This semantic grounding ensures that the learner’s actions are evaluated not only at the level of geometric or physical change, but also in terms of process logic and pedagogical intent. As a result, the system can provide context-aware feedback and guidance that is consistent with authentic craft practice.

The simulation layer of the Apprentice Studio integrates offline and real-time simulation components to support different categories of craft processes. Depending on the craft domain, this includes modelling material deformation, subtractive material removal, tool–material interaction, and process sequencing. Simulation fidelity is balanced against real-time performance requirements to ensure responsive interaction, while preserving perceptually and pedagogically relevant behaviour. The modular architecture of the simulation layer allows different craft-specific simulators to be integrated without altering the overall execution framework.

Visualisation and interaction are central to the Apprentice Studio implementation. The system supports real-time rendering of tools, materials, and evolving artefacts, providing immediate visual feedback linked to learner actions. Multiple visualisation modes can be employed, ranging from simplified representations optimised for learning and clarity to more advanced, physically based rendering used for reflection and assessment. Interaction techniques are designed to mirror real workshop ergonomics as closely as possible, supporting embodied learning and the development of motor skills.

From a pedagogical standpoint, the Apprentice Studio implements learning logic informed by Cognitive Load Theory. Instructional guidance, feedback, and task complexity are adapted according to the learner’s progression within a scenario. The system supports different instructional phases, including observation, guided execution, and exploratory practice. By controlling the timing and amount of information presented to the learner, the Apprentice Studio reduces extraneous cognitive load while fostering germane cognitive processes associated with skill acquisition.

Technically, the Apprentice Studio is implemented as a modular and extensible platform capable of supporting different hardware configurations, including desktop and immersive setups. The separation between authored content and runtime execution allows the same learning scenario to be deployed across multiple contexts without modification. This design choice supports scalability and long-term sustainability of the platform, enabling future extensions such as enhanced sensory feedback, adaptive tutoring mechanisms, or integration with external learning management systems.

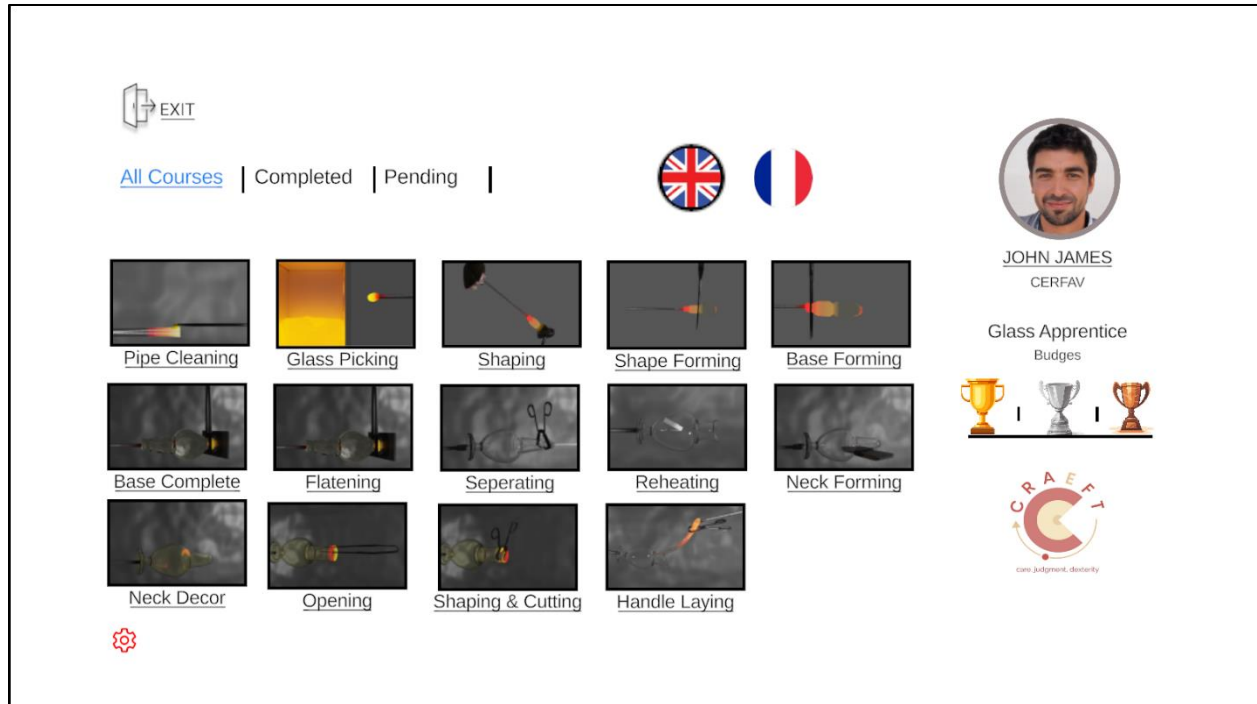


Figure 24. All courses assigned to a specific Student

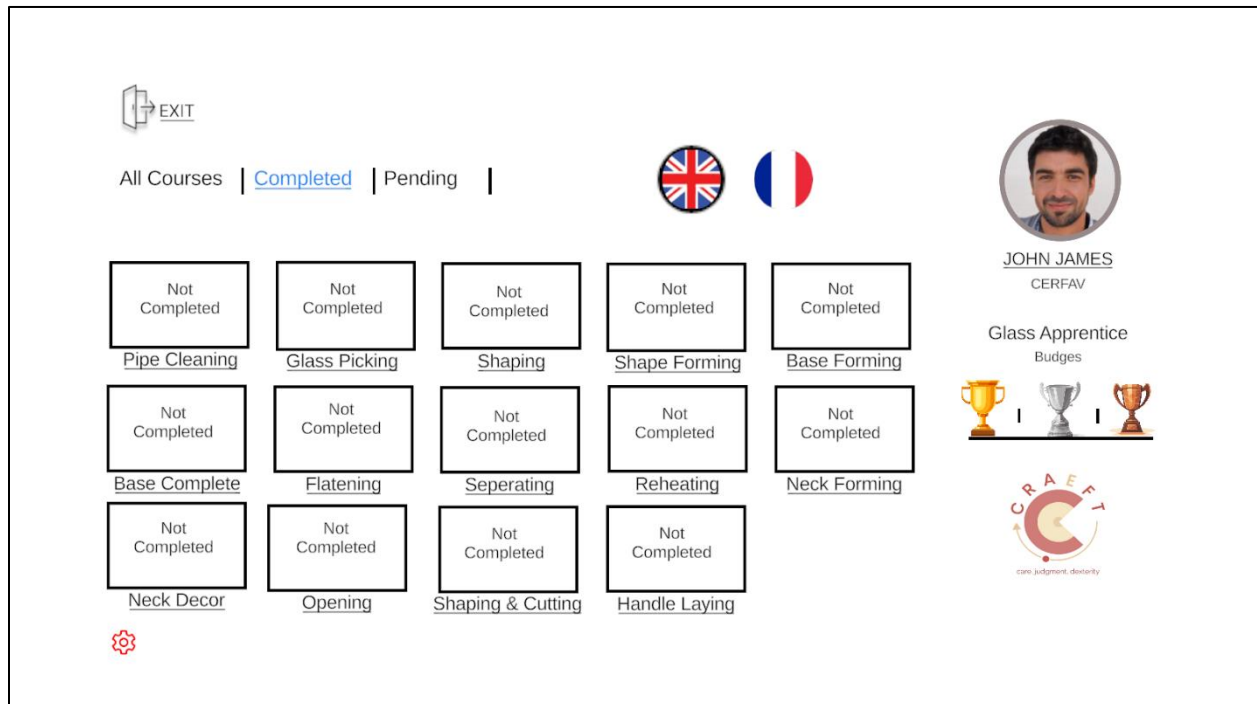


Figure 25. Completed courses

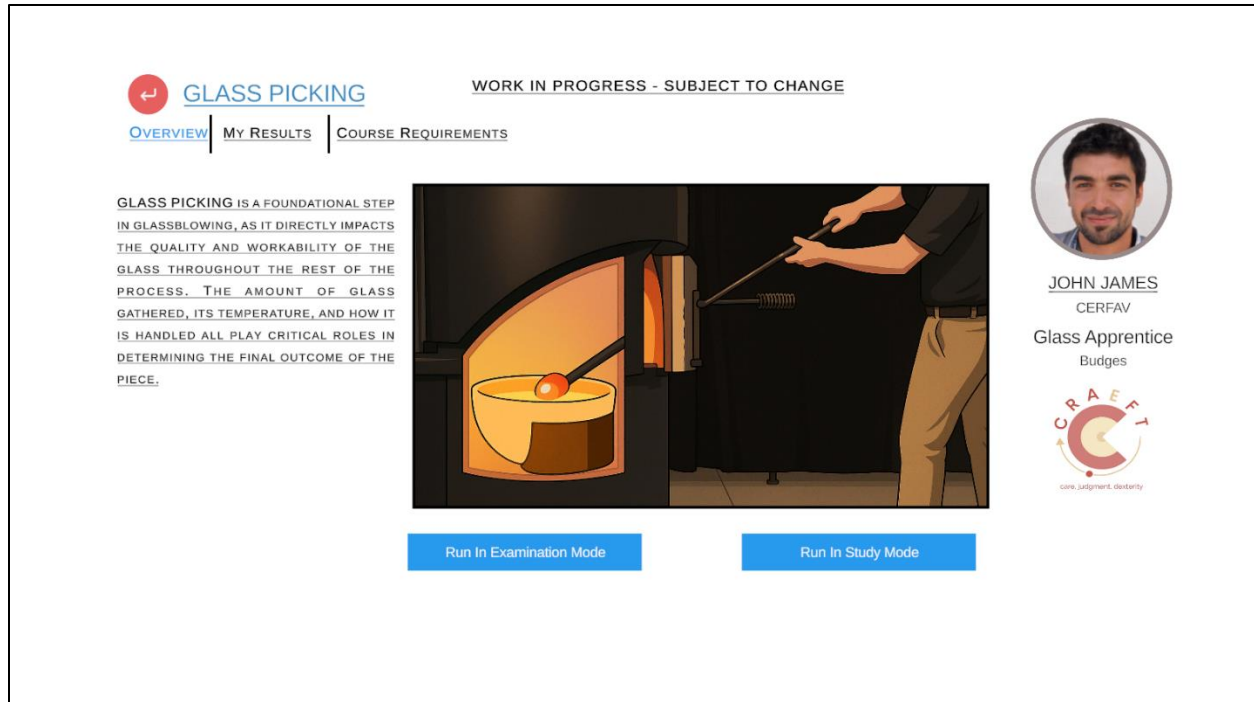


Figure 26. Course overview

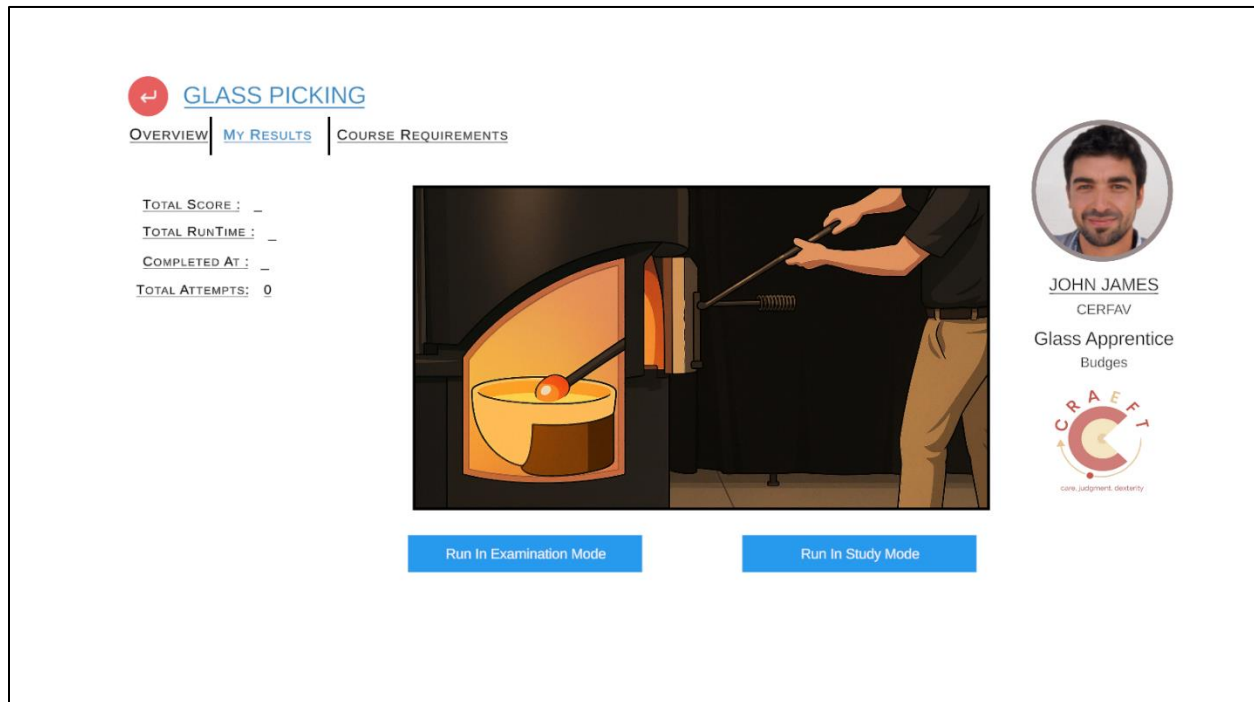


Figure 27. Course – student results

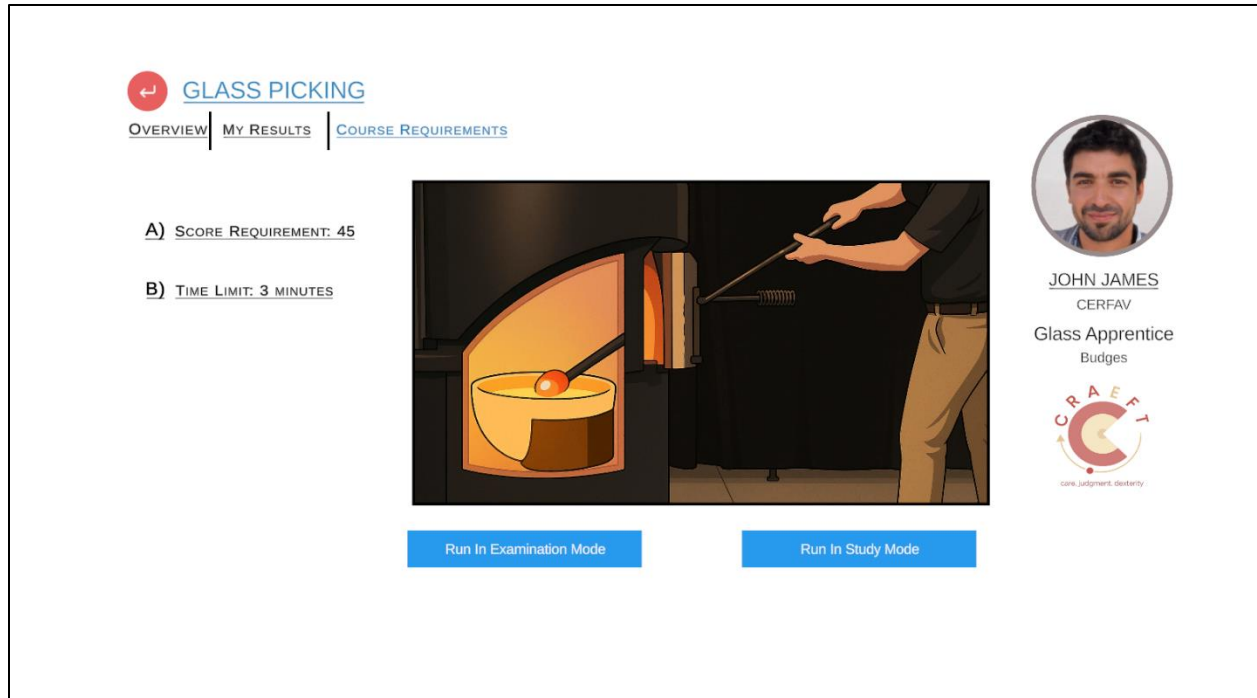


Figure 28. Course requirements

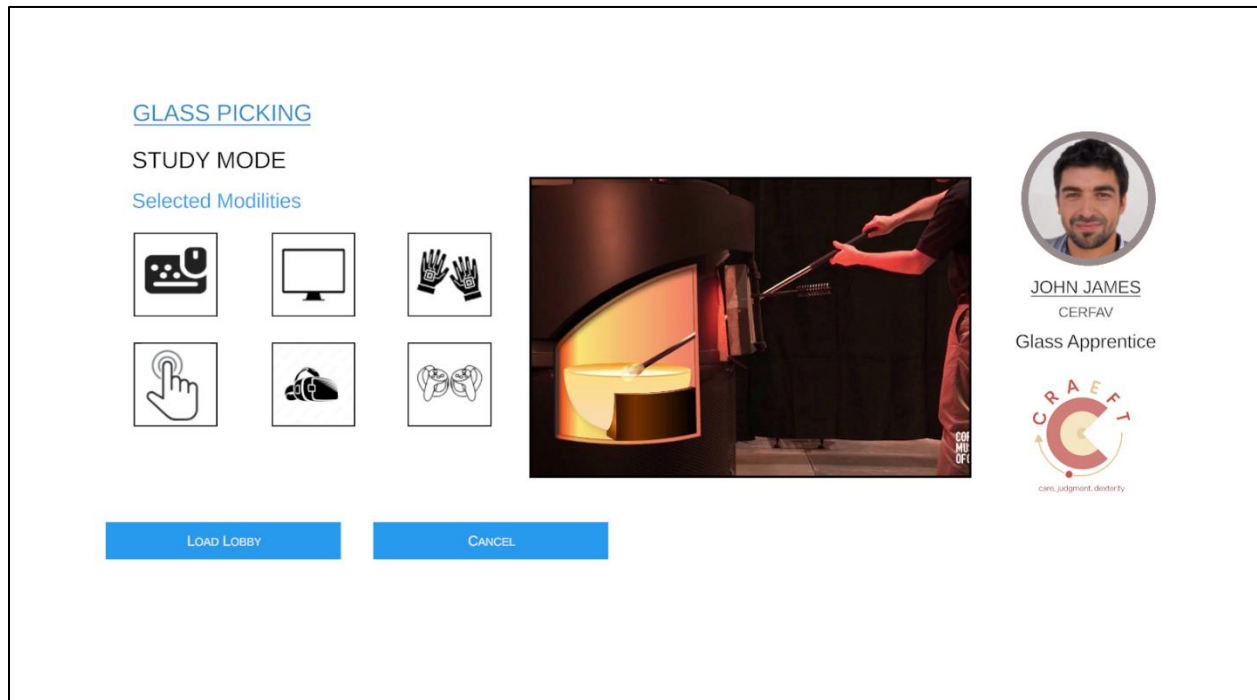


Figure 29. Course – preparation to execute in study mode

GLASS PICKING
EXAMINATION MODE

Selected Modalities

Examination Conditions

Error Rate < 50%
Success Rate > 50%
Completed Actions > 70%

Skills

Dexterity
Attention
Motor Skills

Available Bidges

100-80% 80-50% <50%

LOAD LOBBY

CANCEL

Figure 30. Course – preparation to execute in examination mode

EXIT

All Courses | Completed | Pending |

Not Completed Pipe Cleaning	 Glass Picking	Not Completed Shaping	Not Completed Shape Forming	Not Completed Base Forming
Not Completed Base Complete	Not Completed Flatening	Not Completed Seperating	Not Completed Reheating	Not Completed Neck Forming
Not Completed Neck Decor	Not Completed Opening	Not Completed Shaping & Cutting	Not Completed Handle Laying	

Figure 31. Completed courses for the student

7 Authoring of immersive educational content

7.1 The Craft Studio – Design

The Craft Studio is a sophisticated and integral component of the immersive training ecosystem, tailored for craft masters to create, manage, and evaluate training lessons for apprentices. It offers a comprehensive suite of tools and functionalities designed to facilitate the design and delivery of engaging, interactive, and effective training sessions.

The overall design of the Craft Studio emphasises interactivity and ease of use. Craft masters can quickly navigate between different sections, making it straightforward to create, modify, and review lessons and student performance. Key features include:

- **Visual Diagrams:** The use of visual diagrams in lesson creation allows craft masters to map out the entire training process clearly and logically. This visual approach makes it easier to identify and correct any potential issues in the workflow.
- **Drag-and-Drop Functionality:** The interface supports drag-and-drop functionality, enabling craft masters to effortlessly add, move, and connect components within a lesson. This enhances the flexibility and efficiency of the lesson design process.
- **Real-Time Previews:** Craft masters can preview lessons in real time, ensuring that all components are correctly linked and functioning as intended. This feature helps to verify the accuracy and coherence of the training material before it is deployed to apprentices.

The Craft Studio is designed to be compatible with a wide range of devices, ensuring that lessons can be accessed and executed across different platforms:

- **Standard Desktops and Laptops:** Lessons can be viewed and edited on standard desktop computers and laptops, making it accessible to craft masters regardless of their hardware capabilities.
- **Advanced VR Setups:** For a more immersive experience, the Craft Studio supports advanced VR setups, allowing craft masters to create and test lessons in a virtual environment. This feature is particularly useful for simulating real-world scenarios and ensuring that training material is as realistic and engaging as possible.
- **Haptic Devices:** The platform also supports haptic devices, which provide tactile feedback and enhance the realism of the training experience. This is particularly valuable for teaching skills that require a high degree of manual dexterity and precision.

