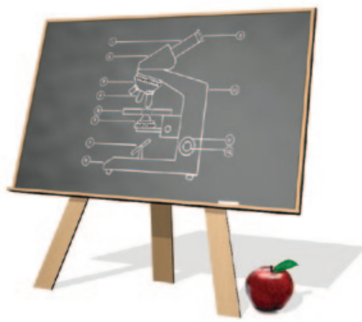
MicroscopyEducation

# Virtual SEM (VSEM)—Ongoing Development of Teaching Resources



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https://doi.org/10.1017/S1551929510000258 Published online by Cambridge University Press

## Introduction

In the last decade, microscopy has been successfully employed by a number of research groups as a means of instilling enthusiasm for science and technology into students of all ages, especially school children [1]. Remote microscopy (or telemicroscopy) and virtual microscopy (in the form of software simulators) continue to play important roles in these efforts and also in the teaching and training of new microscopists [2–4]. Such work and associated electronic teaching resources [5] have become prominent features of conferences such as Microscopy & Microanalysis.

Many of today's instrument operators are not microscopists by training or avocation, so they lack an in-depth knowledge of the fundamentals of SEM science and need more training to effectively use the instrument. If their instrument usage is sporadic, their skill retention can be poor, requiring their training to be refreshed. Heavy demands on instruments and instructors can reduce available training time [6].

Our own efforts in this area since 1998 include the development of the Virtual Scanning Electron Microscope (VSEM), a suite of Internet-based software to provide teaching and training to new and experienced users of the SEM (available free from www.virtualsem.com). This VSEM includes a simulator that reproduces the computer-based user interface of a real SEM and an encyclopedia of SEM-related scientific and operational theory, which can be delivered in stand-alone form or as resources that support courses hosted in a course management system.

## VSEM Simulator

There are a number of software simulations in existence that demonstrate the features of SEM operation [7–9]. Some of these use digital video sequences to show the changes that occur to a microscope image as a single control is adjusted. This approach is impractical for fully simulating an SEM's functionality because the number of images required to represent controls in combination becomes overwhelming.

The alternative to video sequences is to apply digital image filtering to a single real microscope image and by adjusting the severity and the type of the filtering, dynamically create simulated images representing the different settings. This also has the advantage that multiple adjustments can be performed sequentially to the same image—the same image can be "focused," "corrected for astigmatism," and have its brightness and contrast levels adjusted. Such cumulative effects do necessitate greater computing power in order to achieve the desired simulation quickly enough to maintain verisimilitude. Today's desktop PCs routinely exceed the necessary computational requirements for this level of microscope simulation, even despite the greater loads imposed by the latest operating systems. Likewise, improvements to the Java programming language in terms of just-in-time compilers and better Java Virtual Machines have made it possible to implement our VSEM simulator wholly in Java.

Efficient image filtering requires the convolution of an original image with suitable kernels. We have used both spatial domain and frequency domain (via Fast Fourier Transforms) convolution techniques. Spatial domain is fastest for small or simple kernels, whereas frequency domain excels at kernels that are more complex. Careful kernel choices have enabled us to demonstrate the effects of changing focus, brightness, contrast, and astigmatism in a realistic fashion.

There are limits to what can be achieved by filtering to "magnify" an image as the process quickly introduces pixelation artifacts. The only practical solution to simulate the effects of magnification and panning is to capture a series of high-quality micrographs, covering a region of interest, at the maximum required sample resolution. Using this "tiled image viewer" approach (similar to the techniques adopted by ITG VSEM [10] and iSEM [2]), the single large image is then broken down into much smaller tiles. A subset of these is loaded into the simulator's working memory to form the virtual image at the demanded magnification to be simulated and can be filtered as necessary.

