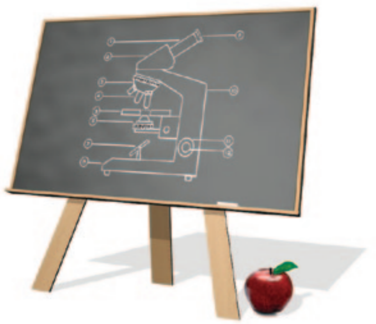
MicroscopyEducation

Bugscope: Online K–12 Microscopy Outreach



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Introduction

Bugscope is a free online microscopy outreach program that offers K–12 classrooms anywhere in the world the ability to remotely operate a high-resolution scanning electron microscope, collect images of insects and other similar arthropods, and chat simultaneously with a team of scientists. It was conceived and implemented in the late 1990s when K–12 schools were beginning to gain broadband Internet access, many as a result of the Telecommunications Act of 1996. One of several projects that took advantage of this opportunity to use the Internet to bring the laboratory into the classroom, Bugscope began as an NSF grant to purchase a field-emission scanning electron microscope and develop sophisticated client and server software to control it via a standard web browser. Inspired by the success of and lessons learned from the Chickscope remote magnetic resonance imaging project [1] and from having successfully established remote web-based control of a transmission electron microscope, Clint Potter and Bridget Carragher created the Bugscope project [2] with the goal of developing a remote microscopy educational outreach project that would be sustainable over the long term. This goal led to two significant design decisions. First, the software involved in setting up and running the live outreach sessions was purpose-built to ensure that only one staff member, if necessary, would be required at the instrument (as opposed to Chickscope, which required staff at the remote location as well as at the instrument). Second, students from a local high school would be employed as a renewable resource to help with pre-session sample preparation and to participate in live chat, answering questions from the remote classrooms. Although we now operate with permanent staff at the instrument, these efficiencies in the original concept/design have allowed Bugscope to operate continuously since March 1999, long after the original funding was exhausted.

The goal of the Bugscope project today is to continue its service of public engagement by bringing research-grade scanning electron microscopy into classrooms around the world. Electron microscopes are nearly as scarce in primary schools as they were in 1999, so the opportunities provided by the project are just as relevant now as they were when Bugscope started. In the intervening twelve years, however, many changes have been made to the Bugscope software to take advantage of the latest technology: adding features and further simplifying the setup and control of the live sessions. Emphasis has been placed on refining the process of classroom participation, particularly the intuitive operational logic applied to the user interface, and key examples of this are discussed below.

Twelve Years of Successful Operation

Reflecting on twelve years of Bugscope sessions, it is safe to say that the project has been a success. We have run over 580 live sessions and amassed a database of 120,000 microscope images, with 230,000 lines of chat text. Although the majority of live sessions have been with classrooms in the continental U.S., we have hosted participants from Asia/Southeast Asia, Australia, Hawaii and Alaska, Canada, Mexico, South America, the UK, and Europe (we have yet to connect with Africa). Interest in the project, as evidenced by the rate of online applications, has continued to grow. Presently we receive about 160 applications per year, the majority of which we accept.

The reaction from participants has been strongly positive. Of the more than 650 proposals we have accepted and scheduled (past and upcoming), 350 have been from repeat participants. Several schools have unofficially adopted Bugscope into their curriculum, returning each year to use it as a supplement or grand finale to their coursework. We also have regular participants in higher education who use Bugscope to expose pre-service teachers to alternative educational tools for the classroom. Many of those pre-service teachers have gone on to use Bugscope in their own classrooms. The Bugscope project has never been actively advertised and continues to draw a steady stream of applicants through word of mouth. Responses to our feedback questionnaires and web traffic analysis indicate that the Bugscope project is actively published in educators' journals and newsletters; referred to educators by technology coordinators, principals, or other teachers; and provided as a link from a large number of educational resource websites.

Session Signup

A teacher initiates participation in Bugscope by filling out a short application, accessible from our website's home page (http://bugscope.beckman.illinois.edu/) with a single mouse click. An automatic email response with a session

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number and application details is then sent to the applicant. Because everyone on the Bugscope team receives a copy of the correspondence, we are able to respond directly if a query or particular request is made on the application. Our group secretary coordinates the scheduling of the session using the applicant's requested date and time, the reservation calendar for the scanning electron microscope, and the Bugscope calendar. A purpose-built internal website simplifies this process and automatically emails applicants with confirmation of their scheduling and participating instructions. We share the microscope with researchers who also have 24-hour access to it, and because of that limitation, the time it takes to set up and run a session, and our own schedules, we allow an average of two Bugscope sessions per week. We are as flexible as possible within those constraints, however, and on some occasions we may work with four or five groups of students (often they are classes) during a single session.