Each educator accesses the Craft Studio using their personal credentials in the same way that apprentices do. This is to organise lessons per educator and allow monitoring of students, assignments, and results. Upon logging in to the Craft Studio, the initial screen provided three main options. The first regards accessing all the created lessons, the second is editing processes and actions that are the components for lesson authoring, and the third regards accessing the results of lessons taken and examined by the educator's students. An overview of the home page for each educator is presented in Figure 32.

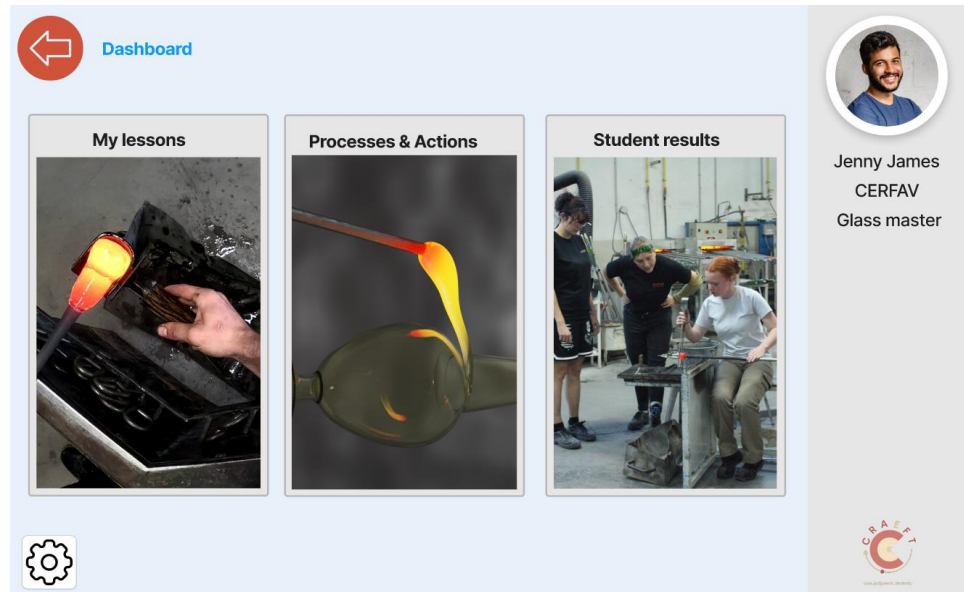


Figure 32. Home page of the Craft Studio per educator

7.1.1 Accessing Created Lessons

The **Lessons** section is the core component where craft masters can access, create, and manage their training content. This functionality includes several essential capabilities:

Craft masters can easily access previously created lessons, enabling them to review, modify, or enhance the training material as needed. This ensures that lessons remain up-to-date and relevant to the evolving needs of the apprentices. An overview of the created lessons for an educator is presented in Figure 33.

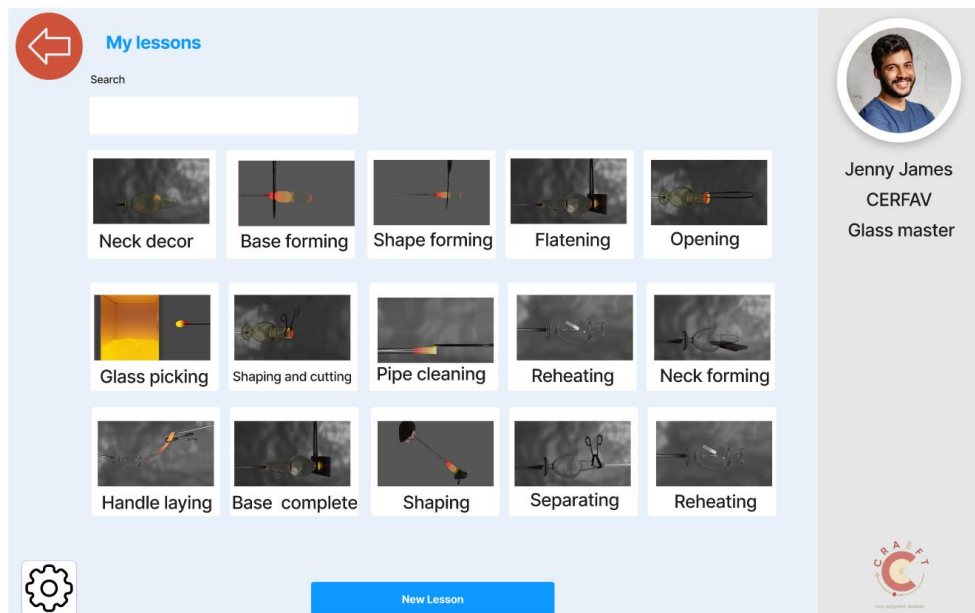


Figure 33. Overview of lessons

7.1.2 Creating New Lessons

Craft masters can develop new lessons from scratch. This process involves integrating various elements such as processes, actions, tools, machines, and workshop equipment. The creation process is facilitated by an intuitive, diagram-making metaphor, where components are visually connected using links, arrows, and other interactive elements. This approach simplifies the lesson design process, allowing craft masters to outline the sequence and flow of activities clearly and efficiently. A lesson authoring operation starts by selecting virtual processes and actions that participate in a lesson. Craft masters can import pre-defined virtual processes and actions into the Craft Studio. These processes and actions form the building blocks of the lessons and can be customised to fit the specific requirements of each craft. Each process or action can be detailed with configurable parameters, such as the devices used, input/output modalities, and the sequence of steps involved. This flexibility ensures that lessons are tailored to the learning objectives and the skills to be developed. An overview of these initial steps is presented in Figure 34.

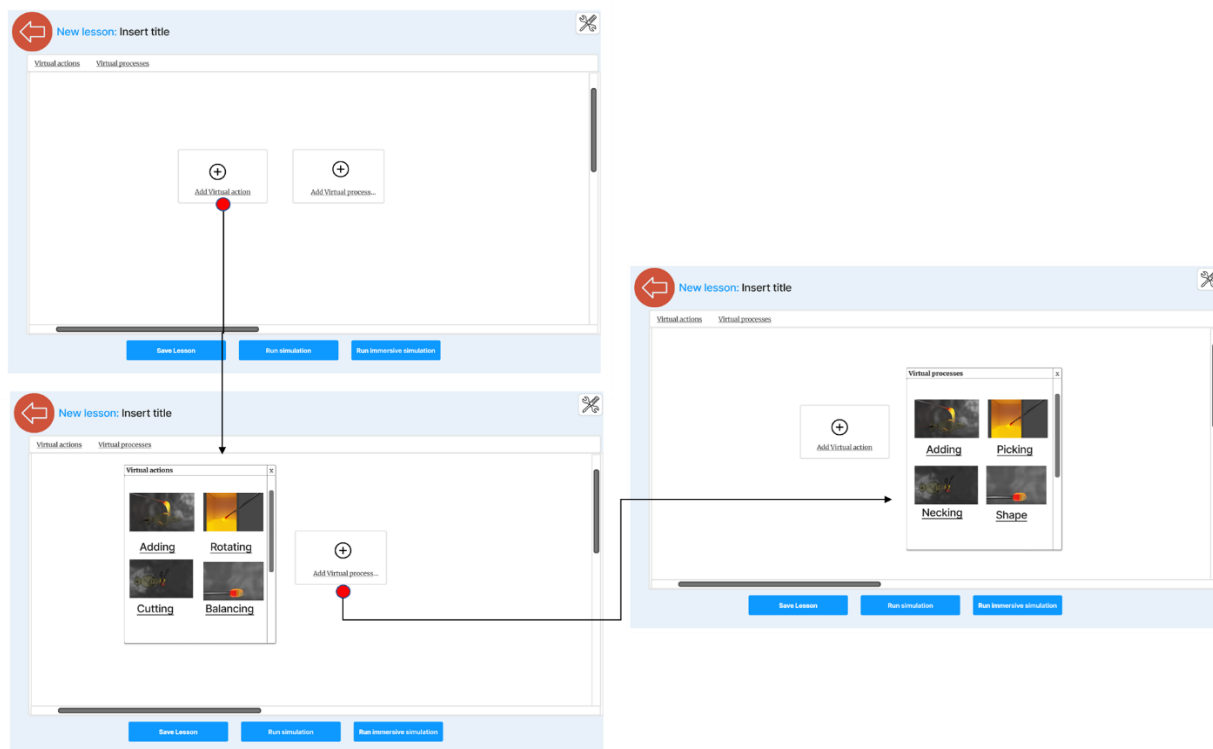


Figure 34. Starting points in lesson creation, selecting virtual actions and virtual processes

After selecting the basic components, the authoring environment is expanded with further components that can be assigned or linked to a virtual process or a virtual action. These include tools, machines, and workshop environments that are used for the initialisation of the virtual actions and/or processes. At the same time, different inputs and outputs can also be assigned to the lesson regarding the devices that are available and compatible with its execution. To do so, the lesson creation interface allows for the easy linking of processes, actions, and equipment. Craft masters can visually connect these components, establishing clear relationships and workflows. This visual representation aids in the logical structuring of

lessons, making it easier for apprentices to understand and follow the intended sequence of activities. An example of an authored lesson with assigned information is presented in Figure 35.

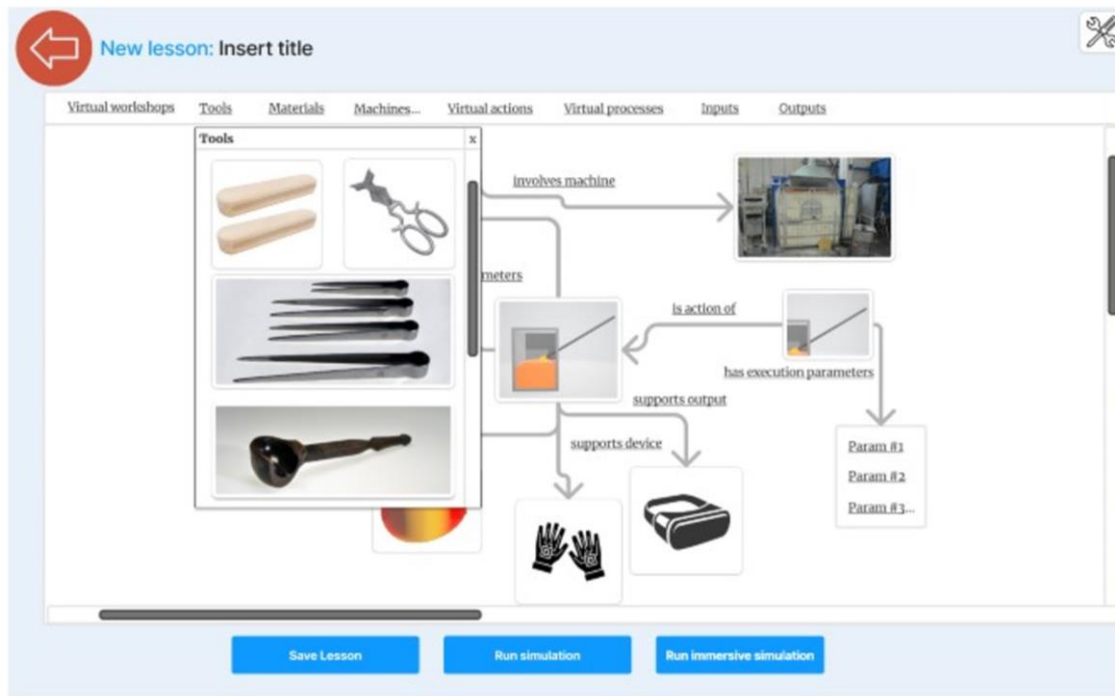


Figure 35. An example of an authored lesson with assigned information on tools, machines, workshops, and also input and output devices.

7.1.3 Student Results

The Student Results section provides a detailed overview of each apprentice’s performance across different lessons. An example of such a section is presented in Figure 36. From this section, several key operations can be done. When apprentices complete lessons in examination mode within the Apprentice Studio, they export and submit their results. This export feature captures essential data, such as the tasks completed, time taken, accuracy, and any errors or issues encountered. Craft masters can import received results from their students into the Craft Studio, where they are organised and displayed for easy access. The imported results are presented in a comprehensive format, showing the performance of each student on a per-lesson basis. This includes metrics such as completion status, score, time spent, and any feedback or observations made during the examination.

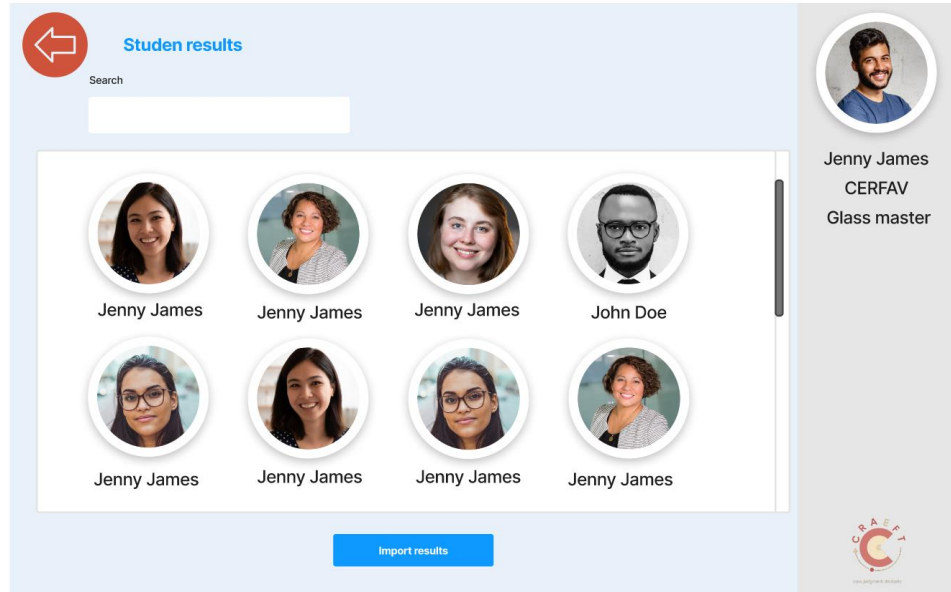


Figure 36. The students' results section.

A detailed overview of each student’s progress, allowing craft masters to analyse performance trends, identify strengths and weaknesses, and tailor future lessons to address specific needs, is provided by selecting each of the individual students. This analytical capability supports targeted feedback and personalised coaching, enhancing the effectiveness of the training program. An example is presented in Figure 37.



Figure 37. A student’s results section.

7.2 The Craft Studio – Implementation

The Craft Studio is implemented as an authoring and configuration environment designed to support the creation of semantically grounded educational content for craft training. Its primary purpose is to enable domain experts, educators, and instructional designers to formalise craft knowledge, define learning activities, and configure interactive training scenarios that can subsequently be executed within the Apprentice Studio. The implementation reflects the layered methodology presented in this deliverable, integrating semantic modelling, simulation configuration, and pedagogical structuring.

At the core of the Craft Studio implementation is the semantic layer, which provides tools for defining craft processes in terms of actions, tools, materials, and constraints. Users can describe craft workflows as structured sequences of activities, capturing both procedural order and contextual dependencies. These semantic descriptions are aligned with the conceptual models introduced earlier in this deliverable, ensuring consistency between authored content and its execution in immersive environments. By grounding authoring activities in explicit semantic representations, the Craft Studio supports reuse, extensibility, and interoperability across different craft domains.

The Craft Studio also provides mechanisms for linking semantic process descriptions to simulation parameters. For each defined action, authors can associate relevant simulation configurations, such as tool geometry, material properties, and interaction constraints. This association enables the offline simulation components to interpret authored content correctly and ensures that interactive execution reflects the intended craft logic. The implementation thus establishes a clear correspondence between high-level pedagogical intent and low-level computational behaviour.

From a pedagogical perspective, the Craft Studio supports the structuring of educational material according to Cognitive Load Theory principles. Authors can segment complex craft processes into manageable learning units, define progressive levels of guidance, and specify instructional scaffolding. This includes the ability to distinguish between demonstration phases, guided practice, and exploratory tasks. By embedding these pedagogical decisions directly into the authored content, the Craft Studio facilitates the creation of learning experiences that manage cognitive load and support gradual skill acquisition.

Technically, the Craft Studio is implemented as a modular software system that separates authoring interfaces from execution components. This separation allows educational content to be authored independently of specific hardware configurations or immersive setups. Authored content is stored in structured data formats that can be interpreted by the Apprentice Studio at runtime, enabling flexibility in deployment and future extensibility. The modular design also supports the integration of new craft domains and simulation modules without requiring fundamental changes to the authoring environment.

Visual feedback and preview functionalities are integrated into the Craft Studio to support iterative authoring and validation. Authors can inspect semantic process graphs, review configured parameters, and verify the logical consistency of learning scenarios before deployment. This reduces the risk of misalignment between authored content and learner experience and supports collaboration between craft experts and technical developers.

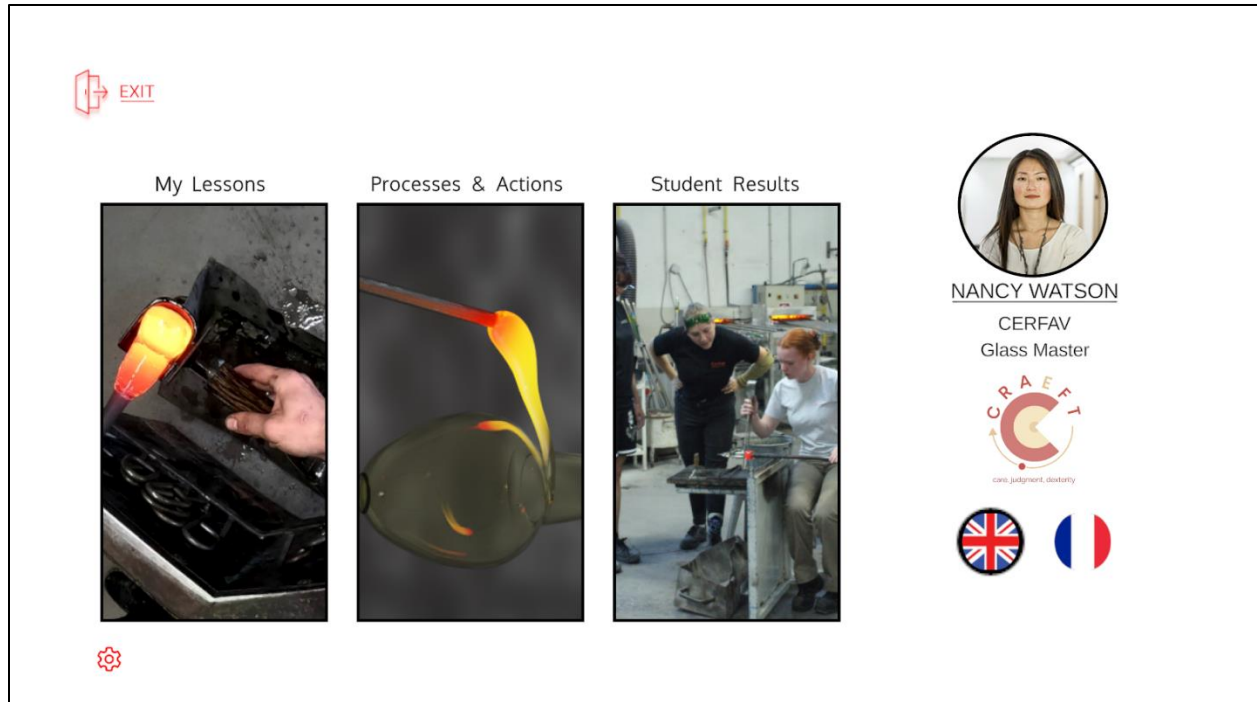


Figure 38. The craft master's home page

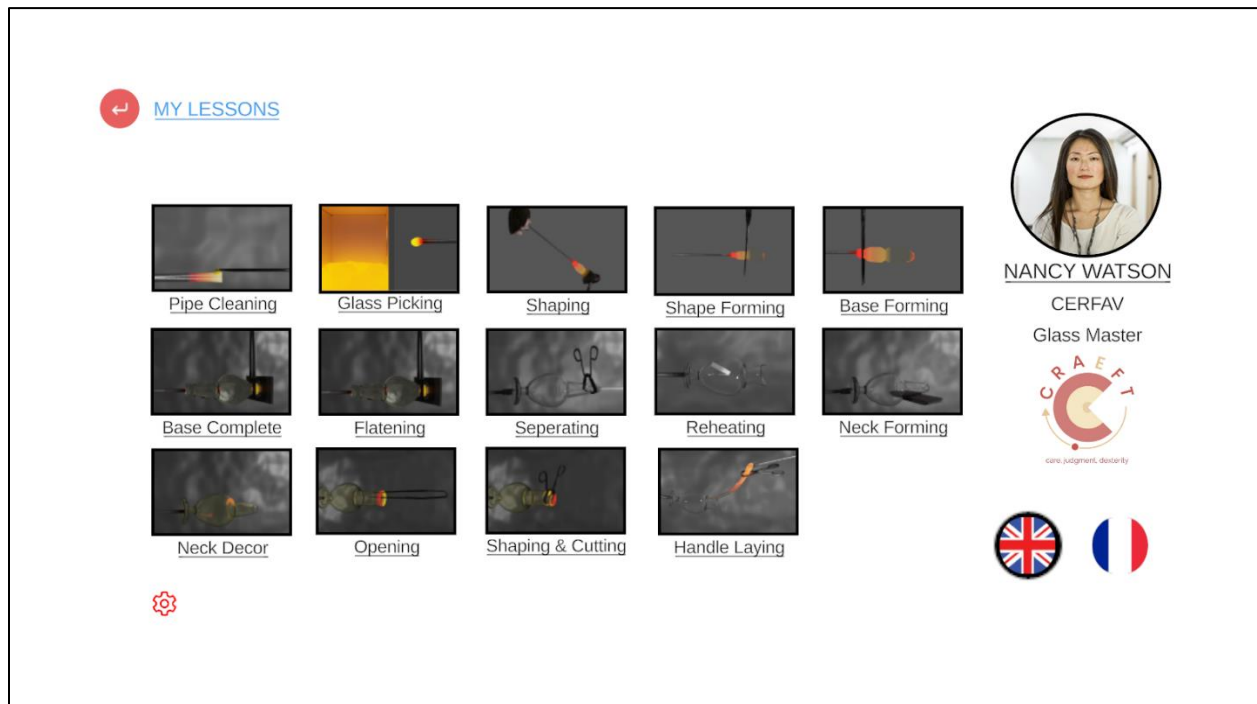


Figure 39. Lessons created by the Craft Master.