We have used a version of the VSEM simulator to support the teaching of microscopy in an SEM practical that forms part of a broader final-year engineering undergraduate course on VLSI design ("4B7") at the University of Cambridge. Following a hands-on session with an expert microscopist, where small groups of students collectively investigate a silicon chip, students are required to use the VSEM simulator on their own time to obtain measurements of features on equivalent chip images for inclusion in the practical report. The students receive a username and password for the software, which they can then download and run on their own computers. The image files are too large to make dynamic real-time processing over the Internet viable for arbitrary server, client, and connection combinations.

 doi: 10.1017/S1551929510000258 

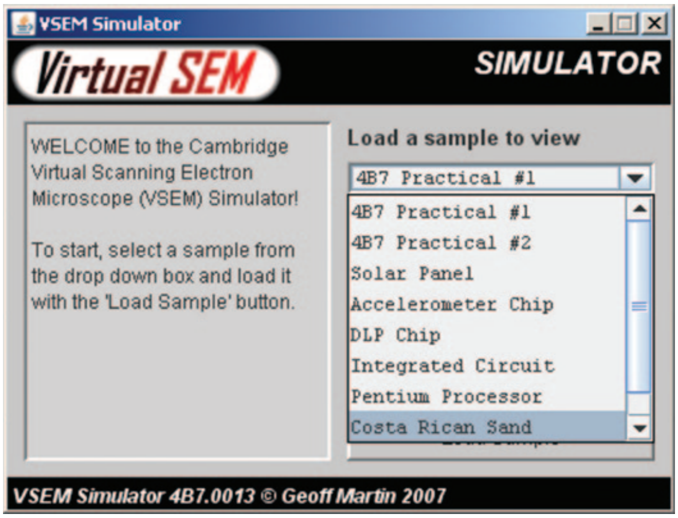


**Figure 1:** Choosing a sample from the VSEM Simulator.

On startup, a VSEM user will see a login prompt and must have a working Internet connection at this point to supply their credentials for authentication to the VSEM server (hosted at www.virtualsem.com). If all is well, the user can then choose which sample they wish to investigate (see Figure 1). The samples available are a mixture of samples generated at the University of Cambridge and those generated for the Imaging Technology Group Virtual Microscope, a component of the NASA-funded Virtual Laboratory Project. Once a sample is chosen, VSEM will pump a "virtual chamber" and switch on the "virtual electron beam." As the VSEM is intended to give users some training in microscopy operation, the actual instrument settings will then be randomized. It is likely that the user will need to adjust accelerating voltage and filament current (for saturation) as appropriate using the sliders (see Figure 2).

Switching from the "Sample/Vacuum/Gun" tab to the "Lenses/Stage" tab provides access to the key instrument controls simulated by VSEM. Clicking and dragging the relevant sliders for magnification, focus, astigmatism (*X*-axis), astigmatism (*Y*-axis), brightness, and contrast will enable all of these to be adjusted with the image updating in real-time. For simplicity, astigmatism is only simulated in the diagonal axes. Panning around the sample can be achieved using the "Stage Movement" arrows. See Figures 3 and 4 for before and after pictures.

The "Image" tab allows the user to investigate how frame averaging affects the signal-to-noise ratio of an image and to perform basic measurements upon an image, an essential component of the real microscopy experience and integral to our use of the simulator with undergraduate engineers. The "Scale Marker" button duplicates the static micron marker feature available on all SEMs, whereas the "Measurement Box" overlays the image with a set of measurement lines that can be adjusted vertically and horizontally to measure specific features in an image (see Figure 5). "Overlay Color" toggles the color of the measurement box and scale marker

