Project ExCEL: Web-based Scanning Electron Microscopy for K-12 Education

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Abstract
Project ExCEL (Extended Classroom for Enhanced Learning) brings the capabilities of scanning electron microscopy (SEM) into classrooms. University and industry personnel, working together, have developed a web-based interface to allow schools to control a modern SEM. The interface allows a user control of the operating parameters of the microscope, stage movement, and chemical analysis. Such total control is not available on any other system. Since Iowa State University (ISU) pioneered the idea of remote SEM for education, researchers have learned that providing teachers access to sophisticated equipment does not ensure that it will be used. Teachers are busy, and structured curriculums are not conducive for incorporating the SEM into classes. A lack of teacher knowledge of SEMs also discourages their use. To overcome these problems, College of Engineering and College of Education faculty are working together to train future teachers in the SEM. The web-based SEM is being used in education courses, and selected students (who receive additional training) prepare lesson plans and present their work to the class. In-service teachers receive instruction in the web-based SEM through workshops. By using this integrated approach, all science teachers in Iowa will eventually gain the confidence to use the SEM in their classrooms.

Keywords
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Disciplines
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Comments

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ABSTRACT

Project ExCEL (Extended Classroom for Enhanced Learning) brings the capabilities of scanning electron microscopy (SEM) into classrooms. University and industry personnel, working together, have developed a web-based interface to allow schools to control a modern SEM. The interface allows a user control of the operating parameters of the microscope, stage movement, and chemical analysis. Such total control is not available on any other system. Since Iowa State University (ISU) pioneered the idea of remote SEM for education, researchers have learned that providing teachers access to sophisticated equipment does not ensure that it will be used. Teachers are busy, and structured curriculums are not conducive for incorporating the SEM into classes. A lack of teacher knowledge of SEMs also discourages their use. To overcome these problems, College of Engineering and College of Education faculty are working together to train future teachers in the SEM. The web-based SEM is being used in education courses, and selected students (who receive additional training) prepare lesson plans and present their work to the class. In-service teachers receive instruction in the web-based SEM through workshops. By using this integrated approach, all science teachers in Iowa will eventually gain the confidence to use the SEM in their classrooms.

I. INTRODUCTION

Since its introduction into the university environment in the early 1960s, the scanning electron microscope has been viewed as essential scientific equipment with nearly unlimited applications for a wide variety of scientific fields. Whether students are studying biology, geology, botany, or any of the numerous engineering disciplines, the SEM can be a valuable tool in the classroom. With its ability to deliver crisp images with the appearance of three-dimensions at high magnifications, the SEM brought the microscopic world to the student in a way never before possible. Subsequent developments in computers and the energy dispersive spectrometer (EDS) have expanded the usefulness of the SEM by allowing rapid qualitative chemical analyses to be conducted with the touch of a button. However, while SEM development forged ahead, training in the use of the SEM remained stagnant. Being a single user instrument, SEM education typically consisted of either one or a few students standing in a dark room looking over the shoulder of an instructor while that person manipulated the controls of the instrument. This inefficient approach to SEM instruction remained virtually unchanged for nearly 30 years.

In the early 1990’s, the Materials Science and Engineering Department at ISU received NSF funding to develop new instructional methods for the SEM. Using a computer-based interface, an existing SEM was modified to allow control of the instrument from a series of remote workstations [1, 2]. This laboratory allowed a large number of students to simultaneously view the image using a series of TV monitors and a large-screen projector. A local area network gave students access to the operation of the microscope. Once it was shown that control could be given to remote workstations located near the SEM, the logical extension was to remotely view the image and control the microscope from locations a greater distance from the microscope. Experiments and demonstrations were conducted in which the microscope was operated by individuals removed from the ISU campus using modems and the internet. The success of this classroom was widely disseminated and the rapid development of remote control, computer-based microscopes began. Within a short time, most microscope companies were advertising remote control features, and ISU and several sites around the country had established laboratories whereby individuals, companies, and K-12 schools could access and operate an SEM using a computer via the internet [3, 4]. With the rise in popularity of the internet, the number of SEM sites has increased. However, while the number of sites has increased, the use of these sites, particularly by K-12 teachers who have expressed a high degree of interest in using the SEM, has remained extremely low. In examining this situation, it is evident that a number of problems must be addressed before remote control SEM will be utilized by in-service K-12 teachers to its fullest potential.
II. THE PROBLEM

In the early stages of remote control SEM development, it was naively assumed that providing access to extremely useful, high technology, such as the SEM, would result in its use by large numbers of K-12 teachers. This has not been the case. By working with in-service teachers, researchers at ISU have identified a number of problems that prevent widespread use of a remote-controlled SEM. These problems are not restricted to ISU and teachers in Iowa but are considered typical of the obstacles that must be overcome by many or all institutions and teachers to significantly increase SEM use by K-12 teachers. These are listed below.