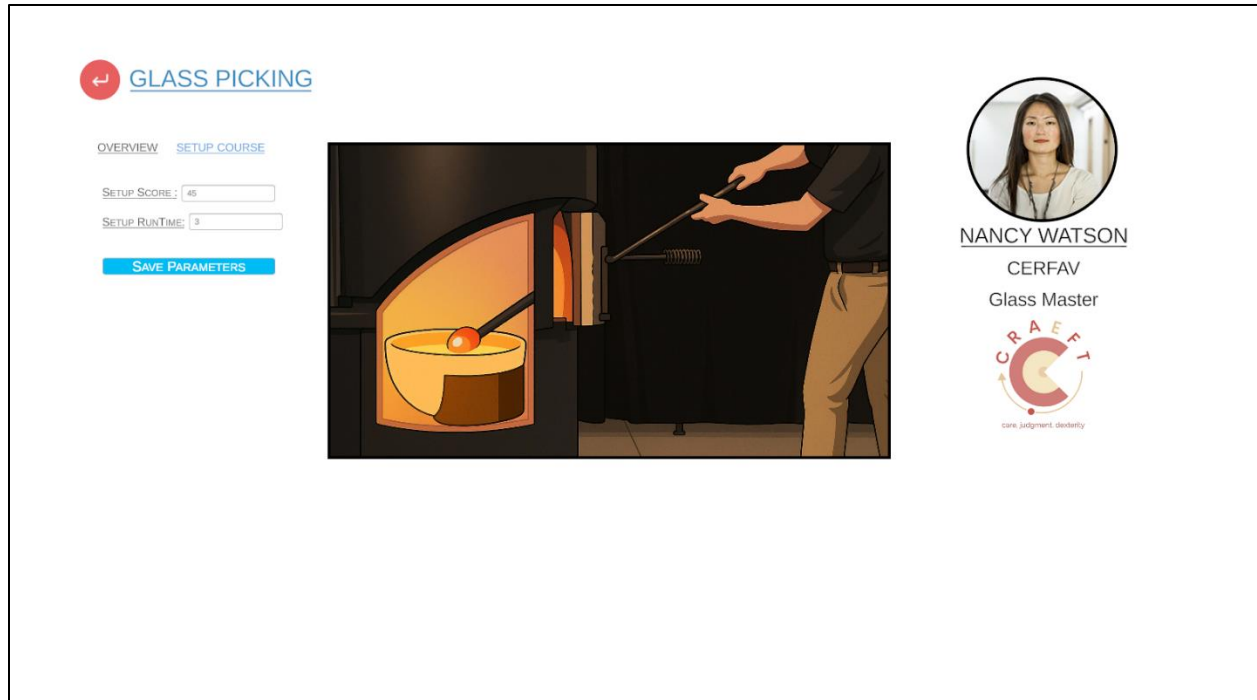


Figure 40. Editing lesson parameters.

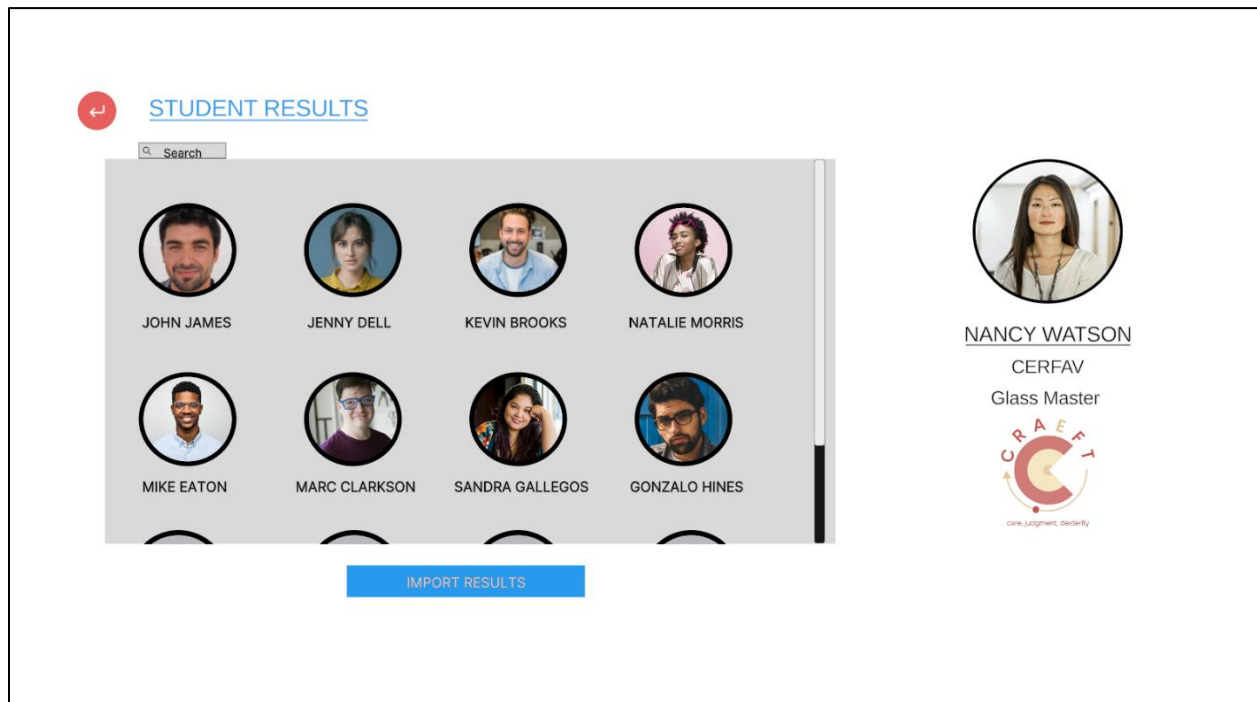


Figure 41. List of students assigned to the Craft Master.

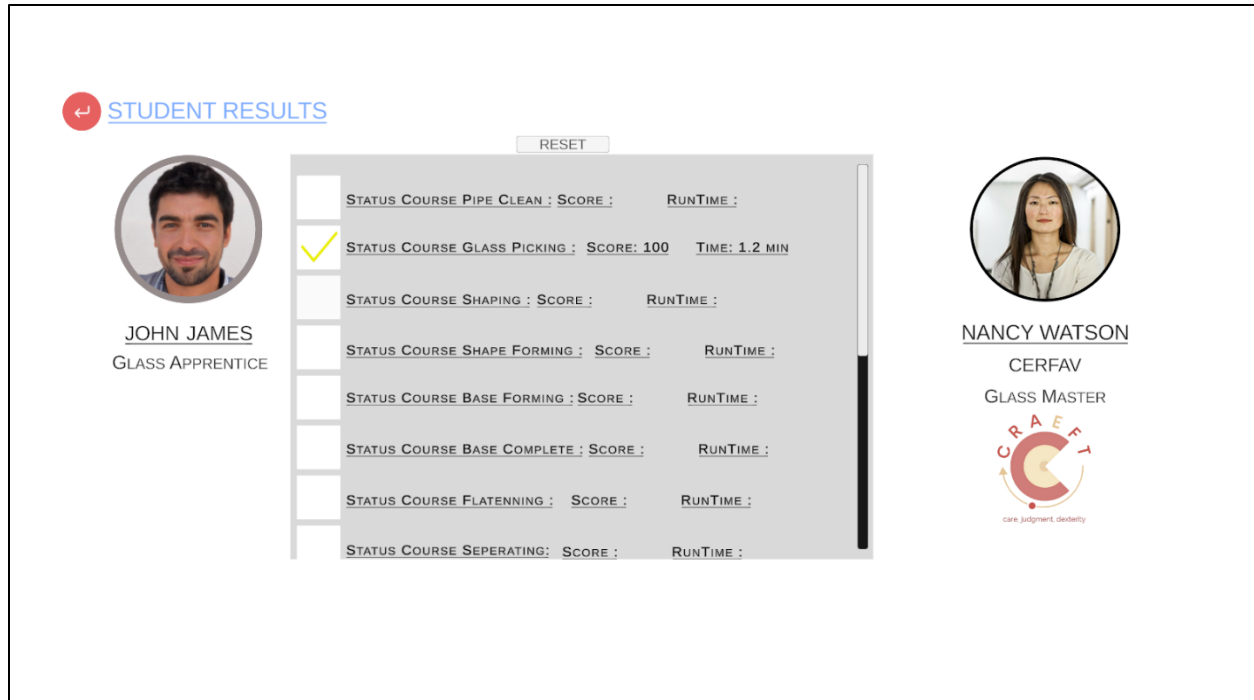


Figure 42. Accessing students' results.

8 Use Case – Glass blowing

KHORA, in collaboration with CERFAV, contributed to the design specification and interaction definition for the VR Glass Workshop prototype and translated these design decisions into implementation-oriented guidance that can be used directly by partners working in Unity.

The contribution focuses on a two-scenario learning structure that distinguishes contextual exploration (Knowledge) from procedural training (Know-how), complemented by a haptic controller playground section. This is all supported by a simple Waiting Room / Lobby which facilitates scenario selection, controller readiness checks, and reliable recovery via a return-to-lobby action.

Across the iterations, KHORA defined a concrete interaction model covering selection and highlighting rules, teleportation and return logic, and tool handling constraints designed to keep the prototype stable and reviewer-credible. KHORA also consolidated review feedback and test observations into a structured improvement backlog for future prototype cycles, with particular attention to UX/UI clarity, highlight reliability, tool grasp and pose realism, and long-tool ergonomics.

Finally, KHORA documented a dedicated haptic controller integration concept, including a separate test track and haptic scenario proposals aligned strictly with ETH-confirmed device modes, to avoid destabilising the main workshop scenarios.

8.1 Design and coordination

8.1.1 Iterative requirements collection and analysis

Requirements for the VR Glass Workshop experience were captured and refined through a sequence of partner meetings, design document iterations, and structured comment rounds, followed by refinements based on usability feedback and prototype testing.

The work progressed from early pedagogical framing and scenario scoping toward concrete interaction rules, content and media feasibility decisions, and targeted UX improvements needed to increase clarity and robustness in a VR workshop setting.

A consistent outcome across the iteration cycles was the confirmation of a two-mode learning structure: a Knowledge mode focused on orientation and tool understanding, and a Know-how mode focused on procedural learning. The pilot team also converged on the need for a Waiting Room / Lobby as a stable entry point that supports scenario selection and basic controller readiness while providing an always-available escape route back to a safe state.

During refinement, the scope of the Knowledge mode was deliberately kept lightweight to reduce implementation and UX risk. This included explicit constraints such as limiting interaction complexity and disabling grabbing. In parallel, the tools and equipment inventory was consolidated and checked for completeness, with missing assets and naming ambiguities identified so that partners could maintain consistent terminology across UI panels, media references, and internal documentation.

Media feasibility was a major driver of decisions in Know-how. The pilot team aligned on a pragmatic approach that prioritises hyper-realistic egocentric 2D video where high-fidelity 3D animation is not feasible, especially for hand-tool realism. This resulted in a hybrid Know-how design in which Gathering remains the primary hands-on practice step, while subsequent stages are delivered as spectator content triggered through zone-based progression in the workshop.

Finally, repeated test feedback was translated into implementable UX requirements, including thicker and more responsive highlighting, UI render-order prioritisation, removal of unclear tool text overlays in favour of well-placed panels, and the introduction of tool-specific hand pose requirements. Open design questions were documented where decisions affect multiplayer UX, such as whether highlights should be visible to all participants or only locally.

A chronological iteration log and traceability table are provided in Annex I.

8.1.2 Scenario design and interaction specification

KHORA and CERFAV specified the VR Glass Workshop experience as a mode-based structure that separates informational exploration from procedural training while maintaining a consistent interaction vocabulary throughout the user journey. The specification was refined across design document versions and aligned with the Unity implementation approach reflected in the project repository, with core work tracked on the main branch and haptic exploration isolated in a dedicated HapticController branch.



The entry point to the experience is a **Waiting Room / Lobby** designed as a simple and stable mode-selection and readiness space. Scenario selection is performed through prominent panels that respond to ray-hover highlighting and confirm selection through a right-hand selection input (for example, trigger/select). The lobby also includes an always-available return-to-lobby function (specified as a left thumbstick click) to ensure that users can recover from any mode at any time without becoming stuck.

In later refinements, the lobby was also positioned as the multiplayer gateway, where one user can initiate a session (teacher role), and others can join as students, with a clear path back to the lobby when a session ends or is restarted.

Scenario 1 (Knowledge) is specified as an open studio tour in which learners explore the workshop and discover tools and equipment through contextual information. Tools with available content are highlighted when targeted, and a selection input triggers an information panel intended to remain readable in the user's field of view. The panel supports longer descriptions (including scroll behaviour where required) and can optionally launch demonstration media (video or animation) where available. A recurring design preference is to keep panel content concise and to place more complex demonstration material in the scene in front of the learner when it improves legibility and reduces cognitive load. To preserve the exploratory learning intent and reduce complexity, Scenario 1 explicitly limits interaction scope by disabling object grabbing and removing unnecessary controller visuals or movement features that do not serve the learning goals.

Scenario 2 (Know-how) is specified as a process-oriented training flow anchored in a mould-blown cup example. The scenario supports both single-user and multi-user sessions, and in multiplayer, the teacher role initiates and guides the session. The interaction design combines one interactive practice phase (Gathering) with staged instructional delivery for later phases. These later steps are presented as spectator content (3D animation preferred, egocentric 2D video acceptable) and are triggered through zone-based progression, where marked floor areas correspond to workshop stations such as the bench/bards, mould area, and annealing furnace.

In contrast to Knowledge mode, Know-how prioritises action flow and interaction fidelity and therefore does not rely on tool information panels during the procedural sequence. The specification highlights a set of realism and comfort constraints that require iterative attention, including long-tool behaviour (blowpipe/cane), gripping rules across hands, collision hotspots around the bench/bards, and teleport behaviour while holding elongated tools. A key refinement requested in review is to avoid control conflicts by separating locomotion from rod rotation through context-based input mapping (for example, the joystick rotates when holding the rod, and teleports when not holding the rod).

8.1.3 Haptic controller integration and evaluation plan

KHORA, in collaboration with CERFAV, planned to document and validate an approach for integrating the ETH haptic controller into the VR Glass Workshop in a way that supports meaningful craft-learning experiments while preventing unintended interference with the main Knowledge and Know-how scenarios.

The work began by reviewing the ETH technical documentation and translating confirmed device capabilities into interaction concepts that match glassblowing training needs. Based on ETH confirmation, the controller currently supports two functional modes. Grabbing mode allows configuration of a



maximum interaction distance intended to mimic real handling constraints for tools such as jacks. Touch mode supports interaction with virtual obstacles and surfaces.

To keep the overall experience stable and reduce the risk of input conflicts, physics side effects, or UI overlap, the haptic work was specified as a separate test track accessed via a dedicated lobby entry point and performed in a dedicated experiment area within the workshop environment. When a haptic session is entered, non-haptic session functions are explicitly inhibited so users are not simultaneously running standard interactions and haptic behaviours.

This separation is also reflected in implementation planning by isolating haptic-related development to a dedicated repository branch (HapticController), enabling targeted testing and iteration without destabilising the mainline scenario implementation.

Within this separated setup, KHORA and CERFAV specified haptic scenarios aligned strictly with ETH-confirmed modes. For Grabbing mode, the primary proposal is a spring-effect tool handling scenario mimicking the use of jacks, where the user enters the haptic test area, picks up the tool from the bench/bands, and tests open/close behaviour supported by clear hand pose definitions and reference media templates. A closely related Scenario 1bis extends the same logic to tweezers, again emphasising repeatable open/close behaviour, defined hand poses, and consistent feedback.

For Touch mode, a surface-finish recognition scenario was proposed in which the user is guided to touch reference objects intended to represent different surface textures. The underlying concept is a systematic mapping from surface properties to a controllable signal representation (waveform translation) that can be used to evaluate whether learners can reliably differentiate surface qualities through haptics.

Overall, the integration plan keeps haptic evaluation tightly coupled to device reality and protects the coherence of the main workshop prototype through architectural separation and controlled session rules.

8.2 Use Case outputs

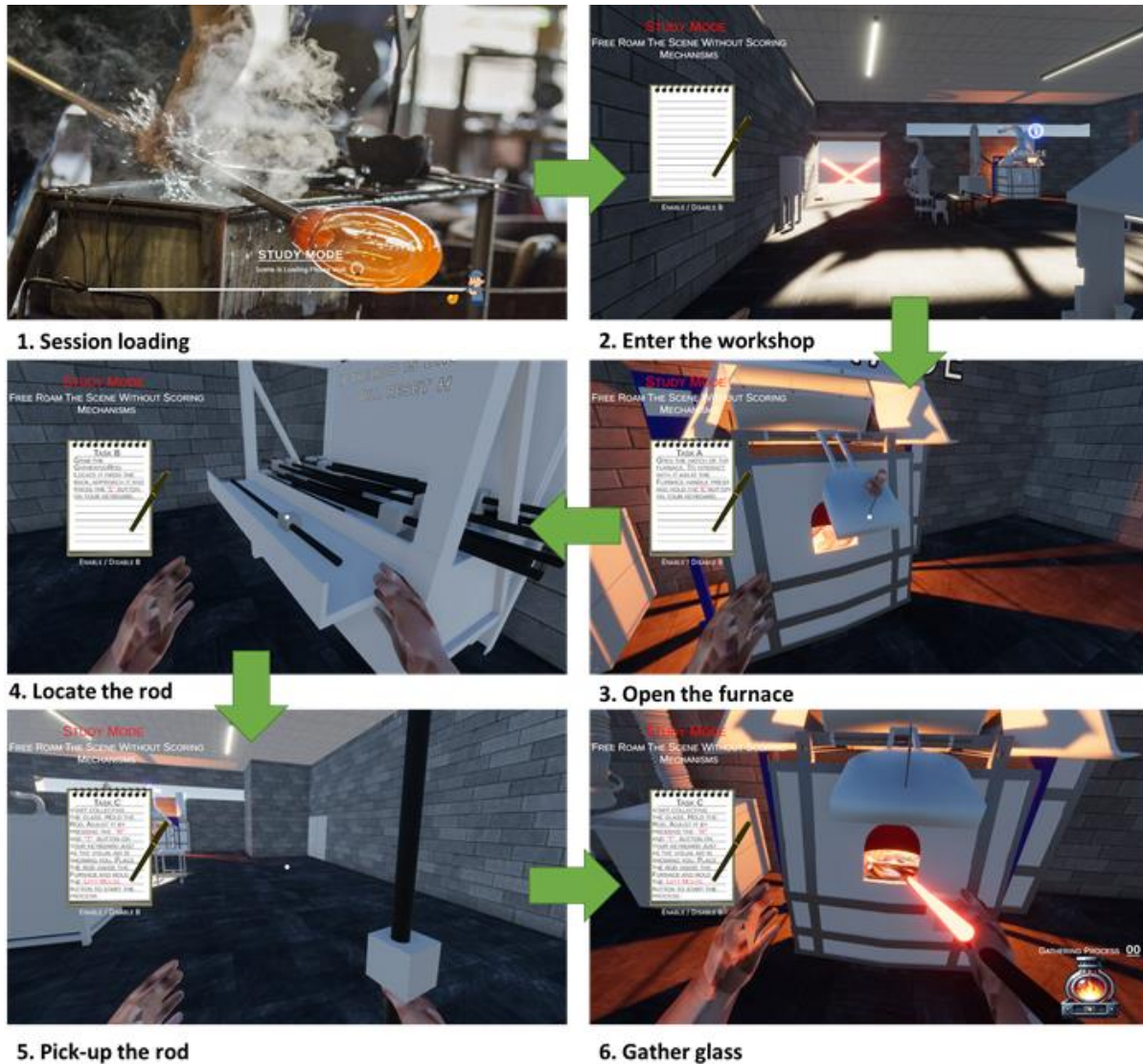
KHORA produced a set of concrete artefacts intended both for inclusion in the pilot team deliverable and for practical use by partners implementing and validating the VR Glass Workshop prototype. These outputs include scenario and interaction specifications for the Lobby, Knowledge, and Know-how modes, as well as structured content resources and iteration planning materials that translate review feedback into implementable tasks.

8.2.1 Lobby / Waiting Room specification artefact

The Lobby / Waiting Room specification defines the entry flow, scenario selection method, hover-highlight behaviour for selection surfaces, confirmation input mapping, and always-available return-to-lobby recovery logic. It is designed to support scenario selection and basic controller readiness, and to provide a stable fallback point for recovering from any scenario state.

8.2.2 Scenario specification artefacts


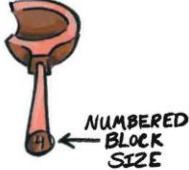

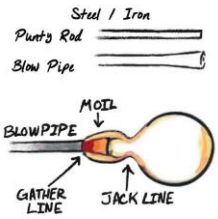
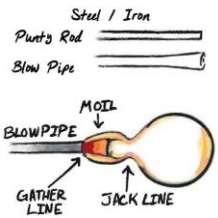
Two scenario specification artefacts were delivered: one for Scenario 1 (Knowledge / open studio tour) and one for Scenario 2 (Know-how / mould-blown cup training). Each specification documents the learning intent, the boundaries of interaction scope (what is enabled and what is intentionally disabled), and the interaction and UI rules required to reproduce the intended experience consistently across prototype iterations.









