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CryoVR: a Virtual Reality Training System for CryoEM Hands-on Operations

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Cryogenic electron microscopy (cryoEM) has emerged as a revolutionary tool for solving the structure of various proteins while preserving their near-native states. However, the availability of equipment, time, and the cost needed for training can substantially limit the opportunity for hands-on training on cryoEM procedures[1]. Modern virtual reality (VR) technology has made the virtual experience much more realistic and affordable. VR devices' high-fidelity simulated visual and audio sensations can create an immersive feeling of presence in a virtual environment for a user. VR training can reduce training costs, especially when traditional training depends on interactive instructions of experts and can suffer from the breakdown of devices used during training[2]. Therefore, we developed a VR-based training system, CryoVR, to assist trainees in familiarizing themselves with the cryoEM operation procedures before the training on expensive and delicate real-world cryoEM equipment.

A typical cryoEM single-particle analysis workflow requires the operation of multiple instruments. Hence, we create separate modules in our CryoVR system to emulate the operation of different instruments, including grid glow discharging (PELCO easiGlow^{TM}), plunge freezing (Vitrobot Mark IV and GATAN CP3), AutoGrid clipping and loading (Titan Krios TEM) (Fig. 1). These modules can be played on major brands' VR devices such as HTC Vive and Oculus Quest.

For each module, we have different modes tailored for various levels of users. For novice users who are not familiar with the experimental procedures of the cryoEM instrument, a Tutorial mode is designed to demonstrate every detail of the cryoEM procedure with fully guided text, sound, UI instructions, and video clips of the experimental procedures (Fig. 2). As a result, users will gain procedural knowledge on the operation of the instrument. We also aim at conferring the users of CryoVR modules the sufficient skills necessary for the use of instruments and their operational procedures to reduce the time needed for their real-life training on physical instruments in a facility. Thus, we have also implemented an Exam mode which compares the user's operations in CryoVR against the standard operating procedures (SOPs) with each operation step specified by the instrument parts or ancillary devices to be operated, the starting/ending positions, allowable time, etc. After each virtual operation procedure is completed, a score will be provided to report the user's performance. The users' operation during the exam will be listed as feedback for users to reinforce the SOPs (Fig. 3A). To ensure mastery and avoid future mistakes on physical instruments, we require a perfect score (100% correct) for users to pass the module and get a certificate verifiable via our CryoVR server (Fig 3B). As a part of the collaborative Merit badge system, the CryoVR certificates are recognized by the national cryoEM centers and curriculum development teams funded by the NIH Transformative CryoEM program.

We have disseminated CryoVR to the cryoEM community and collected their feedback. Most comments are positive and agree that the CryoVR system is a good preview for the operation procedures before the real-life onsite training. In conclusion, our CryoVR training system can create a virtual environment to help users to get acquainted with instrument interfaces, operation procedures, and manipulation skills

before starting hands-on training with physical cryoEM instruments. This project is innovative as CryoVR is the first VR application for the cryoEM workflow.

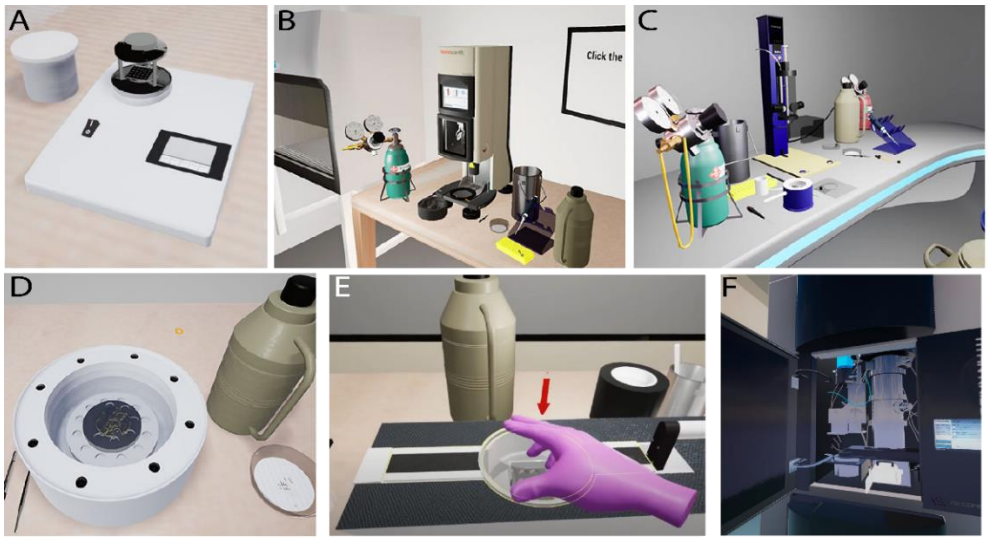

Figure 1: Screenshots of modules in the CryoVR training systems. *(*A) Grid glow discharge module (PELCO easiGlow^{TM}). (B) Vitrobot Mark IV plunger. (C) GATAN CP3 plunger. (D) Autogrid clipping. (E) Autogrid loading station. (F) Titan Krios Microscope.

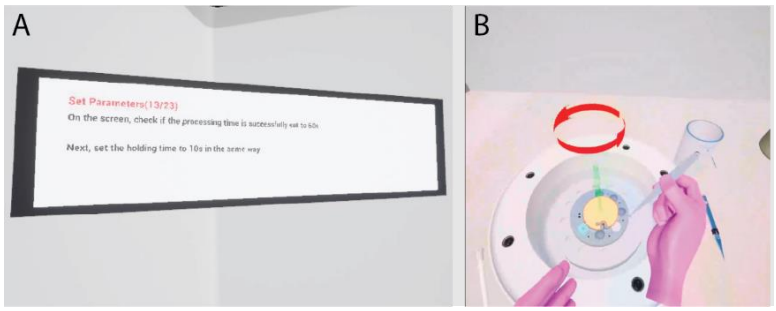

Figure 2: The comprehensive instruction system in the Tutorial mode. (A) detailed voice and text instruction based on the SOP. (B) UI guides.

Figure 3: The Exam mode to help reinforce the standard operation procedure. (A) If a perfect score for the Exam mode is not achieved, an error report will be generated. (B) An example of the certificate.

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