1) Schools possess a wide range of computers and computer expertise. Many teachers are not skilled computer users and/or do not receive the technical support necessary to effectively use computers in the classes.

2) Teachers are not familiar with the SEM and do not understand how they can employ a remote control SEM in their classrooms. Some teachers may see no use for it while others have unrealistic expectations of what it can do and become discouraged when they learn the truth.

3) Teachers do not have the time to try new methods and experiment with a remote control SEM. They also may not have in-class time to conduct an SEM investigation.

4) Faculty and staff in the MSE department do not have the time to give the in-service teachers the instruction they require.

5) Faculty and staff of the MSE department have little or no professional knowledge about public education and the realities of K-12 teaching.

6) Schools possess little or no money to buy additional equipment or software.

7) Some teachers dislike technology and are apprehensive about using expensive equipment.

In evaluating these problems, it was determined that for remote control SEM capabilities to be effectively used at the K-12 level a more comprehensive approach needed to be taken to address these problems. Such an approach should incorporate a more global consideration of the problem and involve persons with professional knowledge about public education and teacher development and who are skilled in curriculum development. Thus, from the inception of this project faculty from the ISU College of Education, and particularly the Department of Curriculum and Instruction (C&I), were consulted and an integrated team approach was taken to address the problems.

III. THE IDEA—PROJECT ExCEL

Project ExCEL is an integrated approach to solving the problems outlined above by taking advantage of the strengths of the cooperating parties while building on the lessons learned from earlier programs. The basic premise of ExCEL is to establish a team of education and engineering professionals who will collaborate to extend the learning resources of K-12 classrooms beyond the traditional four walls. This team would then make use of technologically advanced equipment, such as the SEM, to design and conduct lessons in K-12 classrooms. The basic concept is shown schematically in Figure 1. Pre-service teachers from the ISU College of Education receive instruction in SEM principles as part of their normal curriculum. They then are teamed with MSE students who receive more extensive SEM training as part of their normal coursework. This team is assigned to work with an in-service teacher who is interested in using it in the classroom. The MSE student, the pre-service teacher, and the in-service teacher then work together to schedule and conduct a lesson. The MSE department would be responsible for maintaining the equipment and
scheduling the lessons while the C&I department is responsible for assessing Project ExCEL. In this way, continuous improvement of the teaching strategies and methodologies used are integrated into activities of a cycle year. Both departments would share equal responsibility in conducting summer workshops for teacher training.

Once fully established, Project ExCEL will be a self-sustaining, cyclic program. In the schematic in Figure 1, a number of “outputs” can be identified depending upon which part of the cycle a student enters. The ultimate output is students (future teachers and engineers) who better understand concepts of science and mathematics. Within the cycle, beneficial outputs include better prepared pre-service teachers, in-service teachers who have expanded methods by which to communicate concepts of science and mathematics, and future engineers who are more motivated to support their local school districts in providing science and mathematics instruction.

As envisioned, the entire project must involve the successful completion of three distinct phases.

1) Phase 1: The establishment of a web-based SEM laboratory. Such a laboratory would provide instructional opportunities to schools at the elementary and secondary levels at no cost to them and regardless of the type of computer equipment they may own. MSE students would be trained in the operation of the SEM and would be responsible for ensuring that the lessons conducted during the school year were scheduled and conducted in an organized manner.

2) Phase 2: The training of pre-service teachers in SEM through science teaching methods and instructional technology courses offered by the C&I department. Education students would receive instruction in the SEM and pass on this information to other students through class presentations. These students would also work with interested in-service teachers to develop lesson plans that can be integrated into the normal curriculum of the school. Working in cooperation with the MSE student, the pre-service teachers would assist the in-service teacher in conducting the lesson.