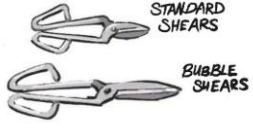

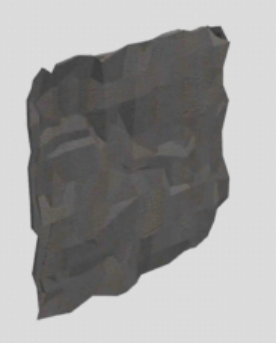


8.2.3 Tool list and functional descriptions

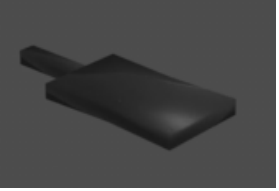

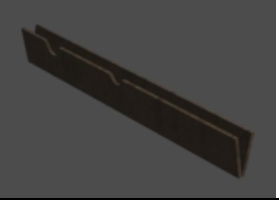

A consolidated tool and equipment list with functional descriptions was delivered for direct inclusion as a table and for reuse in tool panels and reference media. The list provides a shared naming baseline across partners to avoid ambiguity and supports both pedagogical consistency and implementation consistency (UI labels, asset naming, and documentation).

Number	Object	Description
--------	--------	-------------

<p>1</p>	<p>Jacks: Fers</p> 	<p>Mettre en forme le verre, trancher, ouvrir, aplanir, recentrer la pièce</p>
<p>2</p>	<p>Blocks : mailloches</p> 	<p>Utilisé pour former le verre en sphère oblongue avant le soufflage</p>
<p>3</p>	<p>Paddle - Pallet: palettes</p> 	<p>Utilisé pour aplatir le verre et recentrer la pièce lorsqu'elle est retravaillée au pontil, en particulier la base ou le pied d'un récipient.</p>
<p>4</p>	<p>Blowpipe: Cannes</p> 	<p>Permet de cueillir, façonner et de souffler le verre</p>
<p>5</p>	<p>Punty: ferrets et pontils</p> 	<p>Utilisé pour tenir une pièce après l'avoir détaché de la canne et pouvoir continuer le travail, permet de cueillir du verre et de le façonner</p>
<p>6</p>	<p>Pipe warmer: chauffe cannes</p>	<p>Le chauffe-canne permet de préchauffer l'extrémité des cannes, des pontils, ferrets afin que le verre adhère à l'outil lors du cueillage.</p>

		
7	<p>Bucket: Seau</p> 	<p>Permet de transporter de l'eau, utilisé également pour placer les cannes à refroidir en fin de travail d'une pièce.</p>
8	<p>Glory hole : Four de réchauffe</p> 	<p>glory : réchauffer une pièce au cours du travail afin de maintenir le verre dans la zone de températures où il est malléable. T° 80~900 °C</p>
9	<p>Glass-melting Furnace: Four de fusion</p> 	<p>Un four de fusion est une chambre ou un four à haute température, constitué de revêtements réfractaires, conçu pour chauffer et fondre les matières premières utilisées dans la production du verre, généralement un mélange de silice (sable), de carbonate de soude, de carbonate de calcium et d'affinants. Il fonctionne à des températures extrêmement élevées, généralement 1 130 degrés Celsius pour la température de travail.</p>
10	<p>Annealing furnace: Four de recuisson</p> 	<p>usage : requiert une pièce en fin de travail, pour éliminer les tensions internes du verre. 480~520°C</p>

11	<p>Tweezers: Pincettes</p> 	Étirer le verre sur une partie de la pièce ou un apport
12	<p>Straight shears: ciseaux</p> 	coupé un apport de verre ou l'ouverture d'une pièce
13	<p>Diamond shears : Ciseau à anses</p> 	Positionner le ferret lors d'un apport, couper l'apport de verre.
14	<p>Wet newspaper: mouillette</p> 	peut être utilisée pour former le verre chaud directement avec la main et permet un meilleur ressenti du matériau
15	<p>Compas: compas</p> 	Permet de contrôler les dimensions de la pièce par rapport au gabarit
16	<p>Soffieta : soffiETTO</p> 	Outil utilisé pour gonfler davantage une pièce après qu'elle a été retirée de la sarbacane et fixée au pontil.

<p>17</p>	<p>Battledore: grande palette</p> 	<p>Utilisées pour lisser ou former le fond des récipients et d'autres objets, elles peuvent également être utilisées par l'assistant pour protéger le verrier de la chaleur lorsqu'il souffle sur de grandes pièces.</p>
<p>18</p>	<p>Template : gabarit</p> 	<p>Facilite le processus de façonnage et le travail du verre, permet de contrôler les dimensions de la pièce pour correspondre au modèle.</p>
<p>19</p>	<p>Clapper: castagnettes</p> 	<p>utiliser pour presser l'apport de verre pour former le pied</p>
<p>20</p>	<p>Marver: mabre</p> 	<p>Permet de mettre en forme la masse de verre travaillée</p>

8.2.4 Iteration backlog and improvement roadmap

A structured iteration backlog and improvement roadmap were delivered to translate review comments and test observations into actionable tasks for subsequent prototype cycles. The roadmap groups improvements into practical categories such as usability and UI clarity, interaction behaviour and tool

handling reliability, physics and comfort realism (including long-tool behaviour and collision hotspots), and rendering or asset fidelity issues that affect interpretation.

8.2.5 Hand pose requirements

A hand pose specification was delivered to define tool-specific grips and, where applicable, two-state tool handling (for example, open/closed states for articulated tools). This artefact formalises realism requirements that affect usability and comprehension, ensuring that visual affordances and interaction feedback align with the real glassblowing technique. Detailed hand poses used in the development can be found in Annex II - Hand poses.

8.2.6 Haptic integration artefacts

Haptic integration documentation was delivered describing how to evaluate the ETH haptic controller through a separate test track. This includes dedicated lobby access for haptic sessions, an isolated test space to avoid interaction conflicts with the main workshop scenarios, and scenario definitions aligned with ETH-confirmed capability modes (Grabbing and Touch).

8.3. Haptic controller evaluation outcome and scope conclusion

Following the integration approach described in Section 2.3, KHORA and CERFAV carried out a targeted evaluation of the ETH haptic controller in the context of the VR Glass Workshop, focusing on the two confirmed capability modes (Grabbing and Touch) and the corresponding test scenarios.

Across these tests, the pilot team reached a clear conclusion: while the controller demonstrates promise as a direction for haptic experimentation, it requires significant further improvement before it can function as a reliable training device for a glass workshop learning context.

Glassblowing training places unusually high demands on interaction fidelity and stability. Effective training depends on precision grip, consistent and predictable force and response, comfortable sustained use, stable contact feedback, and robust alignment between what the user sees and what they feel. In practice, the controller could not meet these requirements at a level that would support realistic or instructionally dependable workshop training within the scope and constraints of the CRAEFT project.

This outcome is not attributed to a lack of effort from ETH. ETH provided extensive support and worked within the project to improve the controller's performance and confirm usable modes and constraints. However, achieving glassblowing-grade usability would likely require substantial additional R&D, potentially spanning hardware, firmware, and control improvements as well as extended cycles for calibration, ergonomics, and robustness beyond what WP6.1 resources and objectives can reasonably cover.

As a result, the haptic controller exploration is positioned as a valuable feasibility and learning activity that clarified requirements and established a safe integration architecture, while the main Knowledge and Know-how scenarios remain the primary pathway for training delivery in the current project scope.



8.4. Lessons learned, limitations, and recommended next steps

The work carried out in WP6.1 demonstrates that the mode-based structure (Lobby -> Knowledge -> Know-how) is an effective and manageable approach for representing a complex craft workshop in VR. Knowledge mode provides contextual orientation and tool understanding through exploration and information presentation, while Know-how mode supports procedural learning through a hybrid structure that combines one hands-on practice step with staged progression and spatially anchored instructional delivery.

At the same time, the iteration cycles underline that instructional clarity in VR is highly sensitive to a small set of UX fundamentals. Highlight visibility and responsiveness, stable selection behaviour, and a clear relationship between user action and learning content determine whether the intended pedagogical value is actually experienced. When these elements are weak, even well-intended UI concepts can become confusing, which is why review feedback repeatedly favoured clearer, more spatially grounded information presentation, such as dedicated tool showcase areas with in-world panels placed where the learner can naturally see them while manipulating tools, rather than overlays that risk obscuring the scene or breaking attention.

For subsequent iterations, KHORA recommends prioritising a small group of improvements that repeatedly emerged as high-impact. These include strengthening highlight reliability and thickness, refining instruction presentation to avoid unclear overlays and to ensure correct placement relative to the bench/bards, and stabilising selection logic to reduce accidental or multi-selection. In parallel, long-tool ergonomics should be improved by addressing blowpipe/cane behaviour and explicitly resolving control conflicts through context-based input mapping that separates rotation from teleportation.

Finally, realism that directly supports comprehension should be increased by implementing tool-specific hand poses and two-state handling for articulated tools, since grip fidelity affects both usability and the learner's ability to interpret correct technique.

The project also confirmed that certain ambitions, particularly full end-to-end physical simulation of all glassblowing stages and high-fidelity haptics suitable for workshop-grade training, require substantial additional R&D beyond the current scope. This is why the prototype adopts pragmatic but defensible choices such as zone-triggered staged content for later process steps and a separated haptic feasibility track that documents future opportunity contingent on controller maturation.

9 Use Case – Pin stripping

Pointillé emerged in 17th-century European silverware, pewter, and armour, and is distinct from engraving in that it relies on material displacement rather than removal. Each impact produces a small crater with a raised burr, and accumulated impressions form decorative motifs ranging from simple textures to complex representational patterns. The technique depends on tacit control of force, angle, rhythm, and spacing, making it well-suited to semantic modelling and physically grounded simulation. Pointillé is executed using punches with varying tip geometries, including fine prick punches (30°–60°) for detailed work and broader centre punches ($\approx 90^\circ$) for larger impressions; contemporary practitioners may also use automatic centre punches that deliver consistent, spring-loaded impacts. The expressive potential of Pointillé lies in the organisation of dot patterns into gradients, shapes, and ornamental motifs. The Knowledge Graph encodes both geometric pattern templates and the perceptual criteria used by artisans to assess visual quality, including reflectance variations caused by burr morphology, contrast between matte and polished areas, and the continuity of clustered dots forming implied lines or shaded regions. The PBR module reinforces these cues through metallic reflectance, micro-shadowing, and fine surface detail, enabling learners to perceive subtle visual effects typically accessible only through direct manipulation of the object. The displacement-based nature of the technique is modelled semantically through explicit relationships between impact parameters, such as force magnitude, tool orientation, and contact duration, and resulting material deformation. Culturally characteristic practices, including the use of dot density for shading and highlights and the application of matte stippled backgrounds to emphasise polished motifs, are also captured. Examples of pattern templates and the effects of varying impact parameters are presented in the following table, together with their three-dimensional representations.

9.1 Semantic layer

The semantic layer formalises the tools, materials, actions, and procedural knowledge of metal stippling in a Knowledge Graph (KG) grounded in CIDOC-CRM, enabling executable process definitions, simulation parameterisation, and pedagogical reuse. At the core of the model is the Pointillé process schema, represented as an instance of E29 Design or Procedure. This schema encodes the idealised workflow of stippling as a sequence of semantically defined actions, decision points, and potential error branches. Each step corresponds to a stippling impact or a structured sequence of impacts forming a pattern segment. The instantiation of the schema regards the execution of the process with specific parameters, as in the case of simulation. Such an example is presented in Figure 10. Image (a) presents the structure of the process, while image (c) presents the analysis of the process, including a detailed decomposition of each step into micro-actions. Tools used in Pointillé, such as fine prick punches, centre punches, and automatic punches, are represented as instances of E18 Physical Thing, further specialised as E24 Physical Man-Made Thing where appropriate. Each tool entity is associated with geometric attributes (e.g., tip angle, diameter), functional characteristics, and permissible execution contexts. These properties constrain the actions in which a tool can participate and directly inform the parameterisation of physical simulation. A semantic representation of a tool is presented in Figure 10 (b).

Process name Tin Punching Practice Process

Alternative name [el] - Διαδικασία Εξέλιξης στην Τεχνική Tin Punching

Description [en] - The Tin Punching Practice Process outlines the sequential steps for preparing materials, practicing basic punching techniques, and inspecting results in order to develop fundamental metal punching skills. [el] - Η διαδικασία εξέλιξης στην τεχνική Tin Punching περιγράφει τα διαδοχικά βήματα προετοιμασίας, πρακτικής εφαρμογής και ελέγχου που απαιτούνται για την εκμάθηση βασικών τεχνικών διάτρησης και διαμόρφωσης λεπτού μετάλλου.

Process date 2025-12-22

Process material(s) Silver
Copper
Brass

Process tool(s) Pick punch
Center punch
Automatic center punch
Hammer

Semantic annotations <http://vocab.getty.edu/aat/300138076> - processes

Associated with Tin_Punching_image10 (Media object (image))

Process steps	Set order	Substeps
Step 01. Prepare workboard	0	0
Step 02. Trace practice pattern	0	0
Step 03. Select practice metal	0	0
Step 04. Secure metal to workboard	0	0
Step 05. Position pattern on metal	0	0
Step 06. Practice punching techniques	0	7
Step 07. Practice with different punches	0	0
Step 08. Tooling foil techniques	0	0
Step 09. Continue practice and check alignment	0	0
Step 10. Final inspection and preparation for finishing	0	0

(a)

Tool

View Related media objects

Tool name Pick punch

Description [en] - The pick punch is a fine-tipped stippling tool used in the Pointillé technique for detailed work, shading, and the creation of dense patterns. Its tip geometry typically ranges between 30° and 60°. Each impact produces small craters with pronounced local material displacement, contributing to the formation of fine surface texture and tonal variation. The final visual outcome is strongly influenced by execution parameters such as impact angle and applied force. [el] - Το pick punch είναι κορυφαίο στέλες με λεπτή μύτη, που χρησιμοποιείται στην τεχνική Pointillé για λεπτομέρεια, σκίαση και τη δημιουργία πυκνών μοτίβων. Η γεωμετρία της σπύτης του κυμαίνεται μεταξύ 30° και 60°. Κάθε κρούση δημιουργεί μικρό μέγεθος κρατήρας με έντονη τοπική μετατόπιση του υλικού, συμβάλλοντας στη διαμόρφωση λεπτής υφής και τόνων διαβαθμισμένων στην επιφάνεια. Το τελικό οπτικό αποτέλεσμα επηρεάζεται άμεσα από παραμέτρους όπως η γωνία και η δύναμη της κρούσης.

Semantic annotations <http://vocab.getty.edu/aat/300122241> - tools

Associated with Pick punch (Media object (image))

(b)

Tin Punching Practice Process

The Tin Punching Practice Process outlines the sequential steps for preparing materials, practicing basic punching techniques, and inspecting results in order to develop fundamental metal punching skills. Η διαδικασία εξέλιξης στην τεχνική Tin Punching περιγράφει τα διαδοχικά βήματα προετοιμασίας, πρακτικής εφαρμογής και ελέγχου που απαιτούνται για την εκμάθηση βασικών τεχνικών διάτρησης και διαμόρφωσης λεπτού μετάλλου.

Participants N/A

Location N/A

Material(s) Silver
Copper
Brass

Tool(s) Pick punch
Center punch
Automatic center punch
Hammer

Related process media [View all 1 process media](#)

Process steps

Select step	Substeps
Step 01. Prepare workboard	
Step 02. Trace practice pattern	
Step 03. Select practice metal	
Step 04. Secure metal to workboard	
Step 05. Position pattern on metal	
Step 06. Practice punching techniques	<p>Step 6.1. Select punching tool Select an awl or nail to use as a basic punching tool for practicing hole creation.</p> <p>Step 6.2. Establish tapping rhythm Develop a steady tapping rhythm to help maintain consistency in hole size and punching depth.</p> <p>Step 6.3. Increase punching force Apply stronger hammer taps and examine the metal to compare how increased force affects hole size and depth.</p> <p>Step 6.4. Determine desired effect Decide whether the intended result is a light indentation or a fully pierced hole based on the observed punching outcomes.</p> <p>Step 6.5. Practice consistency Practice creating three to four holes or indentations in a row, aiming for uniform size and depth.</p>
Step 07. Practice with different punches	
Step 08. Tooling foil techniques	
Step 09. Continue practice and check alignment	
Step 10. Final inspection and preparation for finishing	

(c)

Figure 43. (a): process semantic structure, (b) Tool representation, (c) Process decomposition.

The metal workpiece undergoing decoration is likewise represented as an E18 Physical Thing, with material-specific properties such as density, elasticity, and yield behaviour defined as part of its semantic description. As the process progresses, the workpiece transitions through successive states resulting from individual stippling actions. These state changes are not represented as new objects but as evolving conditions of the same physical entity, preserving continuity and provenance across the process.

Individual stippling actions are modelled as instances of E7 Activity, each linked to an executing E39 Actor and situated within a spatiotemporal context. Actions are parameterised by semantically defined execution variables, including impact force, tool orientation, contact duration, and spacing relative to neighbouring impacts. Acceptable parameter ranges encode expert knowledge and stylistic conventions,

while deviations from these ranges activate alternative semantic branches corresponding to characteristic errors, such as over-striking, insufficient force, or excessive angular variation.

Patterns and motifs are represented as higher-level semantic constructs associated with the process schema. These constructs encode geometric layouts, repetition logic, and density variations used to create shading, contours, and ornamental emphasis. Rather than prescribing exact positions, pattern definitions specify constraints and relationships between impacts, allowing stylistic variability while preserving the visual logic of the technique.

9.2 Offline Simulation & Rendering

The simulation environment instantiates the Pointillé workflow through KG-defined descriptions of tools, materials, actions, and preconditions. The punch operates as a rigid body, while the metal sheet or plaque is represented as a deformable material whose properties reflect historically accurate values for metals such as silver, copper, and brass. The material parameters, including Young’s modulus, yield strength, and Poisson’s ratio, are presented in Table 4.

Table 5. Material properties in PhysX Simulations.

Material Property	Silver	Copper	Brass
<i>Density (mass/volume)</i>	10 490	8960	8400–8600
<i>Dynamic Friction (dimensionless)</i>	1.10 (vs. steel)	0.53 (vs. steel)	0.35 (vs. steel)
<i>Young’s Modulus (force/area)</i>	83×10 ⁹	110–130×10 ⁹	97–110×10 ⁹
<i>Poisson’s Ratio (dimensionless)</i>	0.37	0.34	0.31–0.34
<i>Elasticity Damping (dimensionless)</i>	1.0	1.0	1.0
<i>Damping Scale (dimensionless)</i>	1.0	1.0	1.0

Each stippling action is represented as an instance of the semantic “Stippling Impact” action and includes execution parameters such as force, vertical alignment, and acceptable angular deviation. The simulation reproduces local displacement phenomena ranging from crater formation to burr development, using FEM deformation models depending on the computational configuration. Through this setup, both correct and erroneous executions—such as over-striking, excessive angle variation, or inadequate force—can be modelled and compared.

9.2.1 Simulation Results

The resulting simulations demonstrate the sensitivity of metal deformation to punch geometry and execution parameters. Fine prick punches generate small, sharply defined impressions with pronounced burrs ideal for detailed shading, whereas broader centre punches produce wider depressions with smoother transitions. Automatic punches create highly consistent marks, revealing the effect of uniform force application. Sequence-level simulations show how irregular spacing, inconsistent force, or angular misalignment disrupts visual uniformity, effects that are typically recognised only after prolonged practice in traditional settings. During the simulation, several execution parameters are studied, such as force,

vertical alignment, and angular deviation. Variations in tool usage are also studied through the modelling and simulation of variant tool nozzles. Exemplary simulation results are presented in Figure 12.