It is important to solve technical issues beforehand because the staff and microscope time invested in each live session are valuable, even if the school fails to connect. Therefore we have developed an automated online tool for testing the compatibility of a participant's computer and the capability of the school's Internet connection. Scheduled participants can access a web link that tests for the required capabilities and submits a report to our server, which we then check for problems before the live session. The latest version of this test can be run at any time of day and concludes with the opportunity for our participant to see the microscope interface and try out the chat feature.

Specimens

If the participating teacher has sent specimens, we open the package upon receipt to ensure that they are dry and ready to use. Sometimes specimens are folded into a sheet of paper and mailed in standard envelopes—smashed despite our recommendations on the web page for sturdy packaging; sometimes they show up as smelly half-liquefied mush in plastic sandwich bags; and sometimes they arrive well-packaged but alive, having eaten all or parts of their fellow specimens. We maintain a stock of insects/arthropods to use when participants cannot send samples or their samples are unusable. We recommend that participants sending aquatic or soft-bodied insects capture them directly into ethanol or, alternatively, vodka. After a few changes into 100% ethanol, we can critical-point dry such specimens, avoiding all or most of the shriveling and collapse of fine features that would be caused by air drying. In addition to keeping their compound eyes from deflating, critical-point drying female mosquitoes from ethanol often causes the skin-piercing components of the fascicle (the lancets or stylets, as well as the siphon tube, through which saliva flows one way and blood the other), which are normally out of view inside the sheath of the proboscis, to spring apart, providing impressive views of the siphon tube and the multiple serrated cutting surfaces (Figure 1). All specimens are affixed to a custom-made 1.75-inch-diameter aluminum disc by laying them on a thin layer of wet silver paint atop double-sided carbon tape. We mount most specimens either ventral side up or on their sides so the antennae, eyes, mouthparts, legs, and most other features are visible. With spiders we often remove legs that may obscure the chelicerae/fangs. The sample stub is then sputter-coated, with eccentric rotation, using two to three times the thickness of gold–palladium we would put on a research specimen; this of course helps minimize charging, especially in specimens with loosely attached scales, such as moths, butterflies, silverfish, mosquitoes, and a small number of weevils and beetles.

Setup for the Session

We reserve an hour of setup time on the microscope before the scheduled session plus an extra hour after the session in case the teacher would like more time or we have online visitors who might wish to try "driving" the microscope. The hour following the session is also helpful for teachers with an upcoming session who want to practice using the controls before their own sessions. During setup time we put the sample stub into the microscope, pump it down, turn on the beam, and perform the preliminary alignments. We set the microscope stage at its longest working distance, which obviously hinders our ability to achieve the best resolution, but this tradeoff allows students to see the whole body of a small insect and as much of the body of a large insect as possible, giving them a crucial sense of perspective. The resolution of the microscope is still good enough to provide satisfactory images of bacteria, pollen, and submicron-scale features such as brochosomes or the individual projections visible on moth or butterfly ommatidia. We start the Bugscope software on our server

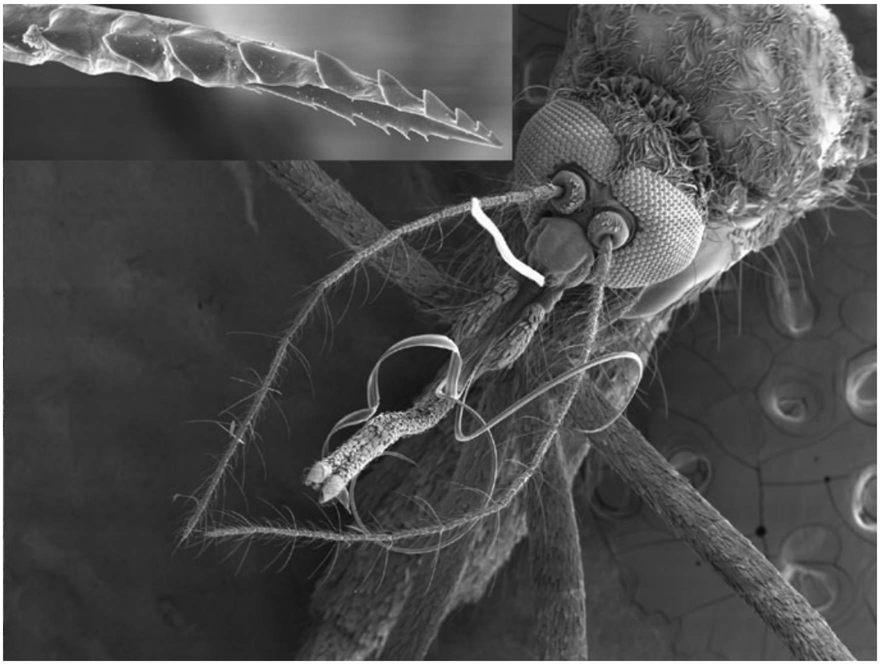

Figure 1: Female mosquito, critical-point dried from ethanol. The inset shows one of the four serrated stylets.