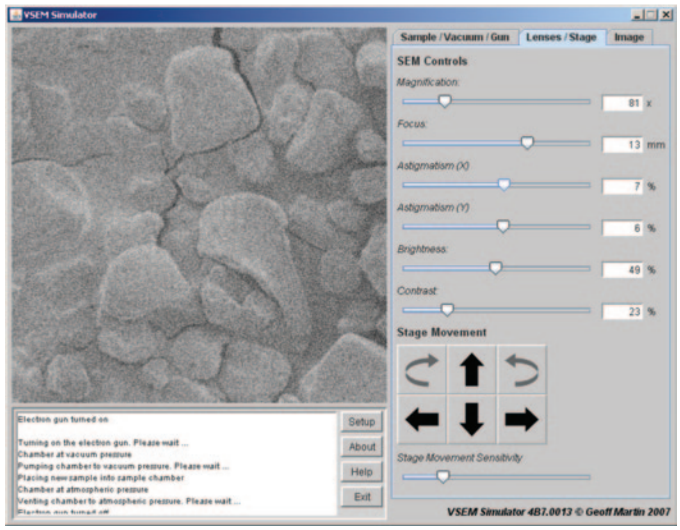


**Figure 3:** View of the Costa Rican sand (partially focused) and the SEM controls of the virtual parameter panel.

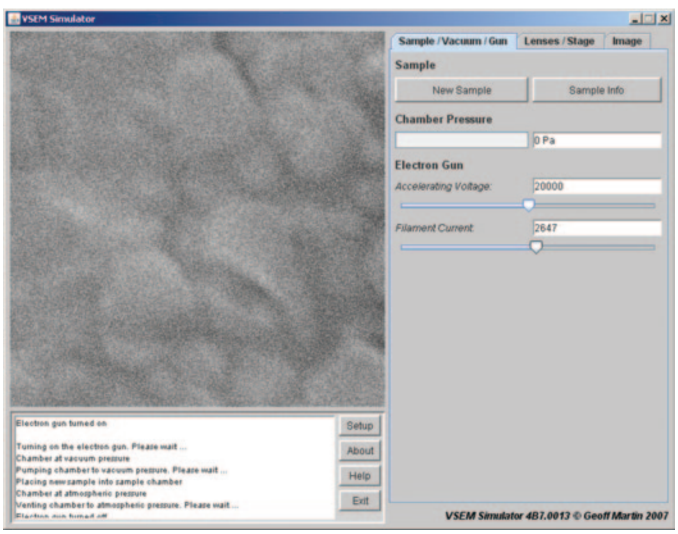


**Figure 2:** Initial unfocussed view of some Costa Rican sand prior to the user adjusting the virtual parameters.

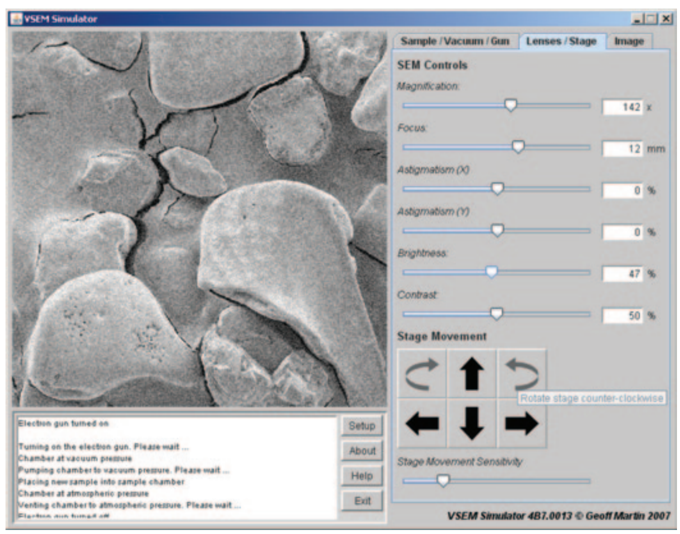


**Figure 4:** View of the same Costa Rican sand after the user has adjusted the virtual parameters. Note the presence of "virtual noise" in the focused image.

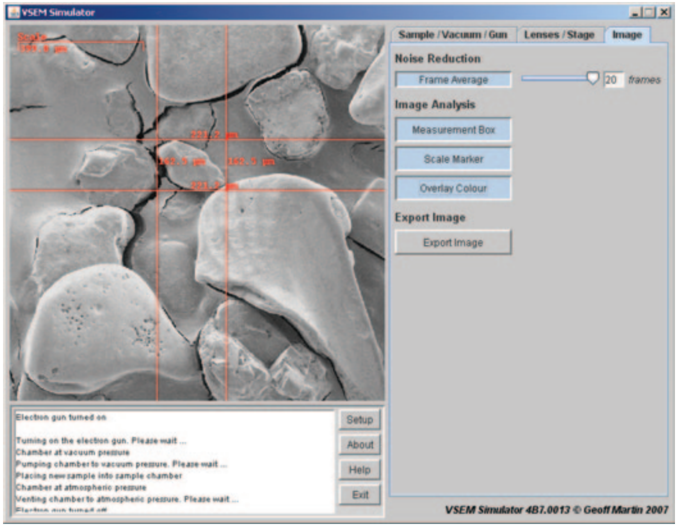


Figure 5: View of the measurement features available in the VSEM Simulator. Note the use of "Frame Averaging" to remove "virtual noise" from the image.

between red and green. "Export Image" enables the currently displayed simulated image to be saved as a gif file. If any overlays are on the image, they will be saved as part of the gif file. Our students use this feature as a means of providing evidence of their measurements, rather than merely quoting a number.