3) Phase 3: The offering of summer workshops for in-service teachers. Both the MSE and C&I departments would share equal responsibility in conducting these workshops. The workshops would be designed to provide science and technology education to in-service teachers in a number of areas, one of which would be materials science and SEM operation.

To assist in all phases of this program, a series of web-based instructional modules would be developed. Based on prior experience, the web-based material contains information such as instructional modules on SEM, pictures taken using an SEM, frequently asked questions, sample lesson plans, and other material that in-service teachers could adapt and incorporate into their curricula and classrooms. Initial efforts will be aimed at reaching classrooms in Iowa, with the overall goal being to advertise the program to schools throughout the country.

At the time of this writing Phases 1 and 2 are being implemented while Phase 3 is being conducted in a modified form, awaiting additional funding. The implementation of these phases is described below.

IV. IMPLEMENTATION

Implementation of Phase 1 of Project ExCEL began in 1998 with an NSF grant that provided the funds for the purchase of a new SEM [5]. The microscope chosen was the R.J. Lee “Personal SEM.” The decision to purchase this microscope was not based solely on price but also on the long-term education interests of SEM manufacturers. Because R.J. Lee has shown an interest in developing hardware and software for educational purposes since the inception of the project, the R.J. Lee “Personal SEM” was chosen for ExCEL. (R.J. Lee has contributed funds to employ students as web authors and they continue to develop the web-based control software in cooperation with ISU.) The “Personal SEM” is designed to be extremely user-friendly, making it much easier for students to learn how to operate it. This feature is especially important when bringing in pre-service teachers from the College of Education who may exhibit the same apprehensions noted from in-service teachers. The “Personal SEM” has a simple point-and-click computer interface. Since it is a low pressure SEM, there are no sample preparation considerations. A picture of the instrument is shown in Figure 2.

The SEM was purchased in December of 1998 and is currently in operation. Since the purchase, R.J. Lee personnel have been working with ISU to develop and refine the web-based software. The “WebSEM,” as it has been named, currently works on PC-based platforms using Netscape Navigator and on Macintosh computers using Internet Explorer. Access to the WebSEM is by means of a web page, which can be seen in its preliminary form at http://www.mse.iastate.edu/excel/. This web page currently provides general information about the WebSEM including the operation manual, tutorials aimed at different educational levels, a number of SEM images that are free to download and use, answers to some frequently asked questions, and connection to the WebSEM. When completed the web site will also contain suggestions for lesson plans, contact points of others who have used the WebSEM who can provide helpful information, and a schedule to allow a teacher to reserve time for a session. The first page of this web site is shown in Figure 3.

It is through this web page that teachers can gain access to the WebSEM. Access is controlled by a password that is assigned when a teacher reserves a session. Using this password the teacher can connect to the WebSEM, move the sample, change magnification, focus, and acquire elemental information using the x-ray detector. Images taken can be saved and downloaded to their computer after the session is completed. The WebSEM server accepts up to eight connections at one time; the first computer that connects to the WebSEM will have control while the remaining seven act as observers.

Implementation of Phase 2 began this past summer with a second NSF grant that is providing funds for introducing the concept of SEM into science methods classes in the C&I department [6]. The integration of SEM into teacher education courses will ensure that a cadre of new teachers possess the skills and experiences to effectively integrate SEM into science curricula. The incorporation is occurring in four courses: a science learning seminar, a science teaching methods course, and two instructional technology courses.

The integration of the SEM into education courses will occur at the sophomore, junior, and senior levels. At the sophomore level, pre-service teachers will first be exposed to the SEM in the course, Introduction to Instructional Technology (a required course for all education majors).

The purpose of this course is to develop students’ basic skills with information technology and to introduce pedagogical
Figure 2. “Personal SEM” from R. J. Lee Instruments referred to as the “WebSEM.”

Figure 3. Preliminary Project ExCEL home page.
considerations in the use of technology in learning. Taught in a large-lecture and laboratory format, students will observe a demonstration of the SEM in the lecture and engage in hands-on activities in the laboratory. Finally, the students will explore instructional strategies essential for implementing web-based lessons.