computer, establish a connection to the microscope, select the day's session, and begin imaging. Referring to a simple drawing of the sample stub, we locate each specimen and begin choosing suitably intriguing and/or "creepy" features to pique the students' interest: poison pores at the tips of a spider's fangs, the slashing mouthparts of a deerfly, a wasp's stinger, a flea's laciniae, a mite attached to an earwig—as well as bacteria, pollen grains, mold spores, diatoms, and brochosomes. These features are stored as "Presets" in the software by *x,y* stage position, magnification, focus (*z* stage position), contrast, and brightness, and they can be recalled with a single mouse click. Generally, 16 to 24 Presets are accessible during the session on the user interface as image thumbnails with brief titles ("Weevil Head," "Fruit Fly Haltere," "Ladybug Tenent Setae"). The Presets are intended as starting points from which our participants can use the microscope controls to explore their specimens. As soon as the Presets are done, we are ready for our connection.

Chat

Over time a tacit set of rules has evolved regarding how we handle chat. (Regarding the word "evolved," because of one interchange with creationist participants we are usually careful to let evolution speak for itself.) From the flurry of questions that arrive in the chat window, we can tell that students are excited, and they often miss/overlook our answers, asking the same questions repeatedly. Instead of berating them for not paying attention (although sometimes other students do), we try to present the same answer a different way, more fully, and sometimes several times. On our end, we compete informally to answer questions thoroughly, and we work with enthusiasm/humor that the students can pick up on and join into. If someone acts out during chat, we overlook it; there are always other students who want to learn. Sometimes a high-school student will type "This is boring." Instead of ignoring her, we might reply "Jennifer, would you like to drive?" This gives Jennifer the attention she might have been looking for plus a desirable role. After she is given control of the microscope, other students will clamor for the same opportunity. Every session (images and chat text) is archived and available for online review by participants as well as interested visitors. (Presently we are reformatting archived pre-2007 sessions, so they may not be immediately available.)

Certain components of the way we operate Bugscope may seem counterintuitive. Some people, often with no direct experience of the project, have asked us to support higher-technology forms of communication than the current text-based chat interface. They have suggested that audio or video chat might be more engaging and, with respect to video, that the students would like to see what we look like. Beyond the technical issue that Bugscope team members are often in different rooms or even different cities (and there is little space on the user interface for our faces), we believe that the passive style of chat in this context provides a better educational experience for the students. The Bugscope interface allows individuals or small groups of students to log in from different computers, as for example from a computer lab (and occasionally a student in a participating class who is out sick will log in from home). With this scenario, multiple students can ask questions at the same time, and our Bugscope team members can address unanswered questions in parallel. Because most connections last an hour or less, this allows us to answer many more students' individual questions, compared to each of us, plus the classroom members, taking turns asking/answering questions on video chat to avoid speaking over someone else. Perhaps more importantly, the asynchronous nature of text chat allows our Bugscope team members more time to quickly look up answers in online and offline references and better prepare their answers. Using text chat also allows participants to see the spelling of related technical terms, which they are then more likely to recall than if they had just heard the new words. It would also be difficult to archive synchronous video/audio chat with the images from the sessions. Finally, we believe that our text-based chat interface is more democratic in that students have the same opportunity to speak as Bugscope team members. With such an interface, we cannot monopolize the conversation; that is, if what we are typing is not holding the students' interest, they will have already asked a different question. We believe that the students recognize and welcome the freedom this gives them to direct the inquiry/discourse. (Regarding students' wanting to see what we look like, our photos are posted in the "Who Are We" link from the Bugscope home page.)

Future Possibilities

One path for future expansion of the Bugscope project might involve the inclusion of more microscopes from our facility, or from other facilities. Although the scanning electron microscope is distinctly well suited to the goals of Bugscope, Bugscope could also be ported to other microscopy modalities. A few years ago one of our participants sent in owl pellets, which we would normally dissect into their constituent parts (mostly rodent bones, skulls, and teeth) and lay out on the microscope stub. Because the scanning electron microscope was temporarily offline, we used x-ray micro-computed tomography to image the intact pellets and sent our participant teacher short movie files of the results. Thus her students were able to view 3D images of the contents of their owl pellets *in situ* until we had repaired the microscope and were able to provide a normal Bugscope session. This episode highlights our perception that the most successful microscopy modalities for inclusion into Bugscope would have modest sample preparation requirements, a capability for acquiring images quickly, and be visually engaging. Fluorescent light microscopy, for example, meets those requirements. Benefitting from the high degree of automation of today's equipment, students could control all of the microscope's filters, shutters, light sources, and even access images from different types of cameras, allowing educators a vast array of options for demonstrating concepts of optics, physics, and biology. It is notable that education outreach is a commonly required component of federal and state grant applications. Researchers seeking grant funding can participate in projects such as Bugscope as part of that obligation, bringing their unique advanced instrumentation and expertise to those projects and increasing the numbers of participants that could be supported. Thus far Bugscope has participated in several short-term examples of such programs.