Underneath the image display panel is the feedback panel with information on which controls have been adjusted and what VSEM is currently simulating. In addition to online "Help" facilities, VSEM can also be configured via the "Setup" button. Via the Setup panel (see Figure 6), the degree of realism of the simulator can be configured, for instance, toggling the focus change relationship with accelerating voltage on or off or the need to pump and vent the chamber on sample changes,

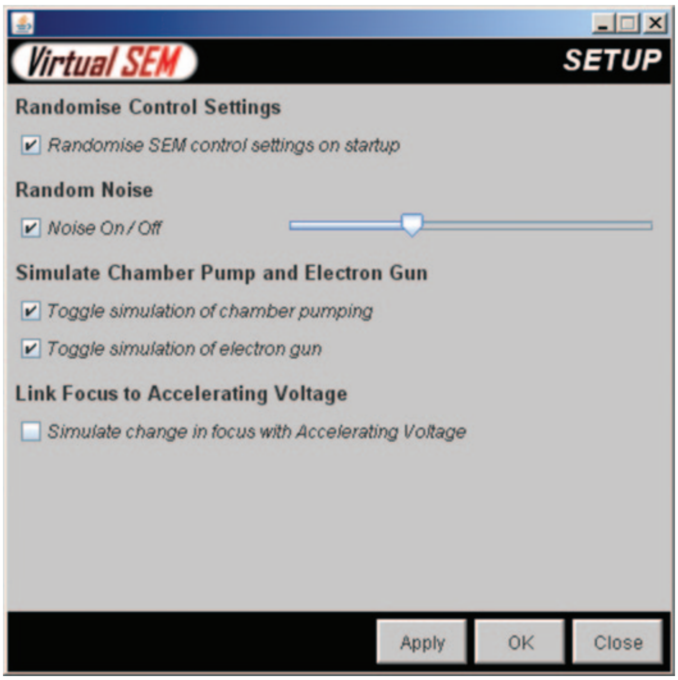


Figure 6: Configuring the VSEM Simulator via its Setup panel.

and the non-instantaneous nature of gun adjustments. The presence and severity of random noise injected into the picture can also be adjusted; this enables a user, for instance, to gain experience in focusing a clean, noise-free image first and then to practice focusing in the more difficult (and common) case of noisy images. Finally, the randomisation of control settings can be toggled on or off, giving users who have become utterly confused an opportunity to see what the image should look like.

## VSEM Encyclopedia

The second strand of our work in this area has been to support the teaching of microscopy theory through interactive online resources, organized into an encyclopedia containing text, images, and animations. This was initially developed using Adobe (then Macromedia) Director as the authoring tool because of its ability to combine diverse types of content into a coherent whole (see Figures 7 and 8) [6]. This original version of the encyclopedia was used successfully as a supporting resource


Figure 7: Initial startup screen of the Shockwave version of the VSEM Encyclopedia.

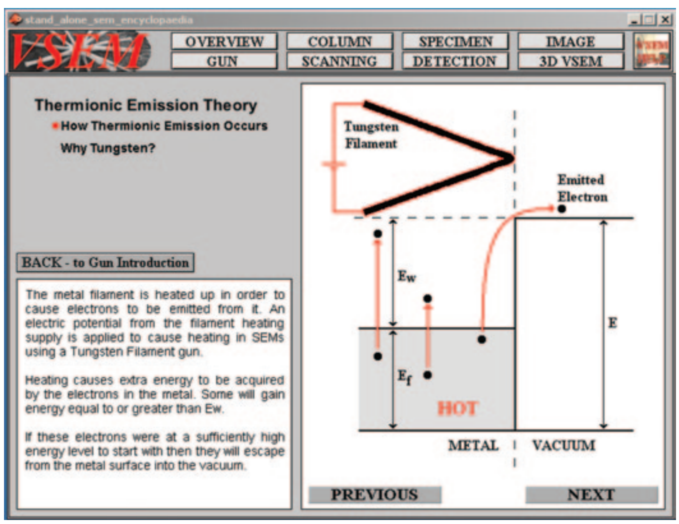


Figure 8: Typical page from the Shockwave version of the VSEM Encyclopedia—in this case explaining the process of thermionic emission.

for the 4B7 course. It does, however, have three drawbacks. The complete encyclopedia is a Windows-only executable program of significant size, which must be downloaded onto a user's machine. Secondly, the executable is fully self-contained and unable to communicate with other applications. Finally, all the content (text, images, etc.) are "hard-coded" within a presentational design, which is precisely customized to supporting that content in terms of layout. The first and third issues have been the most limiting in terms of distributing and maintaining the material.

