Microscopy and precise scientific observation are essential skills that are difficult for students to develop and even harder for their teachers to assess. Yet students must have these skills in order to succeed in most organismal biology laboratories. This conflict commonly creates two student-learning challenges that teachers must confront. Hurried or frustrated students may glance through the microscope with little critical consideration of their observations. More deliberate students may have difficulty articulating questions about their perceptions, and teachers may not be able to adequately assist them. In our experience, hand-drawings produced by both types of students may be unintelligible, proving that they received little benefit from their observations, and may also be challenging to critique well.

Incorporating student-driven digital imaging in microscopy improves the learning outcomes of both types of students in several ways. It builds all students’ technical skills by requiring them to produce incontrovertible proof of their ability to refine image quality (i.e., the digital image), to determine magnification levels, and to consider the section and preparation type of the material in view. These ancillary data can be included along with the image in written reports, and this requirement can compel students to be more deliberate. The process of working with digital images in written reports builds other essential skills, such as the ability to edit images in word-processing software, to follow formatting conventions for standardized scientific communication, and to formally acknowledge others’ intellectual contributions in the form of photo credits. Digital imaging also promotes student engagement and communication, and viewing large color images on computer screens allows students to share, explain, and question their observations with each other and the teacher. Furthermore, digital imaging is an immediate and exacting assessment tool for microscopy. During labs, teachers can assist students with their ongoing microscopic observations by viewing images together. Later, the precise written records of

Microscopy and precise scientific observation are essential skills that are difficult for students to develop and even harder for their teachers to assess.

HOW TO DO IT
Making Microscopy Motivating, Memorable, & Manageable for Undergraduate Students with Digital Imaging Laboratories

ANDREA WEEKS, BEVERLY BACHMAN, SARAH JOSWAY, BRITTANY NORTH, MIRIAN T. N. TSUCHIYA

Abstract
Microscopy and precise observation are essential skills that are challenging to teach effectively to large numbers of undergraduate biology students. We implemented student-driven digital imaging assignments for microscopy in a large-enrollment laboratory for organismal biology. We detail how we promoted student engagement with the material and how we assessed student learning in both formative and summative formats using digital images. Students worked in pairs to collect over 60 digital images of their microscopic observations over the semester and then individually created electronic portfolios, which were submitted for a grade.

Key Words: Active learning; digital cameras; microscopy; teaching with technology; organismal biology.

Much has been written over the past decade about the pedagogical value of digital imaging for enhancing student learning in biology. As the costs of this technology have declined and placed this tool within reach of many faculty and their students, digital imaging has been used to augment a range of courses, from field biology (Jenkins et al., 2003) to biotechnology (Norflus, 2012). However, published case studies in which students must generate their own digital images and teachers must assess them tend to focus on only low-enrollment courses that permit greater time for individualized instruction (Watson & Lom, 2008; DiBartolomeis, 2011; Jackson et al., 2012; Modery et al., 2012). At George Mason University, we have successfully transitioned from using student-driven digital imaging in such low-enrollment courses to high enrollment core courses (>160 students) in order to provide more effective and engaging laboratory experiences for a greater number of students (National Research Council, 2003; AAAS, 2011). Specifically, we use digital imaging to improve our students’ understanding of the structure and function of organisms through microscopic observation.
each student’s observations can be graded objectively and the images can be used in reviews and examinations.

Here, we describe how we implemented digital imaging assignments for microscopy for BIOL 310—Biodiversity, an undergraduate laboratory core course in organismal biology; how we promoted student engagement with the material; and how we assessed student learning though digital imaging. The course is required of all our biology majors at the sophomore to senior levels and comprises multiple laboratory sections each semester (8–10 sections of 22 students taught by 4–5 instructors). During twelve 2.75-hour laboratory meetings, students work in pairs to collect 63 digital images of their microscopic observations. Students then individually create electronic portfolios of their work, which they submit for a grade. Our teaching methods are broadly transferable to other institutions, such as high schools. Most importantly, our teaching methods are not necessarily dependent on the type of digital imaging equipment used by the students, although we list our materials in detail below for convenience.

**Materials**

- Compound or dissecting microscopes with removable oculars or C-mount.
- Tucsen 3.0 MP CMOS TCA-3.0C digital camera, model C30; image resolution: 2048 × 1536 pixels; video streaming 8–30 frames per second; USB 2.0 computer interface; includes C-mount and ocular-insert adaptors; cost, $230 (price quote February 2013; http://www.onfocuslaboratories.com).
- TSView software (version 6.2.3.3) and driver, included with camera.
- PC computer (Windows 2000, XP or Vista OS; Intel Pentium 4, 2.6 GHz processors) with at least 512 MB RAM, 10GB HD, and one USB 2.0 connection.