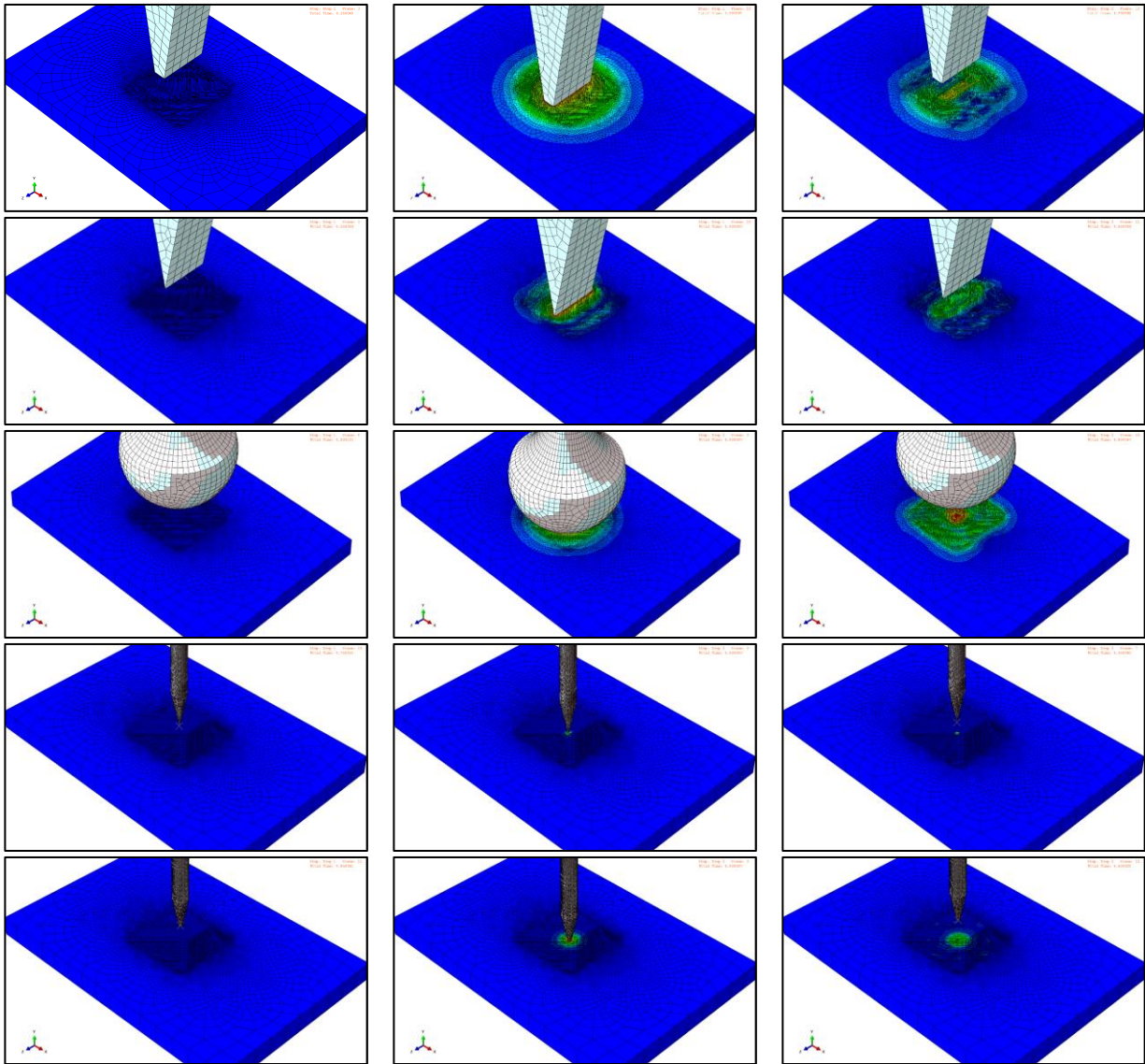
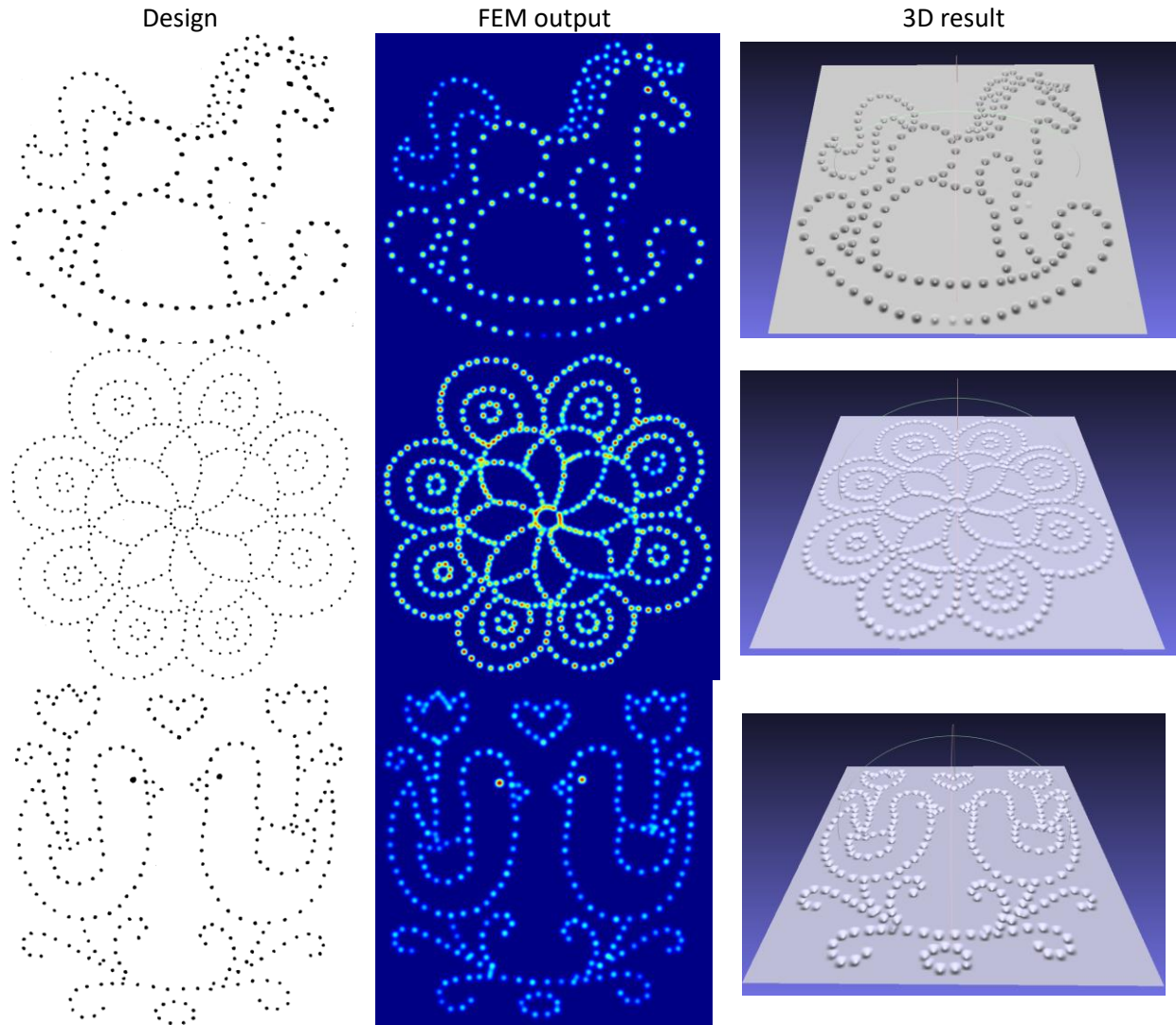


Figure 44. FEM Simulation of impacts with different tools on Silver.

9.2.2 Rendering results

Combined simulation of more actions is structured into simulation scenarios by mapping pattern templates to FEM action scripts. The simulation of these action scripts encodes results that are, in turn, rendered in the form of object geometry to be directly reproducible by game engines. Simulation rendering occurs per action sequence, encoding the entire process in the form of time-controlled object geometries suitable for 3D animation authoring and rendering. The results of FEM-based renderings for the studied Pointillé patterns are presented in Table 4.

Table 6. Pattern templates, FEM outputs, and rendered FEM outputs in 3D.



9.3 Pedagogical and Semantic Integration

In the Craeft eLearning environment, each stippling action is transformed into an instructional unit based on the semantic definitions (see Figure 13 and Figure 14). Demonstration materials, including video, annotated images, and multiview ethnographic recordings, are embedded within structured Lesson pages. Conditional branches derived from the KG guide learners through decision points, such as correcting insufficient force or recognising improper angles. Interactive components, including quizzes and recognition tasks, support the development of perceptual discrimination, while VR simulation exercises allow learners to reproduce impact sequences and receive automated performance feedback based on force consistency, spacing accuracy, and pattern fidelity.

This integration ensures that the tacit aspects of Pointillé, traditionally requiring long-term apprenticeship, can be externalised and systematically taught through a combination of semantic guidance, simulation fidelity, and perceptually rich rendering.

<input type="checkbox"/>	Hands-on: Pointillé step-by-step process	
<input type="checkbox"/>	Common Errors Quiz	
<input type="checkbox"/>	Pointillé Glossary	
<input type="checkbox"/>	Lesson1: Introduction to Pointillé	
<input type="checkbox"/>	Lesson 2: Tools & Materials for Pointillé	
<input type="checkbox"/>	Lesson 3: Materials and Surface Preparation	
<input type="checkbox"/>	Lesson 4: Principles of Dot Placement and Shading	
<input type="checkbox"/>	Lesson 5: Stroke Patterns and Visual Texture Formation	

Figure 45. Lessons overview.

×

- Learning objectives
 - Demonstrate a correct single...
- Materials & equipment
 - Workpiece: thin metal plaque...
- Quick overview of the phys...
 - Pointillé is a displacement te...
- Micro-action step sequence
 - Step 0 – Setup & orientation ...
- Typical errors, diagnostics ...
 - Under-strike (too shallow): cr...

Hands-on: Pointillé step-by-step process

Course
Settings
Participants
Grades
Reports
More ▾

▾ Learning objectives

1. Demonstrate a correct single point (stippling impact) with consistent force, angle and contact time.
2. Produce short patterned runs with regular spacing, consistent burr morphology and predictable visual density.
3. Diagnose and correct three common execution faults (under-strike, over-strike, angular misalignment) and perform a basic recovery.

Prerequisites

- Lesson 1 (Cultural Context) and Lesson 2 (Tools & Materials) completed.
- Familiarity with holding a punch and basic hammer control (two-handed steady strike).
- Workpiece clamped and surface prepared (clean, smooth, appropriate hardness) — see Lesson 3.

▾ Materials & equipment

- Workpiece: thin metal plaque (e.g., silver, brass, pewter, or an aluminium test panel). Specify alloy and thickness in instructor notes.
- Punches: prick punch (30°–60° tip) for fine dots; centre punch (~90°) for larger dots; optional automatic centre punch.
- Hammer (light jeweller’s hammer / brass mallet), anvil or support block (rigid, massy), clamp/vice.
- Marking tools: scribe, dividers, pattern template.
- Safety PPE: eye protection, gloves, hearing protection if mechanical punch used.

Figure 46. Step-by-step process description.

9.4 Interactive simulation

The interactive simulation instantiates the Pointillé process schema within a real-time execution environment, allowing learners to perform stippling actions while receiving continuous, process-aware feedback (see Figure 15). The simulation is driven by the semantic definitions of tools, materials, and actions, ensuring that learner interactions are interpreted and evaluated according to the same knowledge structures used for offline simulation and pedagogical sequencing.

Craeft D4.1

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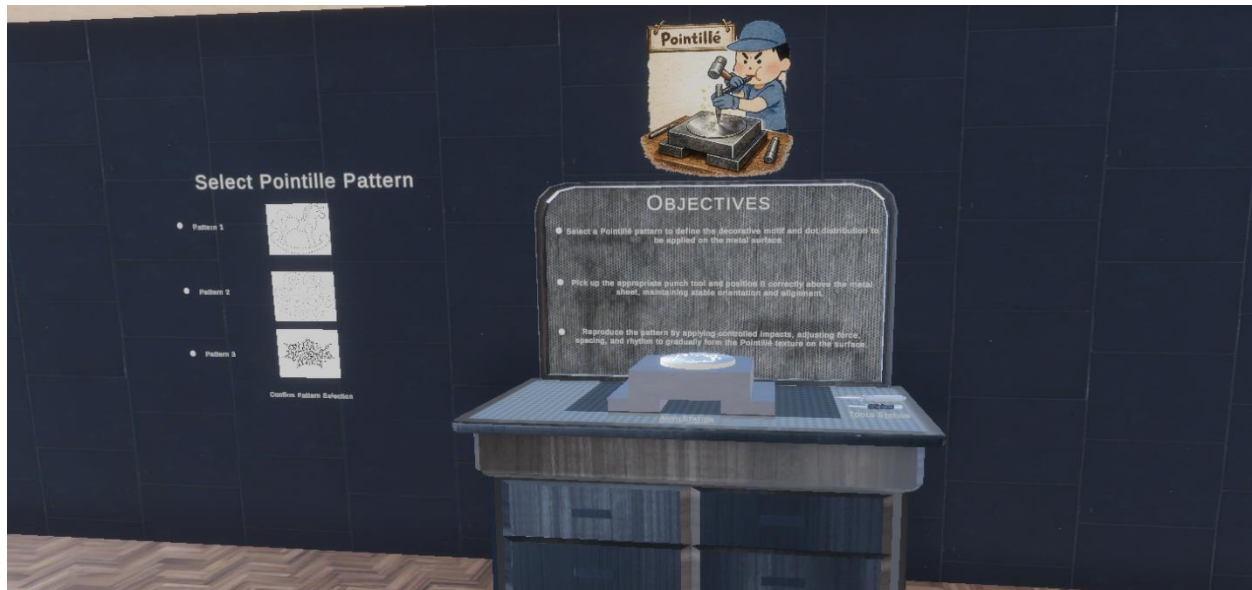


Figure 47. An instance of the simulation environment.

The training environment is instantiated upon selection of the desired training patterns as presented in Figure 16. Learner input is captured through desktop, controller-based, or immersive XR interfaces based on the selections made in the CraftStudio. An example of a VR interaction scenario for the studied use case is presented in Figure 17.

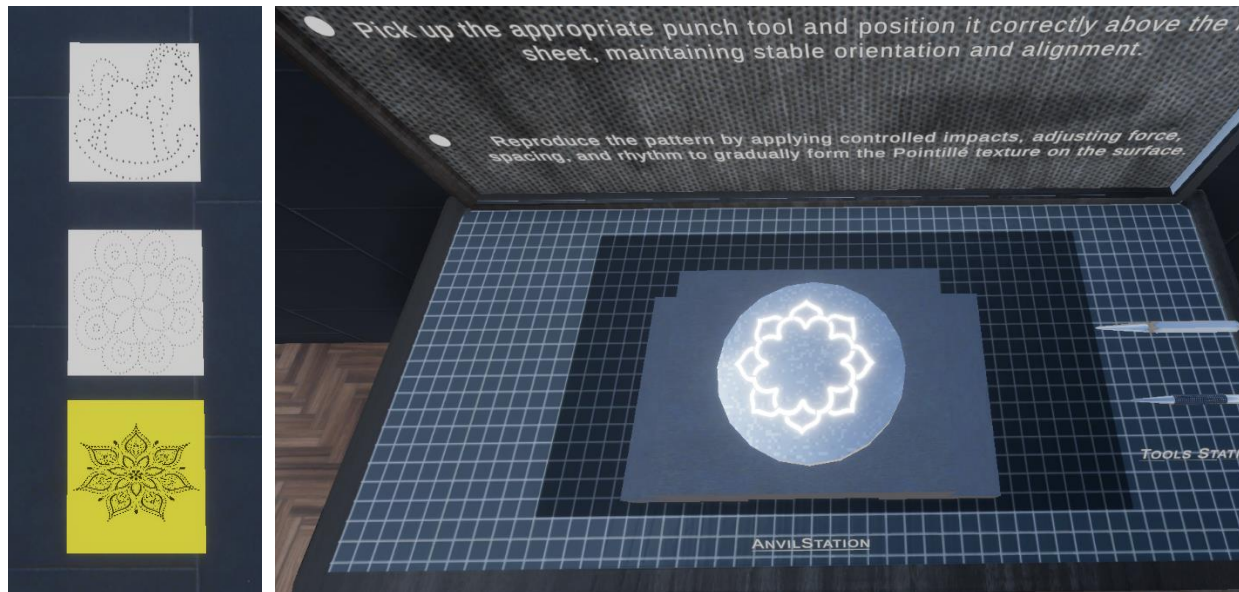


Fig. 16. Pattern selection and placement on practice board

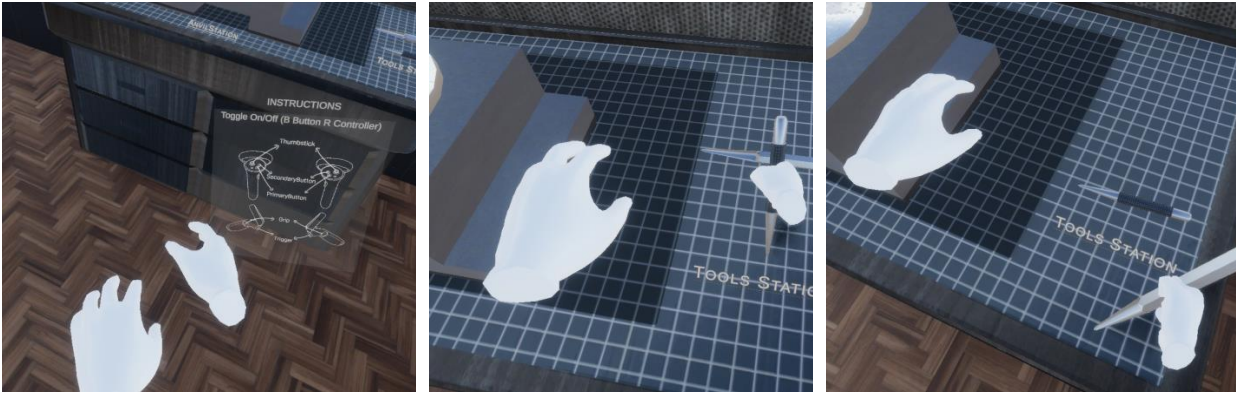


Figure 48. VR interface and tool interaction

Using this interaction modality, the input provided through the VR interface is mapped to semantically defined micro-actions, including tool positioning, orientation, impact force, and timing (see Figure 18). These micro-actions correspond directly to the execution parameters of the Stippling Impact activity defined in the knowledge graph. Device-specific input is thus abstracted into domain-level action parameters, enabling consistent behaviour across interaction modalities.

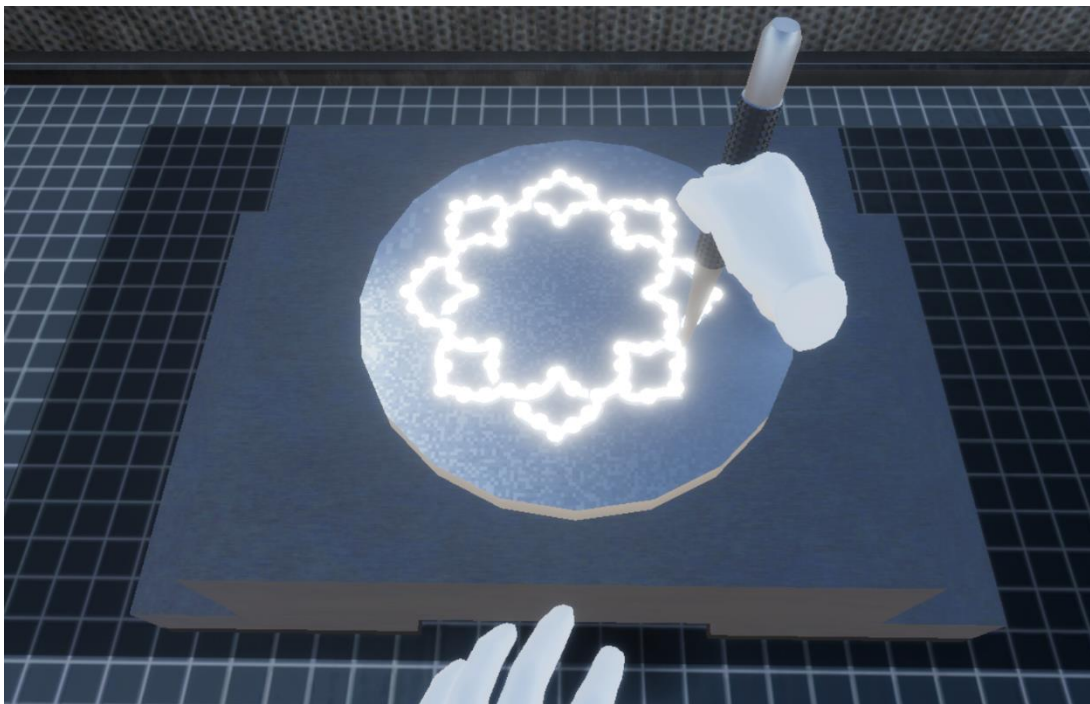


Figure 49. Dot pattern visualisation and execution of micro actions

During interaction, each learner-performed stippling action is evaluated in real time against the semantic constraints specified in the process schema. Parameter ranges define acceptable execution envelopes for force magnitude, angular deviation, and contact conditions. Actions that satisfy these constraints advance the process normally, while deviations activate semantic branches corresponding to common errors, such



D4.1 Craft simulation and immersive craft training



as insufficient force, excessive tilt, or over-striking. Where defined, recovery paths guide corrective action; otherwise, failure states are reached, reflecting irreversible material outcomes.

Physical behaviour during interaction is computed using PhysX-based dynamics coupled with precomputed FEM-informed deformation proxies. This hybrid approach enables real-time responsiveness while preserving fidelity to the material behaviours observed in offline simulation. Resulting deformations, burr formation, and surface disturbances are rendered using physically based rendering, allowing learners to perceive subtle visual cues related to execution quality, such as crater uniformity, reflectance variation, and texture continuity.

The simulation supports both guided and unguided interaction modes. In Study Mode, additional visual aids—such as target trajectories, angular indicators, or force visualisations—may be overlaid to scaffold learning. In Examination Mode, such aids are reduced or removed, requiring learners to rely on perceptual judgment and procedural understanding, thereby approximating real workshop conditions. Performance is continuously assessed through semantic evaluation of action parameters and resulting material states.

10 Use Case – Plaster Model Turning for Porcelain Slip-Casting

This chapter presents an additional use case developed in the context of Craeft, focusing on the interactive simulation of plaster model turning for porcelain slip-casting mould-master design. The use case is based on the research work presented in the paper “*Interactive Simulation of Plaster Model Turning for Porcelain Slip-Casting Mould-Master Design*” and demonstrates how the methodological principles, semantic representations, and immersive training concepts introduced in this deliverable can be applied to a subtractive craft process.

Plaster turning represents a critical intermediate stage in porcelain production, where a plaster master model is produced through freehand turning on a wheel and subsequently used to create moulds for slip-casting. The craft combines geometric reasoning, embodied tool use, and continuous sensory feedback, making it particularly suitable for evaluating interactive simulation as a means of documenting, preserving, and training tacit craft knowledge.

The objective of this use case is twofold: (a) to document and formalise the plaster turning process through a semantically grounded digital representation, and (b) to provide an interactive training and rehearsal environment that reflects authentic workshop practice while remaining computationally tractable for real-time use.