Our most recent work has been to re-implement the entire VSEM encyclopedia as an Adobe Flash package. The individual images, chunks of text, and specific animations were extracted from the original version, and some material was split into smaller pieces to improve accessibility and maintainability. The new Flash encyclopedia loads into a browser window in the form of a "master" Flash "movie," which in turn downloads required content from the server (or hard drive) and displays it inside itself. As the user navigates around the encyclopedia, new data is continually loaded and displayed on-screen (see Figure 9).

The actual textual content of the encyclopedia is now stored in human-comprehensible XML files (one per "page"), which contain links to distinct associated images and Flash animations as well as general instructions for the layout of the page, achieving a substantial separation of content and presentation. Every page update involves the use of three XML files: pageList.XML, sequences.XML, and the actual XML file for the page content itself. pageList.XML lists the unique page ID for each page, its associated title, and a directory path to the page content file. sequences.XML lists the sequence of page numbers per section, dividing up the encyclopedia into a number of chapters of related content. The master Flash movie interprets this file to enable (or disable) navigation buttons and set their target destinations. Each encyclopedia XML content page defines the page layout (allowing up to two text boxes and/or two Flash submovies or images to be embedded and positioned in the main movie), the textual content, and file

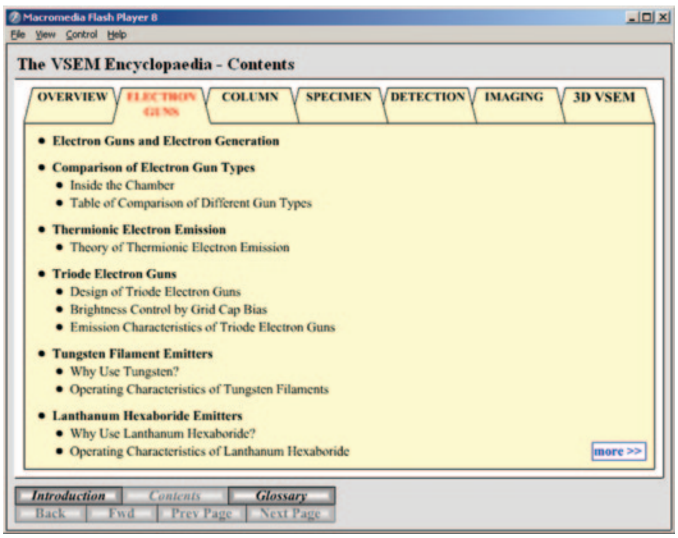


**Figure 9:** Part of the table of contents for the Flash-based version of the VSEM Encyclopedia. Each of the entries is a clickable link to a page or more of material on the topic.

paths to external media. The XML files also potentially allow customized information to be made available for the same encyclopedia page; for instance, differentiating according to user knowledge level, for example "beginner," "intermediate," and "advanced."

The VSEM encyclopedia's glossary is a searchable list of terms, stored in a distinct XML file. VSEM uses a Flash feature to dynamically create and embed hyperlinks within a text box. A function was written that automatically creates a clickable link out of any glossary term found in the explanatory text. Clicking on a highlighted term triggers a floating dialog box containing the glossary definition.

This hybrid XML/Flash approach resolves the distribution issues because it can be run in a web browser over the Internet or from local copies on a hard drive, as well as directly from the desktop. It also has the advantage of simpler code and vastly improved maintainability; almost all corrections or improvements only require modification of the XML files. There are two disadvantages to the new VSEM encyclopedia—one aesthetic, the other practical. The generalized and less granular nature of the new layout means that not all pages are as aesthetically pleasing as their Director Shockwave counterparts (where individual elements could be precisely positioned). A different design might have included more content panels. Practically, Flash lacks comprehensive support for using HTML tags and character entities (for example, for mathematical symbols) in imported XML files, so some compromises in the formatting and presentation of content were necessary in order to ensure all the XML files were readable by Flash.

The new encyclopedia provides material on electron guns, focusing and adjusting the electron beam via the column lenses, sample preparation, sample emission, signal detection, and image formation (see Figure 10 as an example). It is already being used to support microscopy teaching within the authors' institution and is being made freely available on the Web.

