Final Evaluation Report — VR Gearbox Assembly Trainer

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Github Repository Link:

https://github.com/TheShoesAreTragic/XR-Gearbox-Assembly

Video Demo Link:

https://youtu.be/20TGyJhmqOQ

Executive Summary

In this project, we partnered with SEW Eurodrive to develop a full VR training application that trains users on their gearbox assembly procedure in a controlled, repeatable virtual environment. Traditional training for gearbox assembly is expensive, slow to administer, and easily disrupted whenever SOPs change. Our system addresses these challenges by allowing technicians to learn safely without risking damage to materials and requiring constant supervision. Through a state-driven process flow, direct haptic-style interactions, tool-based assembly actions, and dynamically updating step-by-step instruction, we created a system that behaves not just as a prototype, but as a practical and reliable training tool. The final product reflects the real manufacturing procedure, maintains strong usability, and demonstrates clear potential for deployment and future expansion.

Problem Context & Motivation

From the outset, we identified a clear engineering need: onboarding new assembly technicians — or retraining existing ones — is costly and inconsistent when performed manually. The process consumes physical components, requires expert oversight, and leaves room for human variability. We believed VR was the most appropriate modality for training because it offers a standardized workspace, reduces material waste, and lets users learn by doing rather than watching. Unlike AR, VR let us control every aspect of the environment, ensuring every trainee sees the same workspace, parts, tools, and instruction sequence.

Technical Implementation

In the final application, we place the user into a virtual workstation stocked with all necessary gearbox components and tools, an industrial heating station, and a dynamic instruction screen. The trainee progresses through the build using natural hand interactions:

gripping, placing, heating, and striking parts just as one would on a real assembly floor. A state machine enforces the correct order of assembly by activating XR socket assets only once the player reaches its designated step, preventing users from inserting parts prematurely and ensuring procedural fidelity. As tasks are completed, the UI updates automatically with text descriptions and photographs of the relevant assembly stage, while sound cues confirm success and keep the user oriented.

Technically, this project required multiple layers of functionality working together. We built a custom C# logic system to manage state progression, socket activation, collider behavior, tool interactions, and UI transitions. Our hammer and oven were not just decorative elements — we scripted them to trigger step advancement, mirroring real manufacturing procedures. Once we gained headset access, we transitioned from ray-based interaction to near-hand grabbing, which instantly increased realism and comfort. Joystick locomotion allows the user to move freely around the workstation, and all objects were arranged within natural reach to mimic ergonomic setup. These decisions, combined, created a stable and reliable technical foundation.

As a team, we divided responsibilities based on each member's strengths to keep development efficient and focused. One person concentrated on the core interaction logic and state machine, another handled environment design and object behavior, while the third focused on subject matter expertise, research, and didactics. This complementary workflow allowed us to iterate quickly, avoid bottlenecks, and ensure every component was built by the person best suited to the task.

Human-Centered Design Decisions

Our human-centered design choices were equally intentional. We anchored instructions to the workstation so that trainees could always reference them without breaking immersion or losing sight of their workspace. Gearbox components were color-coded to minimize confusion and speed part recognition. The requirement to physically heat or hammer certain parts meant that progression always felt deliberate rather than automatic. We tuned object height and spacing based on live testing to ensure comfort and accessibility. Each interaction triggered audio and visual feedback, reinforcing progress and helping users understand immediately when they had done the right thing.

User Testing & Iteration

Testing shaped much of our final polish. Throughout development, we used the XR Device Simulator to validate interaction logic, socket behavior, and UI transitions. Once we had physical hardware on hand, we shifted focus toward comfort and realism. Our test session on 11/18 marked the point where the project truly came together — we refined hand-based grabbing, added audio confirmation for step completion, implemented our heating and hammer systems directly into the workflow, and verified that our step sequencing felt natural. By the end of testing, users could complete the gearbox assembly without external instruction, confirming strong clarity and repeatability.

Lessons Learned and Trade-offs

Throughout development, we learned a number of practical lessons that shaped the final system and highlighted important technical trade-offs. We very quickly figured out that the XR simulator and the actual VR headsets were very different in terms of user interaction and even getting the right kind of interaction. Once we started testing on physical hardware, we had to retune grabbing distances and hand-tracking behavior to achieve the realism we wanted. Our step-based state machine proved essential, replacing earlier custom script triggers with a reusable structure that made the workflow reliable and maintainable as the assembly sequence grew. Playtesting also revealed that users need more feedback than expected, and adding audio cues, visual highlights, and more deliberate interaction responses dramatically improved clarity. Technically, we made conscious trade-offs between near-hand and ray-based interactions, detailed physics and mesh colliders. Our biggest challenge came from having to make a convex collider out of a series of smaller box colliders. Together, these lessons and decisions made the final system more intuitive, stable, and effective as a genuine training tool.

Success Criteria & Evaluation

We measured our success through three primary lenses: instructional clarity, user comfort, and procedural reliability. In practice, we found that users were able to follow the entire sequence correctly, never progressed out of order thanks to state control, and interacted comfortably with the workstation. While additional data collection — such as completion times or long-term retention — could provide deeper insight, the evidence strongly suggests our system works effectively as a training tool.

We ultimately feel that our completed system exceeded what we originally planned to build. Not only did we recreate the official gearbox assembly process in detail, but we went further by developing fully functional heating and striking mechanics, a polished state-driven UI system, and an interaction model that mirrors real assembly work. The result is not a conceptual demo — it is a complete training workflow. Our only major limitation is that the surrounding environment remains minimal, focused primarily on the workstation. Going forward, we would like to expand the space into a full factory setting, incorporate environmental noise, or support multi-station assembly paths. We also see potential for applying this framework to far more complex machinery than a gearbox.

Conclusion

This project demonstrates how VR can meaningfully improve manufacturing training by providing a controlled, repeatable, and risk-free learning environment. We built an application in which users assemble a gearbox from start to finish using realistic interactions, guided instruction, and procedural safeguards to ensure correctness. The system is immersive, technically sound, and repeatable — and we believe it represents a strong argument for the broader adoption of XR training in industrial settings. With further expansion, we could extend this approach to more complex assemblies and develop a library of XR-based training workflows. We began with a goal to replace costly physical training sessions, and we ended with a functional system that proves that vision is achievable.