10.1 Semantic and Process Layer

The semantic layer of this use case builds on ethnographic observation and expert collaboration with an experienced plaster turner operating within a porcelain production workshop. The craft process is modelled as a sequence of interrelated actions, tools, and material states, capturing not only the physical transformation of the workpiece but also the reasoning and decision-making that guide the practitioner.

Key entities represented in the semantic model include the plaster blank, the turning wheel, handheld turning tools, stabilising supports, and the evolving master model. Actions such as centring, freehand cutting, verification, and finishing are described as process steps with explicit dependencies and constraints. This structure aligns with Craeft’s emphasis on process-centric craft documentation, where knowledge is organised around actions and their intended outcomes rather than static artefacts alone.

The semantic representation also captures workshop-specific terminology and conventions, enabling consistency between physical practice and its digital counterpart. By grounding the simulation in this semantic framework, the system supports interpretability, reuse, and potential integration with broader knowledge-graph-based craft representations.

Figure 50. Porcelain process representation

10.2 Offline Simulation and Geometric Modelling

Unlike forming crafts that rely on plastic deformation, plaster turning is a subtractive process in which material is irreversibly removed. To accommodate real-time interaction while maintaining fidelity to workshop practice, the simulation adopts a geometrically constrained approach rather than a full physical material simulation.

The workpiece is modelled as a solid of revolution aligned with the wheel's rotational axis. Material removal is computed based on tool position, wheel rotation, and contact depth, allowing the evolving geometry to reflect the cumulative effects of successive cutting actions. This approach ensures computational efficiency while preserving the essential relationship between tool motion and resulting form.

The simulation supports centring operations, where material is removed to align the blank's symmetry axis with the wheel's rotation axis, reflecting a critical preparatory step in workshop practice. Subsequent turning actions modify the profile continuously, enabling the practitioner or learner to explore design variations and observe their geometric consequences.

10.3 Rendering and Visual Feedback

Visualisation plays a central role in this use case, as practitioners rely heavily on visual cues to assess symmetry, curvature, and surface quality during turning. The system provides real-time visual feedback that highlights profile changes and makes deviations perceptible as the workpiece rotates.

Rendering prioritises clarity and legibility over photorealism during interaction, ensuring that geometric variations are immediately visible to the user. At the same time, the resulting geometric data are compatible with physically based rendering pipelines, enabling high-quality offline visualisation of completed designs. This dual approach supports both interactive training and subsequent documentation or presentation of outcomes.

By linking visual feedback directly to tool actions and process stages, the simulation reinforces the connection between embodied practice and its visual consequences, a key aspect of learning in subtractive crafts.

10.4 Pedagogical and Interaction Design Integration

From a pedagogical perspective, the simulator is designed to expose not only *how* actions are performed, but *why* they are performed in a particular way. Interaction design reflects authentic workshop ergonomics, such as the use of stabilising supports to separate tool guidance from force absorption, reducing uncertainty during cutting.

The system does not enforce predefined templates or ideal forms. Instead, it supports exploratory, risk-aware practice, reflecting the realities of freehand turning where outcomes depend on continuous judgement and sensory interpretation. This approach aligns with Craeft's emphasis on immersive learning experiences that encourage active engagement rather than passive observation.

The simulator enables learners to rehearse sequences of actions, experiment with tool positioning and cutting strategies, and safely explore the consequences of errors without material cost. In doing so, it supports the gradual acquisition of tacit procedural knowledge that is traditionally transmitted through apprenticeship.

10.5 Interactive Simulation Outcomes and Scope

The plaster turning use case demonstrates how interactive simulation can serve as both a documentation tool and a training environment for traditional crafts. By combining semantic process modelling, real-time geometric simulation, and interaction designs grounded in ethnographic insight, the system makes expert reasoning and workshop practices accessible in a digital form.

The use case confirms the feasibility of representing subtractive craft processes within the Craeft framework and complements other use cases focused on forming or additive crafts. While the simulation abstracts certain physical properties, it successfully captures the core relationships between tool use, material removal, and form evolution that define the craft.

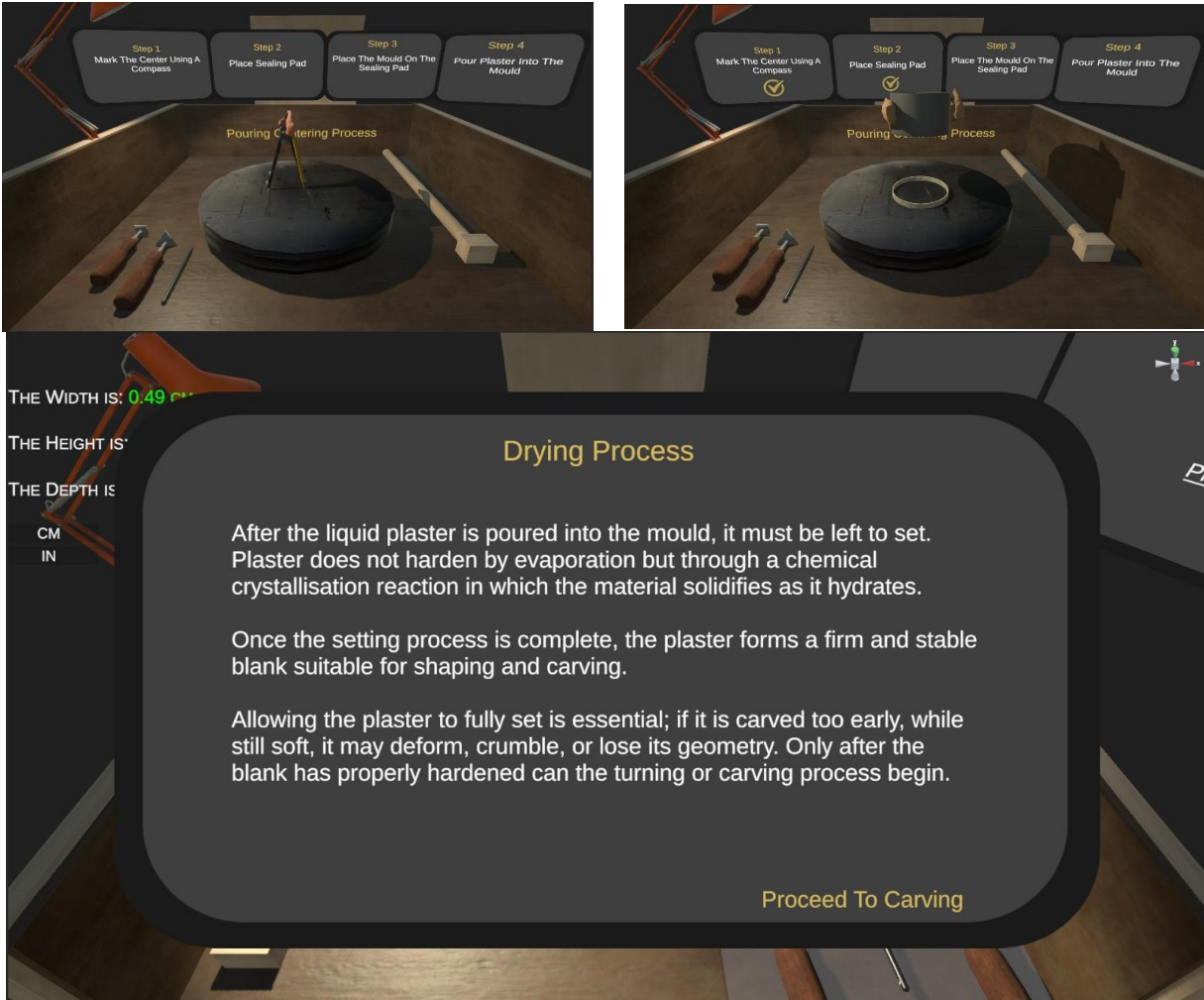
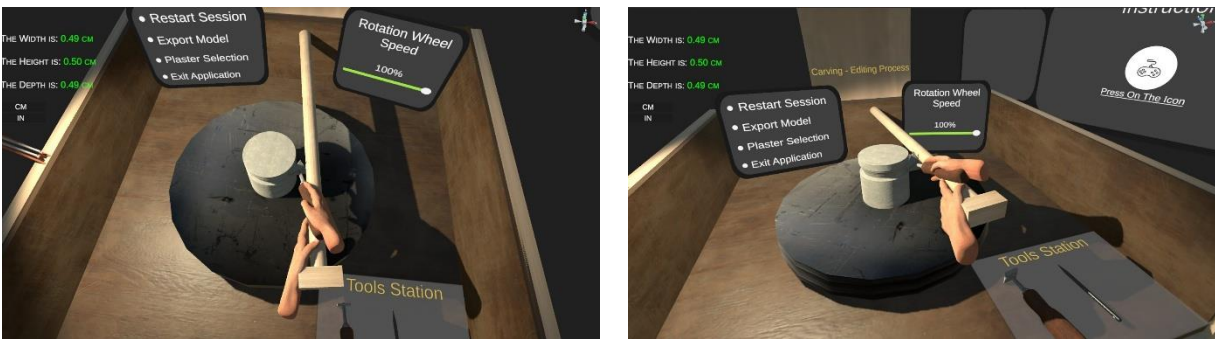


Figure 51. Scene A (Preparation). Left: Compass-based centre marking of the model. Centre: Sealing pad placement between the model and formwork. Right: Information display accompanying the animated drying process.



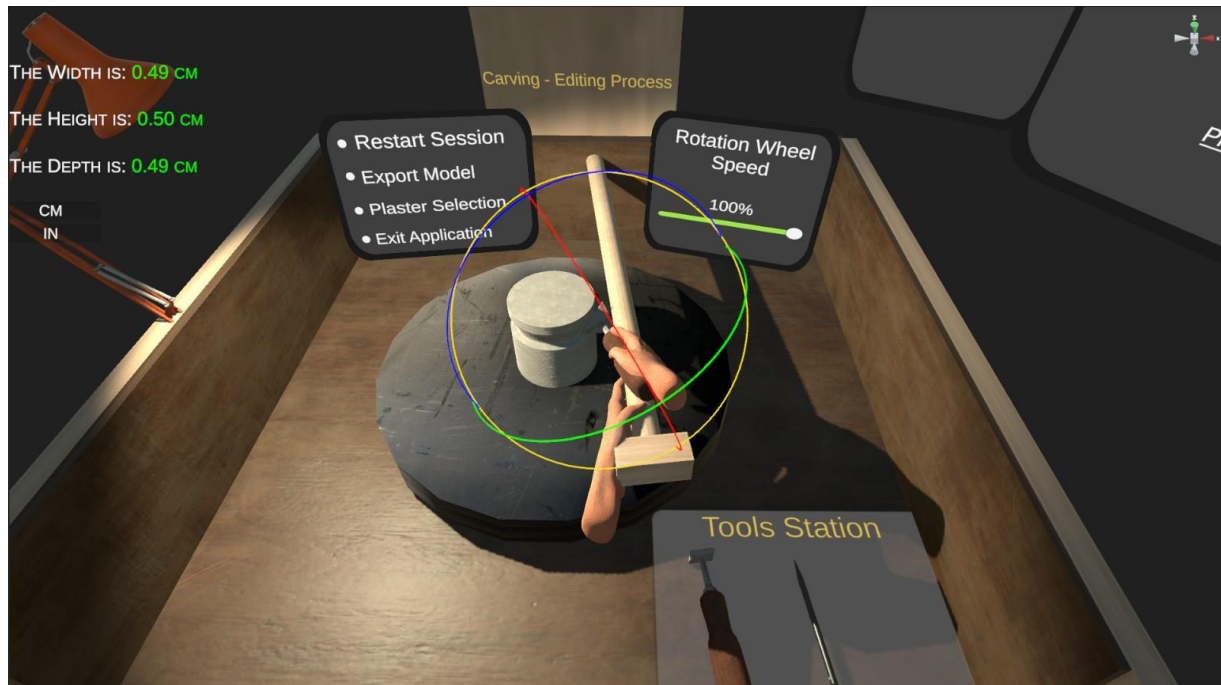


Figure 52. Scene B (Turning). Left, centre: Tool positioning with a virtual hand overlay that visualises handle rotation. Right: Cutting action with the virtual hand superimposed, providing artificial 3D feedback for tool orientation.

Future extensions may include richer sensory feedback, closer integration with immersive devices, and tighter coupling with knowledge-graph-based representations to support adaptive learning scenarios. Overall, this use case reinforces the value of interactive, semantically grounded simulations as a means of preserving, teaching, and disseminating traditional craft knowledge.

11 Use case – Woodworking

This chapter presents a woodworking use case focusing on traditional wood carving performed with hand-held chisels. Wood carving is a representative subtractive craft in which form emerges through controlled material removal guided by tool geometry, wood grain orientation, and embodied expertise. The craft combines precise motor control, perceptual judgement, and tacit knowledge regarding material behaviour, making it particularly suitable for evaluating the Craeft framework for semantic representation, interactive simulation, and immersive craft training.

The use case aims to document and digitally represent fundamental wood carving actions and to explore how interactive simulation can support training, rehearsal, and understanding of chisel-based carving techniques. Emphasis is placed on modelling tool–material interaction, capturing the influence of wood anisotropy, and providing meaningful visual and pedagogical feedback to learners.

11.1 Semantic and Process Layer

The semantic layer for the woodworking use case is grounded in ethnographic observation of traditional wood carving practice and structured around a process schema describing the transformation of a wooden workpiece through successive carving actions.

The physical entities involved in crafting actions are identified, modelled, and semantically characterised. Besides object geometry and composition, conventional simulation entities include the modelling of causing entities, boundary conditions, material properties, and the space and time in which they occur. Actions are classified into a taxonomy of four classes according to their function. Thus, they exhibit similarities in their operation principles and the shape and motion of the tools used. This classification simplifies the creation of archetypal simulators, enabling the development of archetypal simulators for each class that, if used as “templates,” can be refined to simulate craft and material-specific actions.

The process is modelled as a sequence of deliberate actions performed by a practitioner using chisels of varying profiles (e.g., flat, gouge, V-chisel), supported by auxiliary tools such as mallets and work-holding devices.

Key semantic entities include the wooden blank, chisels, mallet, carving bench or vice, and the evolving carved form. Actions such as marking, roughing out, directional carving, detail refinement, and surface finishing are represented as E7 Activities, each associated with specific execution parameters such as tool angle, cutting depth, applied force, and direction relative to wood grain.

The semantic model explicitly captures constraints related to material properties, most notably wood grain orientation and hardness, which critically affect carving outcomes. These constraints are encoded as part of the process schema, enabling branching pathways that represent common errors (e.g., carving against the grain leading to tear-out) and corrective strategies. This structure aligns with Craeft’s objective of formalising tacit craft knowledge into reusable, interpretable semantic representations.

Home > Wood > Processes > Carpentry Process

Carpentry Process

Download JSON-ld

View **Authoring** Process preview

Carpentry Process




The art of building with wood, especially in the construction of buildings and other structures, including the installation of floors, windows, and other trim work. For the making of fine furniture and intricate woodwork, see "cabinetmaking." For the broader activity of working in wood more generally, use "woodworking."

Η τέχνη της οικοδόμησης με ξύλο, ειδικά στην κατασκευή κτιρίων και άλλων κατασκευών, συμπεριλαμβανομένης της τοποθέτησης δαπέδων, παραθύρων και άλλων διακοσμητικών εργασιών. Για την κατασκευή εκλεκτών επίπλων και περιπλοκών ξυλουργικών, ανατρέξτε στην ενότητα "κατασκευή ντουλαπιών". Για την ευρύτερη δραστηριότητα της εργασίας σε ξύλο γενικότερα, χρησιμοποιήστε "ξυλουργική".

Participants	N/A
Location	N/A
Material(s)	Wood
Tool(s)	Hand Saw Mallet Corner Chisel Planes Clamps Workbench Gouges Carving Knives Vise Bow Drill Dowel Scrapers Sandpaper Rasp Polishing Cloth Finishing Nail Claw Hammer Screw Screwdriver
Related process media	N/A

Process steps

Select step	1.Carving and Ornamentation
0.Wood selection and dimensioning	[en] - In this step take place the carving of motifs, such as meanders, acanthus leaves, and palmettes using wood carving chisels, gouges, carving knives, mallet, vise or carving clamp and adding decorative elements to the project.
1.Carving and Ornamentation	[el] - Σε αυτό το βήμα λαμβάνει χώρα η λάξευση μοτίβων, όπως μαϊάνδροι, φύλλα άκανθου και παλιμέτες χρησιμοποιώντας ξυλόγλυπτες σμίλες, αυλάκια, μαχαίρια σκαλισματος, σφυρι, μέγγενη ή σφιγκτήρα σκαλισματος και προσθέτοντας διακοσμητικά στοιχεία στο έργο.
2.Joinery	
3.Surface Preparation	
4.Finishing	



1.Carving and Ornam...

Figure 53. Woodcarving semantic representation

11.2 Offline Simulation & Rendering

Wood carving is a subtractive process characterised by localised material removal under highly directional constraints imposed by the wood’s fibrous structure. To support interactive use while maintaining physical plausibility, the simulation adopts a hybrid approach that combines geometric material removal with anisotropic material behaviour informed by semantic parameters.

The wooden workpiece is represented as a volumetric or surface-based model enriched with grain-direction metadata. Material removal is computed based on chisel geometry, penetration depth, applied force, and cutting direction. The simulation accounts for differences between carving along, across, or against the grain, resulting in variations in chip formation and surface quality.

Rather than simulating full fracture mechanics, which would be computationally expensive, the system focuses on capturing the perceptually relevant effects of carving actions. This enables real-time feedback while preserving the causal relationship between tool manipulation and the resulting form. The simulation outputs successive states of the workpiece geometry, which are passed to the visualisation layer for interactive rendering and analysis.

The approach is validated by specialising the proposed archetypes into indicative craft actions and predicting their results in simulation. The simulated actions are rendered in 3D to create visual demonstrations and can be integrated into game engines for training applications. The figure below shows a diverse illustration of a subtractive affordance availed by the wedge geometry of a tool, the damage behaviour of materials, and how this affordance is realised in diverse crafting actions.

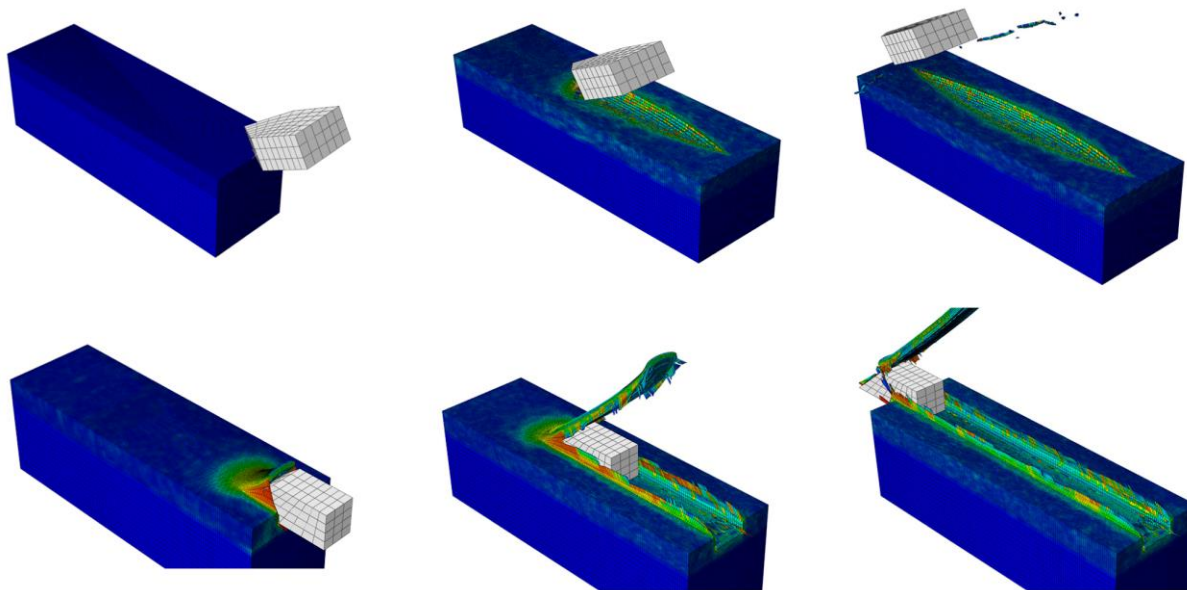


Figure 54. Chisel operation offline simulation

The 3D textured avatar animations are provided in GLB format because, in this format, all assets of the animated model (geometric model, texture, and motion) are compiled in one file. When we make these



animations available on the Web, the corresponding viewer will access all the information needed for rendering through a single file.

11.3 Rendering and Visual Feedback

FEM simulations are more accurate and more descriptive than PBSs, but do not achieve real-time interactivity. In some cases, the FEM is the only means of simulation, specifically when damage and deformation are required, a capability that is unavailable to conventional PBSs. Moreover, conventional PBS do not concurrently enable the use of multiple phenomena, such as the combination of thermal and stress mechanics. The input to FEM simulators is formalised in T2.3 and T2.4 and is sufficient for any FEM engine to carry out the prescribed simulation. In Craeft, the Simulia Abaqus simulation engine is employed.

11.3.1 Simple interactive visualisation

For real-time interaction and training scenarios, the system provides a simplified visualisation mode optimised for clarity and responsiveness. In this mode, the carved surface is rendered with enhanced edge definition and shading that accentuates tool marks, curvature changes, and depth variations. Visual cues indicate cutting direction, tool contact areas, and recently removed material.

This representation prioritises legibility over photorealism, supporting novice learners in understanding the immediate effects of their actions. By clearly linking chisel motion to surface transformation, the visualisation reinforces the procedural logic of carving and helps learners develop spatial awareness and motor planning skills.