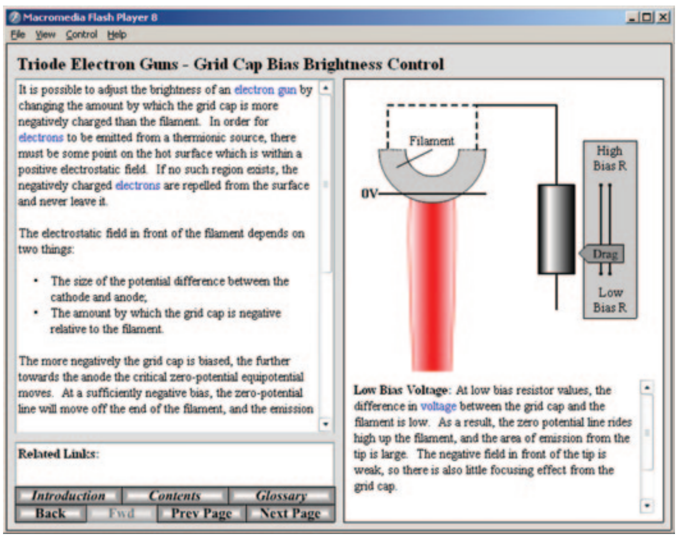


**Figure 10:** A page from the Flash-based version of the VSEM Encyclopedia on the topic of grid cap bias control for triode electron guns. The animation in the right-hand pane allows the user to adjust bias resistance and view the resulting effects on the electron beam and its crossover.



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## VSEM Within a Course Management System

The VSEM simulator and encyclopedia are intended to form parts of a comprehensive teaching and training system. The educational software community has created many course management system (CMS) packages, specifically designed for online teaching. We have incorporated both simulator and encyclopedia into course modules using the Moodle CMS (an open-source, PHP/MySQL implementation). Although we have experimented with enabling both the simulator and encyclopedia to be directly used for assessment purposes within a Moodle-based course, the file and security architectures of Moodle make it difficult for multiple courses to access the same resource (without duplicating the resource or unsecuring the content). Moodle's own lesson delivery mechanisms offer limited support for scripting between resources for assessment [11].

We still use Moodle on the VSEM site to deliver electronic copies of practical handouts and to serve as a repository for micrographs generated during the practicals. We also use the Moodle server to authenticate users of the VSEM simulator.

## Conclusions and Future Work

Both the VSEM Simulator and Encyclopedia are used within the Department of Engineering's 4B7 course at the University of Cambridge. Evaluation copies have been provided to postgraduate students and postdoctoral researchers within the department and interested parties outside the university. Over a hundred evaluation accounts have been issued, and readers of this article should visit www.virtualsem.com to obtain their own account.

VSEM has been successful in helping to introduce undergraduates to the SEM and giving them a better appreciation of the microscope than would otherwise be possible. It also relieves the pressure on real instruments for training and provides a resource to develop the new user's understanding of SEM science.

Having invested the effort in content extraction for the reimplementation of the VSEM encyclopedia, our ongoing and future work will involve the creation of a microscopy-based teaching wiki using the encyclopedia content as a basis and allowing registered users to contribute additional material in their specific areas of expertise.

## Acknowledgments

Much of this work was undertaken by Dr. G.C. Martin as part of his doctoral research, which was funded by an EPSRC Studentship through the Department of Engineering, University of Cambridge, UK. The authors would also like to acknowledge funding from Carl Zeiss SMT, which has enabled dissemination of this work through presentations at conferences.

## Use of ITG Images

The Cambridge Virtual SEM Simulator uses sample images from the Beckman Imaging Technology Group (ITG) Virtual Microscope, a joint project of the Imaging Technology Group (http://virtual.itg.uiuc.edu), Beckman Institute for Advanced Science and Technology (http://www.beckman.uiuc.edu), and the Institute for Genomic Biology (http://www.igb.uiuc.edu)—both at the University of Illinois at Urbana-Champaign. More information about the ITG Virtual Microscope is available at http://virtual.itg.uiuc.edu.

The ITG Virtual Microscope and its supporting materials are components of the Virtual Laboratory Project funded by NASA through the Kennedy Space Center Education Office. The NASA Virtual Lab software, targeted towards high school students and undergraduates, is also available for free download at http://www.nasa.education.ucf.edu/cogs.

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