Comparison with Other Approaches

The Bugscope project differs from many contemporary educational remote instrumentation projects in its use of a custom interface to the instrument. Most modern microscopes are operated through a computer interface, and generally that interface is a software program running on a desktop operating system such as Microsoft Windows or Linux. A simple option, then, for remotely controlling an instrument is to install and run a program that mirrors the instrument's screen to a remote computer while forwarding the remote computer's keyboard and mouse inputs. Many remote instrumentation programs use either off-the-shelf screen-sharing software or modified open-source software to suit their needs. The other approach to implementation of the remote control is to start from the application-programming interface (API), which permits primitive communication with the instrument, and build a customized interactive graphical interface. This path, taken by Bugscope, starts by initiating communication with the microscope to read and control individual parameters, such as magnification or focal working distance.

One primary consideration when choosing between these approaches is cost. By utilizing off-the-shelf software, screen-sharing requires very little development time and is therefore relatively inexpensive. In contrast, a custom software interface could easily require thousands of development hours, a full-time programming staff, and in some cases access to confidential documentation from the instrument manufacturer. Therefore it is not surprising that few educational projects have opted for a fully customized instrument interface. We were fortunate to have dedicated and experienced programmers when we started Bugscope, we had negotiated access to the machine code as part of the purchase of the microscope, and we have always had strong support from the microscope manufacturer. In return, the Bugscope project has benefitted greatly from its custom software. Screen-sharing software is ill-suited for documenting an imaging session, but Bugscope software can record every image, complete with metadata describing the microscope parameters and a full chat transcript. Screen-sharing software generally permits only a single client, whereas Bugscope software can support simultaneous image viewing and chatting from every machine in a computer lab while allowing control of the microscope to be passed effortlessly among participants. In addition, the custom controls restrict the ability of our participants to harm the instrument—an especially important requirement when sharing an instrument that is actively used by other researchers.

Despite the benefits described above, one strong argument for the use of screen-sharing technology is authenticity. Many primary and high education educators go to great lengths to expose their students to authentic scientific instrumentation. Screen-sharing, then, is an attempt to bring the instrument to the classroom when it is not feasible to bring the class to the instrument. Our choice to use a custom interface for the Bugscope project reflects the wide range in age of participants (grades K–12+) and the short 1- to 2-hour duration that most classes are able to reserve. We offer a more intuitive subset of the instrument's controls that are usable by younger participants yet powerful enough to permit serious inquiry by older participants. The Bugscope software is also used in nonpublic remote research applications.

The Payoff

During tours of the laboratory, we often describe Bugscope as "using insects and electron microscopy as a Trojan Horse to get kids interested in the possibility of science as a viable career choice." At the beginning of a Bugscope session, the students may ask "Why is the fly so hairy?" or "What are the claws for?" Later they may ask "Why isn't there color?", "How big is the microscope?", and "How does it work?" After that, they may say "Is the microscope easy to use?" When the students ask "What did you have to learn in school to be able to do this?" we begin to consider the session a success.

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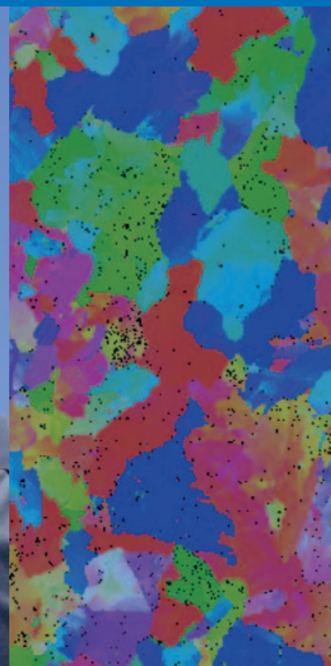

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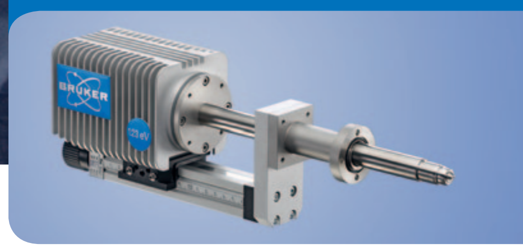

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