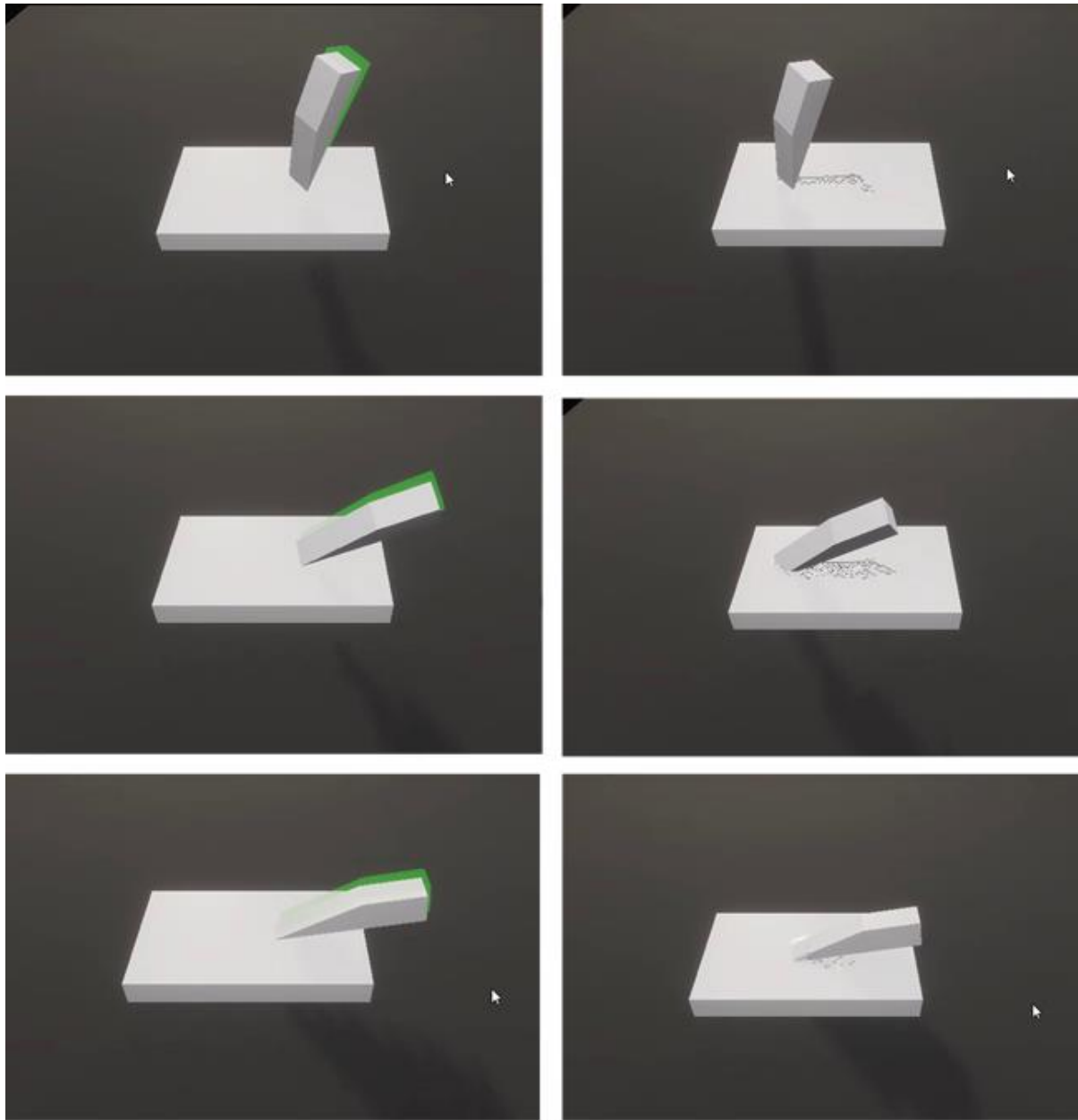


Figure 55. Interactive visualisation.

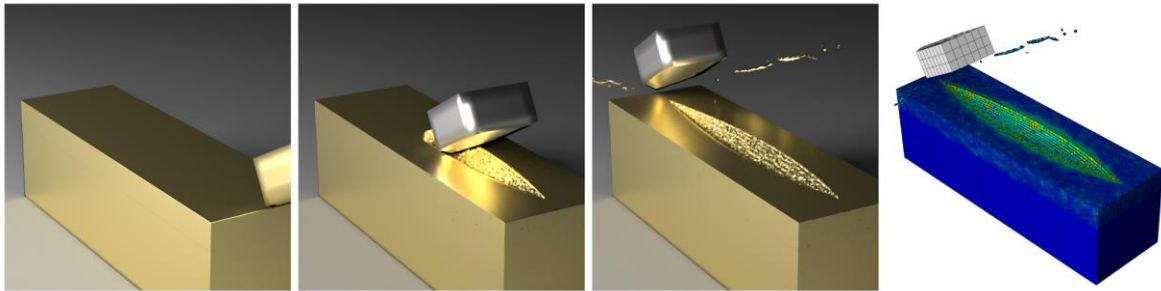
11.3.2 Advanced visualisation

For documentation, reflection, and expert review, an advanced visualisation mode employs physically based rendering techniques to depict wood material appearance with higher fidelity. This includes anisotropic reflectance aligned with wood grain, subtle surface roughness variations, and realistic shading of carved grooves and facets.

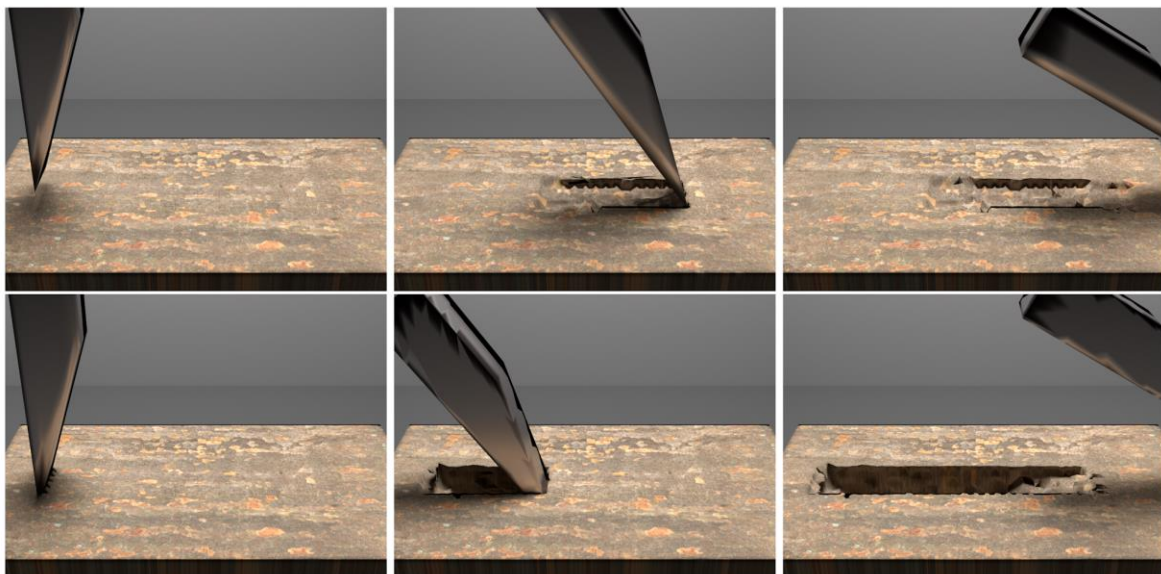
Advanced visualisation enables close inspection of carving outcomes, making it possible to assess surface quality, consistency, and stylistic characteristics. This mode supports comparative analysis between

learner-produced results and expert exemplars, strengthening the link between practice, evaluation, and aesthetic judgement.

The example below illustrates how a FEM simulation is rendered using the visualisation toolbox. In the example, a metallic surface is engraved by a sharp tool. The leftmost image shows the FEM simulation, while the three images on the right show the rendering of the action.



A way to create highly realistic, interactive simulations of a specific single action was implemented by parameterising according to an action parameter of interest. Specifically, all the executions of the action are simulated beforehand and, at interaction time, the appropriate one is looked at and presented (“replayed”). In the figures below, we illustrate a wood carving action executed using the same motion but with different pressure.



11.4 Pedagogical and Interaction Design Integration

The pedagogical design of the woodworking use case emphasises embodied learning and progressive skill acquisition. Interaction metaphors are derived from authentic workshop practice, including two-handed coordination between chisel and mallet, controlled freehand carving, and the stabilisation of the workpiece.



The system supports scaffolded learning scenarios in which learners begin with guided actions, such as predefined cutting paths and constrained tool angles, before gradually transitioning to freer carving tasks. This progression aligns with Cognitive Load Theory principles, reducing extraneous load while fostering germane cognitive effort.

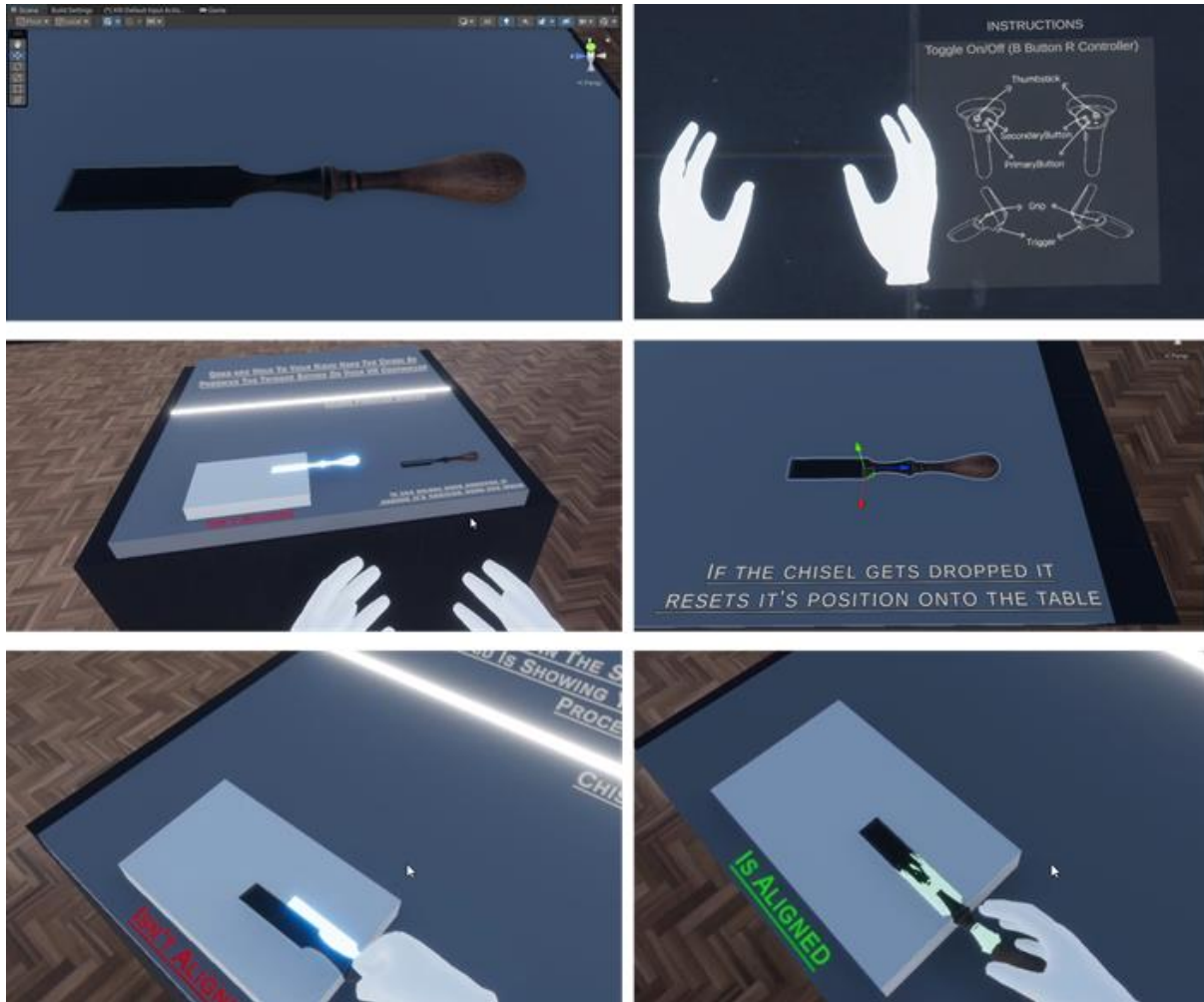
Pedagogical integration also includes exposure to common mistakes and their consequences, such as excessive force or improper grain alignment. By allowing learners to safely experience and recover from errors in simulation, the system supports reflective learning and a deeper understanding of material behaviour.

11.5 Interactive Simulation Outcomes and Scope

The woodworking use case demonstrates the applicability of the Craeft framework to subtractive crafts characterised by strong material anisotropy and fine-grained tool control. By combining semantic process modelling, interactive simulation, and layered visualisation, the system captures essential aspects of wood carving practice in a form suitable for training and documentation.

The scenario here is that the user locates the woodworking bench and, from there, the chisel. Then, a pose for the chisel is provided by the system, and the user should grab and align the chisel with the provided pose. The system tracks the alignment achieved by the user and provides feedback regarding the successful or unsuccessful alignment. When the chisel is aligned, the user can proceed with the action. The exercise, in technical terms, regards the selection by the user of the rotation and translation of the chisel in the virtual space to achieve the desired effect.

In this scenario, the case of using data stemming from the FEM simulation is presented, and at the same time, two variations in the interaction metaphors are demonstrated. The first is the VR interaction metaphor, while the second is the point-and-click metaphor. The process, as implemented in VR, is presented in the following figure.



12. Conclusions

This deliverable addressed the pedagogical and technological challenges inherent in craft education and training by proposing and validating a comprehensive framework that integrates Cognitive Load Theory (CLT), semantic knowledge representation, interactive simulation, and immersive learning environments. The preservation and transmission of traditional crafts as intangible cultural heritage requires approaches that respect embodied practice and tacit knowledge while adapting to contemporary digital learning paradigms. This work demonstrates that such a balance is both feasible and beneficial.

At the pedagogical level, the deliverable introduced a structured set of guidelines grounded in CLT, tailored specifically to the characteristics of craft learning. These guidelines provide practical support for designing eLearning and immersive training content that manages cognitive load, promotes active engagement, and supports progressive skill acquisition. By addressing intrinsic, extraneous, and germane cognitive load, the proposed approach enables learners to engage meaningfully with complex craft processes in digital environments.

At the methodological level, the work presented a layered framework comprising a semantic layer for formalising craft knowledge, an offline simulation layer for modelling material transformation and tool–material interaction, and a visualisation and feedback layer for delivering interactive learning experiences. The alignment of semantic process schemas with physics-based simulation and physically based rendering ensures consistency between conceptual understanding, physical behaviour, and perceptual feedback. This integration supports both documentation and training objectives, enabling craft knowledge to be preserved, explored, and practised in a structured and interpretable form.

The practical applicability of the proposed framework is demonstrated through multiple use cases. The authoring of eLearning courses using Moodle illustrates how CLT-informed guidelines can be applied within existing, widely adopted platforms to create scalable and ergonomic learning experiences. The design and implementation of the Apprentice Studio and the Craft Studio further extend this approach into immersive training, enabling the execution and authoring of interactive lessons grounded in semantically structured craft knowledge. The use cases spanning glass blowing, pin stripping, plaster model turning, and woodworking with chisels demonstrate the versatility of the framework across diverse craft domains, including forming and subtractive processes with distinct material behaviours and interaction requirements.

Overall, this deliverable shows that the combination of cognitive theory, semantic knowledge modelling, and interactive simulation can significantly enhance the digital transmission of craft skills. By bridging traditional apprenticeship practices with eLearning and immersive technologies, the proposed framework contributes to sustainable strategies for safeguarding and revitalising crafts in the digital age. The results of this work provide a solid foundation for future developments, including richer sensory feedback, adaptive learning scenarios, and tighter integration between knowledge graphs and intelligent tutoring systems. In the intersection of tradition and technology, the Craeft framework offers a robust and extensible approach for educators, researchers, and cultural heritage stakeholders committed to the continued vitality of craft practices.

References

1. UNESCO. Traditional Craftsmanship. Available online: <https://ich.unesco.org/en/traditionalcraftsmanship-00057> (accessed on 15 November 2023).
2. Partarakis, N.; Zabulis, X. Safeguarding Traditional Crafts in Europe. *Encyclopedia*. 2023, 3, 1244–1261. <https://doi.org/10.3390/encyclopedia3040090>.
3. Zabulis, X.; Partarakis, N.; Demeridou, I.; Doulgeraki, P.; Zidianakis, E.; Argyros, A.; Theodoridou, M.; Marketakis, Y.; Meghini, C.; Bartalesi, V.; et al. A Roadmap for Craft Understanding, Education, Training, and Preservation. *Heritage* 2023, 6, 5305–5328.
4. Petts, J. Good work and aesthetic education: William Morris, the arts and crafts movement, and beyond. *J. Aesthetic Educ.* 2008, 42, 30–45.
5. Jena, P. K. Globalization of Indian handicrafts: A human development approach. *Orissa Rev.* 2008, 65, 19–25.
6. Hosfield, R.T. *Modes of Transmission and Material Culture Patterns in Craft Skills*; University of California Press: Berkeley, CA, USA, 2009; Volume 2, pp. 45–60.
7. Ionică, P. Traditional Crafts. What About? *Cult. Soc. Econ. Politics* 2022, 2, 51–59.
8. Sharmin, F.; Hossain, S.T. Revitalization of handloom communities for preserving the craft heritage of Bangladesh. *Urban Reg. Plan.* 2020, 5, 1–10.
9. Zbucea, A. Traditional Crafts. A Literature Review Focused on Sustainable Development. *Cult. Soc. Econ. Politics* 2022, 2, 10–27.
10. RICHES Project, European Policy Brief. Available online: https://resources.riches-project.eu/wp-content/uploads/2016/04/EUROPEAN-POLICY-BRIEF_Craft_final.pdf (accessed on 15 November 2023).
11. Gautam, S.S.; Tiwari, M.K. Components and benefits of E-learning system. *Int. Res. J. Comput. Sci.* 2016, 3, 14–17.
12. Lambert, J.; Kalyuga, S.; Capan, L.A. Student Perceptions and Cognitive Load: What Can They Tell Us About eLearning Web 2.0 Course Design? *E-Learn. Digit. Media* 2009, 6, 150–163.
13. Mayer, R.E. Using multimedia for e-learning. *J. Comput. Assist. Learn.* 2017, 33, 403–423.
14. Sweller, J. Cognitive load theory. In *Psychology of Learning and Motivation*; Academic Press: Cambridge, MA, USA, 2011; Volume 55, pp. 37–76.
15. Van Merriënboer, J.J.; Ayres, P. Research on cognitive load theory and its design implications for eLearning. *Educ. Technol. Res. Dev.* 2005, 53, 5–13.
16. Kalyuga, S. Enhancing instructional efficiency of interactive eLearning environments: A cognitive load perspective. *Educ. Psychol. Rev.* 2007, 19, 387–399.
17. van Mierlo, C.M.; Jarodzka, H.; Kirschner, F.; Kirschner, P.A. Cognitive load theory in eLearning. In *Encyclopedia of Cyber Behavior*, IGI Global: Hershey, PA, USA, 2012; pp. 1178–1211.
18. Al Asraj, A.; Freeman, M.; Chandler, P.A. Considering cognitive load theory within eLearning environments. *Pacific Asia Conference on Information Systems, PACIS 2011: Quality Research in Pacific Asia*, Brisbane, Queensland, Australia, 7-11 July 2011.
19. Galagan, P.A. The eLearning revolution. *Train. Dev.* 2000, 54, 24–24.
20. Zhang, D.; Nunamaker, J.F. Powering eLearning in the new millennium: an overview of eLearning and enabling technology. *Inf. Syst. Front.* 2003, 5, 207–218.
21. Huang, C.C.; Wang, Y.M.; Wu, T.W.; Wang, P.A. An empirical analysis of the antecedents and performance consequences of using the Moodle platform. *Int. J. Inf. Educ. Technol.* 2013, 3, 217.
22. Hyland, T. Craft working and the “hard problem” of vocational education and training. *Open J. Soc. Sci.* 2017, 5, 304.



