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Teaching Microscopy Beats Analysis

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Elemental and chemical analysis in the TEM/AEM delivers spatial resolution below the atomic level (~0.2 nm). Analytical sensitivity is at the single-atom level, via both atomic-excitation (energy-loss) and atomic-relaxation (X-ray emission) signals. Now, imaging at the atomic level using EELS and XEDS is routine. Local determination of bonding (ELNES), atomic arrangements (RDFs via EXELFS), etc., is also on the single-atom scale (both MDM and MMF).

Such analytical performance was predicted for XEDS three decades ago [1] and measured two decades ago [2]. EELS single-atom detection was first reported almost 3 decades ago [3]. Combined spatial and analytical atomic resolution required advances in sources (reliable IVEM field-emission guns) lenses (with Cs corrector) and detectors (single-electron and SD) as noted in the appropriate chapters in [4]. Likewise, specimen preparation, always the limit to any TEM technique, has advanced to the point where reproducible specimens from specific regions of a bulk sample can be reliably produced. Integrated FIB/SEM systems (that cost more than AEMs did those same few decades ago) are now an essential component of any EM facility.

Such progress comes at a price. Figure 1 shows the fundamental dichotomy of increasing TEM cost as resolution improves. (Figure 1 tracks image resolution; analytical/spatial resolution has shown even greater improvements over the past decades.) Cost is only one challenge because delivering atomic resolution requires that the specimen be stable within a couple of Å during a typical data collection time (at least one coffee break [4] or longer [5]). Most EM facilities are built in existing buildings which are not designed to meet such stability specifications.

Extrapolating the cost/resolution curves in Figure 1 implies that, in the lifetime of most EM students today, the cost of fully equipped AEMs may exceed the annual budget of many colleges and even universities (~$50-100M). Such an extrapolation (*ad absurdum?)* leads to the inevitable conclusion that (unless a fundamentally different method of atomic-level imaging and analysis emerges) AEMs will invariably be located in a few centers which have to be accessed remotely.

With the current and projected costs of TEMs, teaching accessibility becomes an economic limitation. This imbalance is exacerbated because usually only one student at a time can learn the operation of a TEM/AEM. Teaching time thus reduces access to AEMs for research (hence the (somewhat forced!) title) diminishing income, causing heartache to deans and their senior fiscal officers. One approach to mitigate this is remote, parallel teaching of multiple students on one AEM. While remote access for teaching EM has been around for ~ 25 years [5], its application to multi-student teaching has been slower to develop. At CEMAS at OSU, we have pioneered this approach [6] and engage up to 30 students simultaneously (Figure 2) in learning to operate Cs-corrected AEMs. Thus remote, combined teaching and research EM centers are the way to educate future students so that they don't have to look up all the TMBA used in this paper [7,9].

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[9] DBW and CBC thank their students, postdocs, friends, colleagues and advisors with whom they have worked over the past 49 years. There may be TMB acronyms but never TM friends, colleagues or collaborators; in fact TM is *the* essential part of TEM.

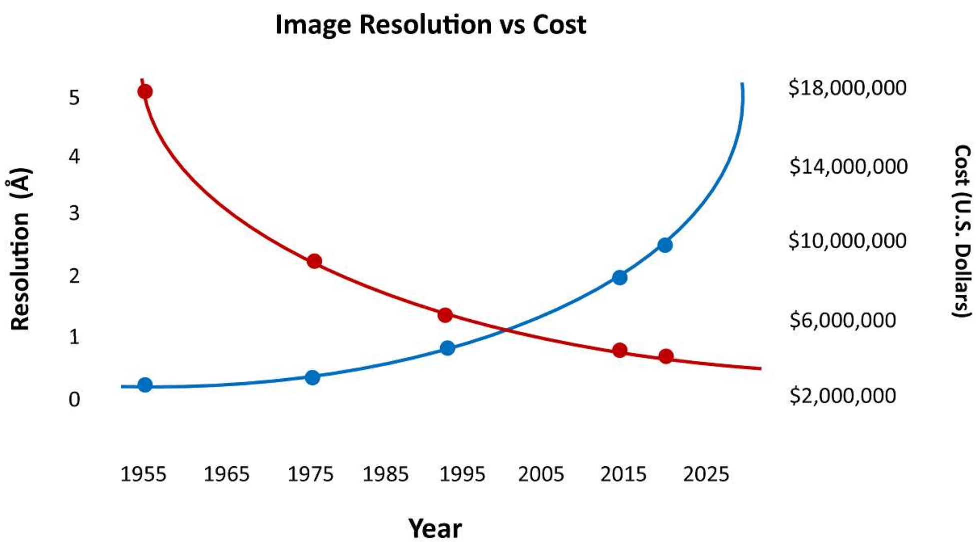

Figure 1. The trade off between improved TEM image resolution and cost.

Figure 2. Simultaneous hands-on TEM training of multiple students at CEMAS.

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