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An Electron Microscopy Collaboratory for Correlative Imaging Sciences

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Transmission and scanning transmission electron microscopes, (S)TEMs are enabling groundbreaking discoveries in fields ranging from materials science to medicine. Scanning electron microscopes (SEMs) and dual-beam focused-ion-beam (FIB) instruments are multi-technique platforms that are being used for research ranging from *in situ* studies of mechanical properties to 3D reconstruction of biomaterials. Multimodal and multiscale correlative approaches are combining imaging and analytical modalities such as optical microscopy, scanning electron microscopy (SEM), and (S)TEM, and FIB with X-ray diffraction (XRD), X-ray absorption spectroscopy (XAS), and X-ray micro-tomography (XMT), to yield complementary and unique insights beyond that achievable with a single method.

Coupling these powerful instruments with high-speed digital communications promises to revolutionize the way scientists collaborate with each other and train the next generation of researchers. By duplicating the control interface and connecting to the microscope through a high-speed network, users outside of the microscope control room can operate the instrument as if they were sitting in front of it. This enables researchers in different locations to work together, sharing observations in real time, and enables trainees to gain the hands-on experience they require to become proficient in the use of these sophisticated techniques. IT also provides new opportunities for correlative analysis of data, leading to opportunities for machine learning in data acquisition. The creation of a digital lecture theater that provides this capability at every seat results in an *electron microscopy collaboratory* that revolutionizes teaching, learning, and research in electron microscopy and characterization.

The feasibility and practicality of operating electron microscopy instruments from a distance has often been explored in the past [1-4]. In general, the goal is to enable the highest possible utilization of a scarce resource, namely powerful, expensive electron microscopes and associated analytical instrumentation. Universities and research organizations require the use of electron microscopes but may not have the infrastructure or the capital to acquire and maintain the modern, high-performance, corrected TEM instruments.

At the Center for Electron Microscopy and Analysis (CEMAS) at The Ohio State University (OSU) the focus is to enable tools to expand local user base and build a critical mass of users by fostering high quality collaborations. Facilitating remote operation to teach and train large groups of students, simultaneously [5-7] helps to build this user base and expand exposure to characterization techniques. Whether an off-campus outreach effort, or a classroom demonstration, these educational efforts seek to build excitement for science, and show the wonderment of "seeing the unseen" to students of all ages.

In this contribution we will discuss the implementation of high-performance remote operation of the CEMAS facilities. We will describe our "collaboratory" – a hybrid teaching environment that allows students to interact with every instrument at CEMAS and allows educators to integrate practical training

into their teaching materials. [8] This integration of remote operation of electron optical and x-ray instrumentation into existing Material Science and Engineering (MSE) courses at OSU has led to valuable insights and revealed curricular challenges that need to be addressed. In particular, there is a need for an evidence-based course development process that will leverage the curricular enhancement afforded by technology mediation via remote instrument operation. CEMAS, in conjunction with North Carolina Agricultural and Technical State University (NCA&T) and the Department of Engineering Education at OSU, is in the process of planning such a course development effort that, if successful, will lead to a new paradigm in both local and distance characterization education. Beyond the local environment, we will describe how CEMAS is installing TEM consoles across the state of Ohio using OARnet—the Ohio Academic Resource network. With the implementation of remote consoles at partner sites such as the Air Force Research Laboratory (AFRL), University of Dayton, NCA&T and Lehigh University, CEMAS seeks to demonstrate production quality remote operation, act as a hub for research and establish a model for a "hub and spoke" microscopy resources [9].

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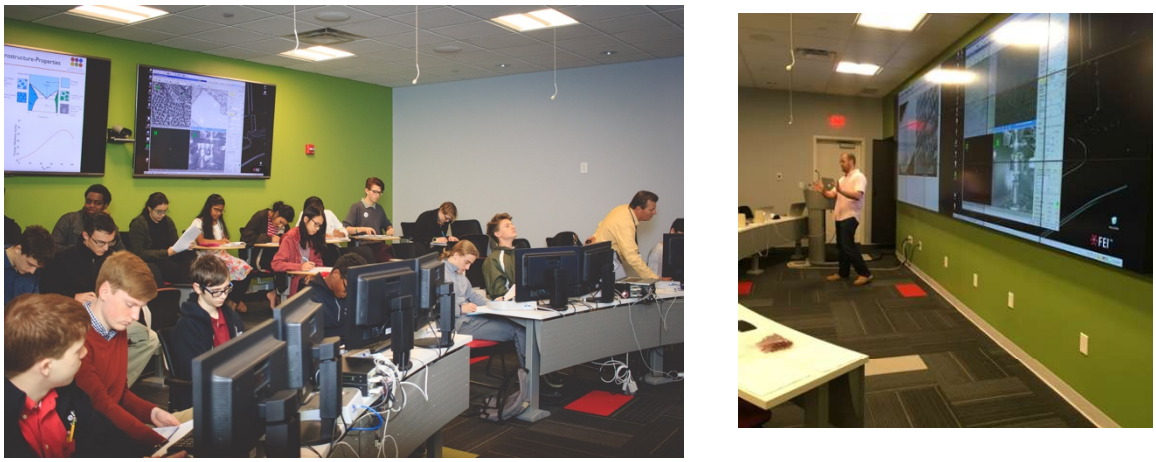

Figure 1. Images of the electron microscopy collaboratory space at CEMAS. Every instrument in the facility can be operated from this space, providing an environment for active and engaged learning of electron microscopy techniques. In built video conference technology allows the suite to be utilized for active research collaborations as well as remote educational opportunities.

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