23. Schroeder, N.L.; Cenkci, A.T. Spatial contiguity and spatial split-attention effects in multimedia learning environments: A meta-analysis. *Educ. Psychol. Rev.* 2018, 30, 679–701.
24. Schöler, A.; Scheiter, K.; Schmidt-Weigand, F. Boundary Conditions and Constraints of the Modality Effect; *Zeitschrift für Pädagogische Psychologie*: 2011 Merkelstr. 3 37085 Göttingen Germany.
25. Chan, S.; Strickland, J. Examining the Multimedia Redundancy Effect among Education Majors: Assessing Pedagogical Usability of Instructional Videos. In *E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education*; Association for the Advancement of Computing in Education (AACE): Morgantown, WV, USA, 2014; pp. 333–343.
26. Song, D. Expertise reversal effect and sequencing of learning tasks in online English as a second language learning environment. *Interact. Learn. Environ.* 2016, 24, 423–437.
27. Darejeh, A.; Mashayekh, S.; Marcus, N. Cognitive-based methods to facilitate learning of software applications via E-learning systems. *Cogent Educ.* 2022, 9, 2082085.
28. İltüzer, Y.; Demiraslan Cevik, Y. Effects of self-explanation on applying decision rules in an online learning environment. *Educ. Inf. Technol.* 2021, 26, 4771–4794.
29. Kala, N.; Ayas, A. Effect of instructional design based on cognitive load theory on students' performances and the indicators of element interactivity. *J. Turk. Sci. Educ.* 2023, 20, 468–489.
30. Abu-Salih, B., Alotaibi, S.: A systematic literature review of knowledge graph construction and application in education. *Heliyon.* 10, e25383 (2024). <https://doi.org/10.1016/j.heliyon.2024.e25383>
31. Weichselbraun, A., Waldvogel, R., Fraefel, A., Van Schie, A., Kuntschik, P.: Building Knowledge Graphs and Recommender Systems for Suggesting Reskilling and Upskilling Options from the Web. *Information.* 13, 510 (2022). <https://doi.org/10.3390/info13110510>
32. Fan, X., Sun, Y., Wang, Q., Wang, X.: Research on the Application of Knowledge Graph in Higher Education of Art and Design. In: Kaki, S., Majoul, B., Mohd Sharif, M.F., and Syed Mohammed, S.F. (eds.) *Proceedings of the 2024 6th International Conference on Literature, Art and Human Development (ICLAHD 2024)*. pp. 494–501. Atlantis Press SARL, Paris (2024). https://doi.org/10.2991/978-2-38476-319-1_57.
33. Qu, K., Li, K. C., Wong, B. T., Wu, M. M., & Liu, M. (2024). A survey of knowledge graph approaches and applications in education. *Electronics*, 13(13), 2537.
34. Abu-Salih, B., & Alotaibi, S. (2024). A systematic literature review of knowledge graph construction and application in education. *Heliyon*, 10(3).
35. Abu-Rasheed, H., Weber, C., & Fathi, M. (2024, May). Knowledge graphs as context sources for llm-based explanations of learning recommendations. In *2024 IEEE Global Engineering Education Conference (EDUCON)* (pp. 1-5). IEEE.
36. Osterloh, M., Frey, B.S.: Motivation, Knowledge Transfer, and Organisational Forms. *Organ. Sci.* 11, 538–550 (2000). <https://doi.org/10.1287/orsc.11.5.538.15204>
37. Zabulis, X., Partarakis, N., Demeridou, I., Doulgeraki, P., Zidianakis, E., Argyros, A., Theodoridou, M., Marketakis, Y., Meghini, C., Bartalesi, V., Pratelli, N., Holz, C., Strelis, P., Meier, M., Seidler, M.K., Werup, L., Sichani, P.F., Manitsaris, S., Senteris, G., Dubois, A., Ringas, C., Ziova, A., Tasiopoulou, E., Kaplanidi, D., Arnaud, D., Hee, P., Canavate, G., Benvenuti, M.-A., Krivokapic, J.: A Roadmap for Craft Understanding, Education, Training, and Preservation. *Heritage.* 6, 5305–5328 (2023). <https://doi.org/10.3390/heritage6070280>
38. Zabulis, X., Meghini, C., Dubois, A., Doulgeraki, P., Partarakis, N., Adami, I., Karuzaki, E., Carre, A.-L., Patsiouras, N., Kaplanidi, D., Metilli, D., Bartalesi, V., Ringas, C., Tasiopoulou, E., Stefanidi, Z.: Digitisation of Traditional Craft Processes. *J. Comput. Cult. Herit.* 15, 1–24 (2022). <https://doi.org/10.1145/3494675>
39. Zabulis, X., Partarakis, N., Bartalesi, V., Pratelli, N., Meghini, C., Dubois, A., Moreno, I., Manitsaris, S.: Multimodal Dictionaries for Traditional Craft Education. *Multimodal Technol. Interact.* 8, 63 (2024). <https://doi.org/10.3390/mti8070063>



40. Partarakis, N., Zabulis, X.: Applying Cognitive Load Theory to eLearning of Crafts. *Multimodal Technol. Interact.* 8, 2 (2023). <https://doi.org/10.3390/mti8010002>
41. Olivas-Padilla, B.E., Glushkova, A., Manitsaris, S.: Motion Capture Benchmark of Real Industrial Tasks and Traditional Crafts for Human Movement Analysis. *IEEE Access.* 11, 40075–40092 (2023). <https://doi.org/10.1109/ACCESS.2023.3269581>
42. Wang, Y., Liu, J., Wang, W., Chen, J., Yang, X., Sang, L., ... & Peng, Q. (2024). Construction of a cultural heritage knowledge graph based on a graph attention neural network. *Applied Sciences*, 14(18), 8231.
43. Doumanas, D., Ntalouka, E., Vassilakis, C., Wallace, M., & Kotis, K. (2025). Stitching History into Semantics: LLM-Supported Knowledge Graph Engineering for 19th-Century Greek Bookbinding. *Machine Learning and Knowledge Extraction*, 7(3), 59.
44. Huang, S. H., & Chiou, S. C. (2025). Constructing a Knowledge Management System for Traditional Craftsmen through Digitalisation. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 48, 601-606.
45. Zhu, X., Li, Z., Wang, X., Jiang, X., Sun, P., Wang, X., ... & Yuan, N. J. (2022). Multi-modal knowledge graph construction and application: A survey. *IEEE Transactions on Knowledge and Data Engineering*, 36(2), 715-735.
46. Knudson, M.M., Khaw, L., Bullard, M.K., Dicker, R., Cohen, M.J., Staudenmayer, K., Sadjadi, J., Howard, S., Gaba, D., Krummel, T.: Trauma Training in Simulation: Translating Skills From SIM Time to Real Time. *J. Trauma Inj. Infect. Crit. Care.* 64, 255–264 (2008). <https://doi.org/10.1097/TA.0b013e31816275b0>
47. Menghal, P.M., Laxmi, A.J.: Real-time simulation: A novel approach in engineering education. In: 2011 3rd International Conference on Electronics, Computer Technology. pp. 215–219. IEEE, Kanyakumari, India (2011). <https://doi.org/10.1109/ICECTECH.2011.5941592>
48. Chambers, T.L., Aglawe, A., Reiners, D., White, S., Borst, C.W., Prachyabrued, M., Bajpayee, A.: Real-time simulation for a virtual reality-based MIG welding training system. *Virtual Real.* 16, 45–55 (2012). <https://doi.org/10.1007/s10055-010-0170-x>
49. Lee, Y., Ko, C., Lee, H., Jeon, K., Shin, S., Han, C.: Interactive plant simulation modeling for developing an operator training system in a natural gas pressure-regulating station. *Pet. Sci.* 14, 529–538 (2017). <https://doi.org/10.1007/s12182-017-0170-5>
50. Vergnano, A., Berselli, G., Pellicciari, M.: Interactive simulation-based-training tools for manufacturing systems operators: an industrial case study. *Int. J. Interact. Des. Manuf. IJIDeM.* 11, 785–797 (2017). <https://doi.org/10.1007/s12008-016-0367-7>
51. Tang, L., Cao, Y., Liu, Z., Qian, K., Liu, Y., Liu, Y., Zhou, Y.: Improving the quality of preclinical simulation training for dental students using a new digital real-time evaluation system. *Eur. J. Dent. Educ.* 25, 100–107 (2021). <https://doi.org/10.1111/eje.12580>
52. Antonovsky, A., Pollock, C., Straker, L.: Identification of the Human Factors Contributing to Maintenance Failures in a Petroleum Operation. *Hum. Factors J. Hum. Factors Ergon. Soc.* 56, 306–321 (2014). <https://doi.org/10.1177/0018720813491424>
53. Wolff, R., Preusche, C., Gerndt, A.: A modular architecture for an interactive real-time simulation and training environment for satellite on-orbit servicing. *J. Simul.* 8, 50–63 (2014). <https://doi.org/10.1057/jos.2013.10>
54. Marinkovic, D., & Zehn, M. (2019). Survey of finite element method-based real-time simulations. *Applied Sciences*, 9(14), 2775.
55. Zabulis, X., Partarakis, N., Demeridou, I., Bartalesi, V., Pratelli, N., Meghini, C., Nikolaou, N., Fallahian, P.: Modelling and Simulation of Traditional Craft Actions. *Appl. Sci.* 14, 7750 (2024). <https://doi.org/10.3390/app14177750>



56. Zabulis, X., Stamou, A., Demeridou, I., Koutlemanis, P., Karamaounas, P., Papageridis, V., Partarakis, N.: Simulation and Visualisation of Traditional Craft Actions. *Heritage*. 7, 7083–7114 (2024). <https://doi.org/10.3390/heritage7120328>
57. Xu, R., Xu, J.: Research on Interactive Traditional Craft Diagram Model and Simulation System: Take Nanjing Rong Hua Craft as an Example. In: *Proceedings of the 2016 2nd International Conference on Advances in Energy, Environment and Chemical Engineering (AEECE 2016)*. Atlantis Press, Singapore (2016). <https://doi.org/10.2991/aece-16.2016.54>
58. Pharr, M., Jakob, W., & Humphreys, G. (2023). *Physically based rendering: From theory to implementation*. MIT Press.
59. Craftsby. Available online: <https://www.craftsy.com/> (accessed on 15 November 2023).
60. Udemy. Available online: <https://www.udemy.com/> (accessed on 15 November 2023).
61. Thegreatcourses. Available online: <https://www.thegreatcourses.com> (accessed on 15 November 2023).
62. Skillshare. Available online: <https://join.skillshare.com> (accessed on 15 November 2023).
63. Dougiamas, M. Moodle. Retrieved Online 2004, 27, 2004.
64. Al-Ajlan, A.; Zedan, H. Why moodle. In *Proceedings of the 2008 12th IEEE International Workshop on Future Trends of Distributed Computing Systems*, Washington, DC, USA, 21–23 October 2008; pp. 58–64.
65. Calvert, I.W. *Investigating the One-On-One Master-Apprentice Relationship: A Case Study in Traditional Craft Apprenticeship*; Brigham Young University: Provo, UT, USA, 2014.
66. Taylor, A.D.; Hung, W. The effects of microlearning: A scoping review. *Educ. Technol. Res. Dev.* 2022, 70, 363–395.
67. Adipat, S.; Laksana, K.; Busayanon, K.; Asawasowan, A.; Adipat, B. Engaging Students in the Learning Process with Game-Based Learning: The Fundamental Concepts. *Int. J. Technol. Educ.* 2021, 4, 542–552.
68. Habib, K.R. *Designing Digital Art and Communication Tools Inspired by Traditional Craft*; Department of Computer Science, School of Computing, National University of Singapore: Singapore, 2014.
69. Ringas, C.; Tasiopoulou, E.; Kaplanidi, D.; Partarakis, N.; Zabulis, X.; Zidianakis, E.; Patakos, A.; Patsiouras, N.; Karuzaki, E.; Foukarakis, M.; et al. Traditional Craft Training and Demonstration in Museums. *Heritage* 2022, 5, 431–459.
70. Stefanidi, E.; Partarakis, N.; Zabulis, X.; Adami, I.; Ntoa, S.; Papagiannakis, G. Transferring traditional crafts from the physical to the virtual world: An authoring and visualization method and platform. *ACM J. Comput. Cult. Herit.* 2022, 15, 1–24.
71. Carre, A.L.; Dubois, A.; Partarakis, N.; Zabulis, X.; Patsiouras, N.; Mantinaki, E.; Zidianakis, E.; Cadi, N.; Baka, E.; Thalmann, N.M.; et al. Mixed-reality demonstration and training of glassblowing. *Heritage* 2022, 5, 103–128.
72. Yang, H.O. Research on the Application of Interaction Design in the Digital Education of Traditional Crafts. In *Proceedings of the International Conference on Human-Computer Interaction*, Springer Nature Switzerland: Cham, Switzerland, 2023; pp. 221–238, Copenhagen, Denmark.
73. Osman, S.; Zin, N.A., H.M. Proposed model for courseware development of virtual teaching and learning traditional craft. In *Proceedings of the 2010 International Symposium on Information Technology*, Kuala Lumpur, Malaysia, 15–17 June 2010; Volume 1, pp. 1–6.
74. Van Merriënboer, J.J.; Krammer, H.P. Instructional strategies and tactics for the design of introductory computer programming courses in high school. *Instr. Sci.* 1977, 16, 251–285.
75. Nimkulrat, N., Oussoren, A., Day Fraser, H., & Doyle, K. (2019). Collaborative Craft through Digital Fabrication and Virtual Reality. In *Proceedings of Research Through Design (RTD2019) Method & Critique*. Delft: Delft University of Technology. DOI: 10.6084/m9.figshare.7855781.v1



76. Jimenez, I.A.C.; Nonis, F.; Olivetti, E.C.; Ulrich, L.; Moos, S.; Monaci, M.G.; Marcolin, F.; Vezzetti, E. Exploring User Engagement in Museum Scenario with EEG-A Case Study in MAV Craftsmanship Museum in Valle d'Aosta Region, Italy. *Electronics* 2023, 12, 3810.
77. JE; T; Sweller, J. A comparison of cognitive load associated with discovery learning and worked examples. *J. Educ. Psychol.* 1999, 91, 334–341.
78. Clark, R.C.; Nguyen, F.; Sweller, J. *Efficiency in Learning: Evidence-Based Guidelines to Manage Cognitive Load*; John Wiley & Sons: Hoboken, NJ, USA, 2011.
79. Pouw, W.; Rop, G.; De Koning, B.; Paas, F. The cognitive basis for the split-attention effect. *J. Exp. Psychol. Gen.* 2019, 148, 2058.
80. Krause, T. *An Evaluation of the Modality Effect: The Impact of Presentation Style and Pacing on Learning, Mental Effort, and Self-Efficacy*; Arizona State University: Tempe, AZ, USA, 2018.
81. Demir, B.; KARABIYIK, C.E.Y.H.U.N.; Özdemir, M.; Baturay, M. Revisiting the Modality and Redundancy Effect in an Augmented Reality-Based Language Learning Environment. *J. Educ. Technol.* 2022, 19, 1–21.
82. Toh, S.C.; Munassar, W.A.S.; Yahaya, W.A.J.W. Redundancy effect in multimedia learning: A closer look. In *Proceedings of Ascilite*; Universiti Sains Malaysia: Kepala Batas, Malaysia, 2010.
83. Liu, T.C.; Lin, Y.C.; Wang, T.N.; Yeh, S.C.; Kalyuga, S. Studying the effect of redundancy in a virtual reality classroom. *Educ. Technol. Res. Dev.* 2021, 69, 1183–1200.
84. Baceviciute, S.; Lucas, G.; Terkildsen, T.; Makransky, G. Investigating the redundancy principle in immersive virtual reality environments: An eye-tracking and EEG study. *J. Comput. Assist. Learn.* 2022, 38, 120–136.
85. Kalyuga, S. Expertise reversal effect and its implications for learner-tailored instruction. *Educ. Psychol. Rev.* 2007, 19, 509–539.
86. Kester, L.; Kirschner, P.A. Effects of fading support on hypertext navigation and performance in student-centered eLearning environments. *Interact. Learn. Environ.* 2009, 17, 165–179.
87. Leopold, C.; Mayer, R.E. An imagination effect in learning from scientific text. *J. Educ. Psychol.* 2015, 107, 47.
88. Zabolis, X.; Partarakis, N.; Meghini, C.; Dubois, A.; Manitsaris, S.; Hauser, H.; Thalmann, N.M.; Ringas, C.; Panesse, L.; Cadi, N.; et al. A Representation Protocol for Traditional Crafts. *Heritage* 2022, 5, 716–741.
89. Caldwell, B.; Cooper, M.; Reid, L.G.; Vanderheiden, G.; Chisholm, W.; Slatin, J.; White, J. Web content accessibility guidelines (WCAG) 2.0. *WWW Consort.* 2008, 290, 1–34.
90. Partarakis, N.; Doulgeraki, C.; Mourouzis, A.; Grammenos, D.; Stephanidis, C. Establishing a process for collaborative development of guidelines and standards. In the *Proceedings of the 2nd Intuition International Workshop "VR/VE & Industry: Challenges and opportunities"*, Espace CETIM, Senlis, France, 24–25 November. [CD-ROM].
91. Partarakis, N.; Mourouzis, A.; Doulgeraki, C.; Stephanidis, C. A portal-based tool for developing, delivering and working with guidelines. In *Proceedings of the Universal Access in Human-Computer Interaction. Coping with Diversity: 4th International Conference on Universal Access in Human-Computer Interaction, UAHCI 2007, Held as Part of HCI International 2007, Beijing, China, 22–27 July 2007*; *Proceedings, Part I 4*; Springer: Berlin/Heidelberg, Germany, 2007; pp. 507–516.
92. H5P. Available online: <https://h5p.org/> (accessed on 15 November 2023).
93. Zainuddin, Z.; Shujahat, M.; Haruna, H.; Chu, S.K.W. The role of gamified e-quizzes on student learning and engagement: An interactive gamification solution for a formative assessment system. *Comput. Educ.* 2020, 145, 103729.
94. Cook, B.R.; Babon, A. Active learning through online quizzes: Better learning and less (busy) work. *J. Geogr. High. Educ.* 2017, 41, 24–38.



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95. Purba, L.S.L. The effectiveness of the Quizizz interactive quiz media as an online learning evaluation of physics and chemistry 1 to improve student learning outcomes. In Journal of Physics: Conference Series; IOP Publishing: Bristol, UK, 2020; Volume 1567, p. 022039.

Annex I. Iteration Log and Requirement Traceability

This annex documents requirement evolution and key decisions across meetings and structured comment rounds, providing traceability from early scope and pedagogy through scenario definition, media strategy, asset feasibility, and UX/controller refinements.

Date	Format	Topic / Artefact	Key requirement decisions captured	Impact/follow-up for implementation
18/01/2024	Partner meeting	Early concept + pedagogy baseline	Established two-mode structure (Knowledge vs Know-how); identified tool list needs; set early tutorial framing and learning flow expectations.	Baseline scope for scenarios and tool inventory; informed later UI/panel content and interactions.
29/08/2024	Design update	Pedagogical progression update	Clarified guided vs free-roaming learning approaches; confirmed both scenarios require tutorials; addressed feedback mechanisms (visual guidance vs sound cues); clarified trainer role in VR.	Informed progression, feedback, and facilitation assumptions (teacher presence; feedback on correctness).
04/11/2024	Comment round	Scenario scoping	Keep Scenario 1 (Knowledge) low complexity; disable grab in Knowledge mode.	Reduces UX/implementation risk; separates interaction scope by scenario.
05/11/2024	Meeting + comments	WP6.1 concept + lobby	Confirmed Waiting Room/Lobby as entry point; requested precise step list for mould-blown cup; clarified grab = Scenario 2; required prioritised tools list.	Drives sequencing and content planning; supports production prioritisation.
06/11/2024	Comment round	Lobby + completeness checks	Validated lobby layout (simple room; options in front); requested confirmation of missing elements in Knowledge mode; requested full list of practice actions/gestures; refined tool images and added missing tool assets (e.g., pipe warmer).	Improves completeness and asset readiness; stabilises scenario selection flow.

12/11/2024	Partner coordination	Media sources + integration	Added action video sources and linking strategy; discussed scene management and motion controller usage; raised potential 360° informative video before scenarios; initiated integration discussion with broader apprentice studio framing.	Clarified content pipeline (video sourcing) and system integration assumptions.
13/11/2024	Comment round	Media strategy (feasibility)	Preference for hyper-realistic egocentric 2D videos over 3D MOP videos due to the fidelity of hand/tool interactions.	Anchors content format for Know-how steps and tool demonstrations.
14–15/11/2024	Comment round	Why VR? / Scope realism	Clarified VR value even with 2D media (immersion, spatial audio); acknowledged full physical simulation as unattainable; confirmed pragmatic approach as first step.	Aligns expectations for prototype realism; justifies approach while keeping future upgrade path.
26/11/2024	Comment round	Know-how scope clarified	Confirmed hybrid model: Gathering remains hands-on; later steps are spectator (3D preferred, 2D acceptable) and triggered via teleport to marked zones.	Defines core instructional mechanics (zone triggers) and content requirements per step.
27–28/11/2024	Comment round	Asset access + feasibility constraints	Identified limitations downloading YouTube content; originals confirmed with FORTH and transfer arranged; warned video-based hand tracking would be shaky due to occlusions; explored alternative data options.	Ensures correct source assets; avoids fragile assumptions about motion extraction from video.
13/01/2025	Meeting/te st review	December feedback → UX fixes	Actionable feedback: thicker highlights; UI render order highest; remove tool text overlays; require VR hand positions (reference images); tool descriptions placed on panels.	Converts testing into implementable backlog; improves clarity and usability.
26/05/2025	Comment round	Instruction + highlight quality	Standardise highlight colour (red) but improve sensitivity/responsiveness and thickness; instruction panel approach identified as placeholder; recommendation	Drives interaction clarity improvements; triggers redesign of instruction approach.



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			to remove non-functional display and fix tool positioning (bench orientation).	
03/06/2025	Comment round	Tool showcase direction	Preference shift to a dedicated tool showcase zone with in-world info panels (instead of hand-level panels); requirement to keep the panel within the view field during manipulation.	Improves comprehension and reduces UI confusion; informs spatial UI design.
03–05/06/2025	Comment round	Highlight purpose + multiplayer visibility	Clarified highlight purpose in showcase (identify tool to grab + access info); raised question whether highlights should be visible to all players to indicate pointing.	Flags a multiplayer UX decision; informs networking/visibility rules.
05/06/2025	Comment round	Controller mapping + realism	Allow left-hand rotation of cane/blowpipe without teleport conflict (context-based mapping: joystick rotates when holding rod, teleports when not); terminology clarified; logged texture/asset oddities and grasp precision issues; reiterated zone-based sequence logic for steps.	Improves ergonomics and realism; informs input mapping and asset polish backlog.

Annex II. Hand poses

This annex demonstrates the required hand poses for both hands and each tool used in the VR development.

Jacks

Open state



Closed state



Tweezers

Open state



Closed state



Diamant sheers

Open state



Closed state



Block

Blocking position



Bucket position



Pipe

Basic position



Left hand



right hand

Gathering position



Left hand



Right hand

Blocking position with a pipe



Blocking position with a pipe