Also at the sophomore level, pre-service teachers will have the chance to learn about and use the WebSEM in the course, Learning Science. Taken concurrently with a science content course (e.g., geology, meteorology), the purpose of the Learning Science seminar is to help future teachers connect their learning of science to the teaching of science they will conduct. To that end, the seminar helps students to understand the nature of learning in scientific disciplines. In this course, the pre-service teachers will learn how to use the WebSEM and develop lessons that incorporate the WebSEM.

At the junior level, education students who choose to minor in educational computing (approximately 12% of education majors) will receive a more in-depth experience with the SEM in the course, Using Computers in Education. The sole purpose of this course is to develop students’ ability to design and implement technology-based learning environments for K-12 students. In this course, the pre-service teachers will develop proficiency in using the WebSEM and design and implement science lessons that effectively incorporate SEM. In addition, in this course the pre-service teachers will critique the WebSEM interface and provide feedback to the developers to refine the web page.

Generally completed the semester prior to student teaching, all elementary education majors (N = 1,000) enroll in the senior-level course, The Teaching of Science. The purpose of this course is to prepare future teachers to teach science to children. In this course, emphasis is placed on developmental implications, teaching processes, and discovery-inquiry approaches of science instruction. A “train-the-trainers” approach will be used to ensure that each pre-service teacher is knowledgeable in operating the WebSEM. This will be accomplished by selecting a cadre of pre-service teachers from each science teaching methods class. The group will receive direct training on the SEM and the web interface. As part of their involvement in the science teaching methods class they will train the remaining pre-service teachers in the use and operation of the system. Then, as part of the science teaching methods class (which students take concurrently with a teaching practicum), each pre-service teacher will serve as a WebSEM mentor to an in-service teacher. In this manner, the pre-service teachers will develop proficiency in the operation of the WebSEM, assist in-service teachers in designing lessons in which SEM activities are appropriate, and experience classroom use of the WebSEM with K-12 students.

The workshops proposed as the major focus of Phase 3 have been conducted on a small scale for the past four years. Since 1996, the MSE department has been conducting a one-day summer workshop for secondary science teachers. The workshop consists of lectures on materials science principles and concepts and two hands-on laboratories, one that covers the measurement of the elastic modulus of several materials and one on the SEM. Although not operational at the time, this past year the attendees were introduced to the WebSEM and the planned capabilities of the system. The system has also been introduced to secondary teachers attending workshops held by the Department of Chemistry as a part of Iowa Chemistry Education Alliance. From these preliminary efforts, several tests have been conducted and lessons are scheduled to begin in Spring 2000.

For the goals of Phase 3 to be fully implemented, a third NSF proposal is being planned for submission in Spring 2000. This proposal will be based on our experiences with the WebSEM and, if granted, will provide funding for the expanded summer workshops that are critical to the overall success of the program. The ideal workshop scenario is as follows. In-service teachers win be invited to the ISU campus and provided a stipend for attending a one-week workshop on the use of technology in the classroom conducted by the C&I department. As part of this workshop, the attendees will receive instruction on the theory of SEM and will be introduced to the capabilities of the WebSEM. Pre-service teachers who have received instruction on the WebSEM as part of their science methods classes will act as facilitators, as will selected MSE department students trained in SEM operation. Working together, the in-service, pre-service, and MSE student will develop a lesson plan based on the in-service teacher’s established curriculum that utilizes the WebSEM. The WebSEM will be used to conduct trial lessons that all the attendees will view, and the lesson plans will be shared among all the participants as a part of the workshop. The lesson plans also will be placed on the Project ExCEL web site for reference by other teachers. At the end of the workshop the attendees will leave having used the WebSEM and will have seen how it can be used in various classes. Tentative lessons will be scheduled for the coming school year and teams comprised of attendees and facilitators will conduct the lesson at the proper time during the upcoming school year.