**Student & Teacher Procedures**

Digital imaging is introduced to students during the second laboratory, as microscope training occurs during the first session. Each pair of students shares a Tucsen digital microscope camera, which is transferable between compound and dissecting microscopes and is controlled via a USB 2.0 computer interface and the TSView software program. Students are given the option of using them with the desktop computers in the lab or with their personal PC laptops. Students who use their laptops are given a copy of the software and drivers and coached through the correct installation procedures. Instructors then walk students through the process of configuring the software, controlling image quality, and managing the electronic image files using prepared whole-mount slides of diatoms. Students are prompted to take an image of diatoms, and of all other items over the course of the semester, by bold italicized text in the lab manual, for example, “DIGITAL IMAGE 1. Image of a diatom with 4X obj., labeling a silicon dioxide test.” The step-by-step imaging directions adapted from the software manual (available from author upon request) are also are provided in the lab manual.

Once the instructor has verified that all students have collected the diatom image successfully, he or she trains students in how to prepare the digital image portfolio. Students download an MS Word document template from the course’s Blackboard site. They then learn how to insert their diatom image into the Word document, how to reduce the image height to 2.5 inches, and how to use the drawing tools to insert arrows and text boxes to label the structures required by the directions in the lab manual. The teacher also reviews the written guidelines and the accompanying checklist for constructing the portfolio, which are provided as appendices in the lab manual. The training takes a total of 30–45 minutes.

**Engagement Strategies**

We have found that after the initial camera training, most students are able to collect high-quality digital images of their microscopic observations (Figure 1). Our students readily consult each other to resolve hardware or software problems that may arise and, more importantly, discuss the content of their microscopic images at length. Students are required to purchase a biological photo atlas

![Image from Lab 3, Digital Image #1. Coleus shoot leaf primordium, shoot apical meristem and axillary bud primordium. 20X total magnification of a prepared longitudinal section. Photo credit: Ruth and Elizabeth](https://example.com/image.png)

**Figure 1.** Example of a student-collected digital image showing microscopic observations and ancillary data as they are presented in the image portfolio assignment.
and use this reference extensively in class. However, constructive student–teacher interaction is far greater than it was before the introduction of digital imaging. Not only do students ask questions about their observations, but instructors can ask students to explain the image on the computer screen.

Not surprisingly, many students develop a strong sense of pride over the aesthetic quality of their images. Holding a contest among students for the best pictures can encourage this level of engagement. For example, in a previous course, we held a competition at the end of the semester to create a course calendar (Figure 2). Students were invited to submit their two favorite images and then voted to select the top 12, one image for each month. The winning digital images were submitted to an online photo-printing service, and students were able to purchase a photo calendar of their work as a memento.

**Assessment of Student Learning**

Student-driven digital imaging allows instructors to use both formative and summative assessment strategies to improve student learning via microscopy. As students are engaged in lab activities, instructors ask students to take them on a tour of the current image to locate and describe the functions of specified structures. Quick formative assessments like these low-stakes explanations give the instructors immediate feedback about student comprehension. Instructors can then identify knowledge gaps and modify teaching strategies to increase understanding. After students have completed each lab, they take a formal exit quiz. These summative assessments, which are worth half of the lab course grade, test student mastery of the cumulative lab unit and usually include questions that require students to label and define structures from images taken during lab. Including images on the quizzes not only tests student comprehension of the material, but also encourages students to carefully and thoroughly examine each slide and the specified structures while working through the lab.

Collecting, processing, and assessing the images for the digital image portfolios does take time, and we have learned how to avoid making these exercises burdensome. First, we limit the number of required images per laboratory in BIOL310 to less than 10 in consideration of the time that it takes students to collect high-quality images. Second, portfolios are submitted only at the middle and end of the semester but carry a significant graded weight to make their necessary effort worthwhile. They account for 20% of the lab course grade. Lastly, although students collect 63 images over the course of the semester, we require students to include only eight images in each digital image portfolio – seven of the teacher’s choice and one of the student’s. This strategy increases the quality of assignments, reduces the grading load, and preserves the pedagogical value of creating all of the images during laboratory, because students are not told which images will be required for their portfolios until after the laboratory has ended. Each laboratory section is assigned a different set of images as well, which reduces the opportunity for plagiarism. Students then format each required image with clearly labeled structures, a descriptive legend with ancillary data about the image including photo credits (Figure 2), and textual definitions of the labeled structures below the legend. Students upload their completed
portfolio to Blackboard, and instructors grade them using a rubric (Table 1) that evaluates each student's skills of microscopy, scientific observation, and understanding of the material in view.

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Table 1. Grading rubric for digital image portfolio, with point values for each criterion and overall weighting of style and content categories.

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