If fully developed and funded as hoped, the integrated approach of Project ExCEL will address all of the concerns noted as problems in Section II. Having a web-based SEM eliminates, to a large extent, any proprietary hardware and software required by the schools. It provides the service at no cost to the school and greatly simplifies the operation of the SEM for in-service teachers. The summer workshops provide the time and training necessary for in-service teachers to become comfortable with the WebSEM. Introducing the concept of SEM into science methods classes assures that future teachers will already have an understanding of how it works and how the WebSEM can be used in the classroom. Many of these students may serve as facilitators for the summer workshops, giving them even more experience in using the WebSEM. These same students may use the WebSEM as part of their student teaching experiences, providing exposure of the capabilities of the system to in-service teachers who have yet to attend the summer workshops. In this event, the pre-service teacher may act as a recruiter to bring more teachers to the following workshop. In all cases, the benefits to pre- and in-service teachers are enormous. The benefits to the MSE department and its students, while less tangible, are just as great. By providing this service the MSE department receives valuable publicity among teachers and students, increasing name recognition and helping in recruitment efforts. The students that subsequently attend ISU come with some knowledge of SEM capabilities making them better prepared for engineering careers, such as MSE, that rely heavily on such instruments. Teaming MSE students with C&I students not only eliminates much of the workload from MSE staff but also has significant social benefits for the MSE students. By interacting with pre- and in-service teachers, MSE students will have a greater understanding of problems faced by professional educators. This will make them better citizens upon graduation and, hopefully, better parents, who are more willing to get involved in their local schools.
V. CONDUCTING A LESSON USING THE WEBSEM

A typical WebSEM experience would go as follows. The interested class or teacher first contacts the MSE or C&I departments to schedule a session. Ideally this will be a teacher who attended the summer workshop, but not necessarily. A preliminary date and time is agreed upon and a two-person team consisting of a pre-service teacher from C&I and an MSE student will be assigned as lesson facilitators. Once again, ideally these would be the same students who served as facilitators at the summer workshop. The students will contact the teacher, discuss lesson possibilities, and arrange to receive the sample or samples the in-service teacher wishes to observe during the lesson. The pre-service teacher can assist in the development or refinement of the lesson plan while the MSE student can provide more experienced technical assistance, if needed. An initial training session for the class instructor, held after school hours, is first conducted to assure that the connection works properly and that the teacher is fully aware of the capabilities of the system. If the results of this trial are satisfactory, a session is scheduled during class time for the students. When the students successfully connect to the WebSEM, they are presented with a page that contains all the controls on the left while the image is shown on the right, as seen in Figure 4.

Students have several imaging options. They can change the magnification, focus, brightness, etc, and they can also conduct EDS x-ray investigations. Images taken during the session are saved and can be downloaded to the school computer after the session is over. The web page shown in Figure 4 provides the most complete level of control possible and is intended for the upper secondary-level classes. A simpler page with limited controls is under development for elementary and lower middle school classes.

The state of Iowa is blessed by having the Iowa Communication Network (ICN), a high-speed fiber optic network that connects all of the schools in Iowa. As part of the ICN, each school has a classroom equipped for two-way audio/video communication. Schools can schedule times and connect to various sites and participate in distance education classes involving many sites. One such ICN lesson on the SEM involving three high schools has already been conducted, and others are planned. The use of the ICN for preliminary lessons provides K-12 students a personal contact and allows them to ask questions and interact with MSE faculty and students. This is then followed by the lesson where the students connect to, and operate, the WebSEM. A speakerphone in the WebSEM lab and the classroom permits communication during the course of the lesson so students can still ask questions and receive assistance if necessary.

![Figure 4. The control web page for the WebSEM.](image)
VI. SUMMARY AND CONCLUSIONS

Earlier efforts at ISU and elsewhere have shown that simply providing access to high technology equipment, such as an SEM, is not sufficient to ensure that in-service teachers will make use of the opportunity. An integrated approach that provides SEM instruction for in-service as well as future K-12 teachers is required if K-12 schools are going to widely incorporate the use of remote control SEM into their established curricula. Project ExCEL seeks to address the problems that presently hinder widespread use of remote SEM sites. As part of this project, a web-based SEM, termed the WebSEM, has been purchased and software is being contributed by R.J. Lee Group to make it totally cross-platform and web compatible. Initial workshops have been held, and pre-service teachers in the C&I department have been introduced to the concept of a web-based SEM for use in K-12 classrooms. Preliminary tests and lessons have been conducted using the WebSEM and more are scheduled. Although still in its initial stages, Project ExCEL has already had significant success in increasing usage of the SEM, in raising the level of awareness concerning SEM capabilities, and in use among in-service and pre-service teachers. Should the program be fully funded as envisioned, Project ExCEL will have a significant impact on science education in the state of Iowa and, hopefully, around the nation.

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