Recently Mills et al. (2001) described how a Pixera Professional digital camera and associated equipment could be used effectively in a microbiology class to assist students in capturing macroscopic and microscopic images of yeast and bacteria found in wine. Mills et al. (2001) showed that the digital equipment and techniques released students from the time consuming task of hand drawing what they saw in the eyepiece of the microscope and also produced computer files that could be made available to students as prints, images on web pages, CDs, etc. to review and reinforce what had been seen previously in the laboratory. The rapidity with which images could be taken and the ability to generate an archive of images as a teaching resource also were shown to be significant advantages to such a system (Mills et al. 2001). Their study clearly demonstrated that a digital system could be used effectively in many biology classes using microscopes.

Although the Pixera (and similar digital imaging systems) works well in the laboratory situation described by Mills et al. (2001), it is a relatively low resolution system by recent standards (1.2 megapixel). It is not designed as a stand alone camera, and cannot be taken outdoors for use on activities such as field trips.

Many recent digital cameras and some associated equipment can be readily and effectively transported and used in classes having both indoor (e.g., with or without microscopes during laboratories and lectures) and outdoor (e.g., without microscopes on fieldtrips) activities. Thus, many classes that involve studying both the micromorphology (e.g., fungal spores) and macromorphological or ecological (e.g., mushrooms growing in the field on a log) aspects of organisms could use a digital imaging system that is versatile enough to be used in any classroom situation.

The objectives of this article are to describe how I have used a digital camera and associated equipment in classes having both indoor and outdoor activities and to provide information about and suggestions for selecting basic equipment (i.e., digital camera, microscope adapter and heat laminator) for that purpose.
Equipment and techniques described in this article should work equally well in any class, elementary through university level, where specimens of nearly any nature are studied (e.g., biological specimens, rocks, fabrics, circuit boards, etc.).

An Example — Spring Creek, an Unknown Fungus & Digital Imaging

I begin each semester in my general botany class with investigative exercises of organisms that help to explain and emphasize to students the importance and interrelationships of the concepts of terminology, description, identification, classification and biodiversity. We initially examine, both microscopically and macroscopically, representative specimens of phyla that can include bluegreen bacteria, green algae, fungi, lichens, mosses, ferns, seed plants, and an occasional heterotrophic protist (e.g., Vorticella this semester). This acquaints students with the basic traits and features of each group (mainly the autotrophs and fungi) so that they can quickly recognize and understand the organisms around them at least to the phylum level. I stress to students that regardless of whether they intend to become botanists or brokers, they will not be able to effectively communicate with their peers, or perhaps clients, about the environment without a good knowledge of these concepts.

In relating these concepts to students in general botany, I have always included field trips in order to demonstrate the role and importance of plants, fungi and algae, and also to provide the opportunity for "hands on" contact with the organisms in the field, Toxicodendron radicans excepted. Although most trips are limited to the campus or immediate area, I generally schedule at least one more extended trip (i.e., 30 to 50 miles distant) to a wooded stream or similar locality. Weather permitting, these trips have provided some of the best and most unique learning experiences for both my students and me.

In recent years, we have taken the extended field trip to Spring Creek, a small perennial stream about 45 miles from our campus in central Kansas (http://www.hku.edu/biology/thomasson/SpringcreekSOI/velvet.html). Mats of algae such as Spirogyra and Cladophora are often abundant in the creek, and it is surrounded by a woody riparian community that includes elm, oak, hackberry and walnut trees, and shrubs and vines such as honeysuckle, coralberry, poison ivy and moonseed. Usually, it is possible to find and observe various fungi on the ground in the organic leaf litter or on trunks or branches of living and dead trees. The woody riparian element thins to nearby grassy slopes that extend a short distance and are surrounded by rust colored, iron rich bluffs of Dakota Sandstone that are replete with a remarkably diverse assemblage of ferns, lichens and mosses.

During one botany field trip (on January 24, 2001), we noticed vigorous toadstools growing at the base of a hackberry stump. Like members of the class, I was surprised by the discovery because the weather had been snowy and bitterly cold, with temperatures well below freezing on a number of occasions just prior to our trip. However, I proceeded to explain to the students how even in the dead of winter the mushrooms served as an excellent example of biodiversity and the application of classification to the phylum level. Unfortunately, when a student asked exactly which mushroom it was, I had to admit I could not provide them with even a common name.

Before leaving, we collected samples and took some digital images of the mushrooms in order to examine and identify them during the next class period. More importantly, I wanted students to communicate more fully and accurately about this unknown fungus. Ultimately, because of both the uniqueness of the specimen and fortuitous timing of its discovery, it served as an excellent example for the application of concepts (i.e., terminology; description, etc.) and methods (including digital imaging) needed to investigate and understand an unknown organism.

Between the field trip and the next class (four days over a weekend), I also had the opportunity to obtain additional digital photographs and samples of the unknown fungus (Figures 1-3). Using an identification guide for Kansas mushrooms (Horn et al. 1993), as well as resources on the Internet (http://www.wisc.edu/botany/fungi/march97.html), I was able to rather quickly identify the unknown basidiomycete as Flammulina velutipes, the velvet foot or, and perhaps more appropriately, the winter mushroom. Features that were valuable in the identification, in addition to the time of collection, included the color and shape of the gills, the sticky nature of the cap, the brownish, velvety surface of the stipe, and a white spore print. Within one day, Dr. Tom Volk of the University of Wisconsin confirmed the identification from information and JPEG images of the fungus I downloaded to him by e-mail, and Richard Kay, one of the authors of the Kansas mushrooms guide, indicated later that the fungus was most likely Flammulina velutipes (Thomasson 2001).

During the first class period following the field trip, I provided a brief lecture to the students concerning basic features of basidiomycetes. Using both dissecting
and compound microscopes, students examined specimens we had collected previously, and they were instructed to write a description of the fungus. In addition to the actual specimens, I provided students with laminated, color digital images of the specimens, and also projected digital images of the fungus onto a screen in the classroom. This allowed the students to see as wide a variety of examples of the toadstools and their features as possible. With the assistance of their written descriptions and digital aids, they used dichotomous keys from the Kansas mushroom guide to identify the fungus. To confirm their identification we searched the Internet and found a number of sites, including Dr. Volks's, (http://www.wisc.edu/botany/fungi/march97.html) displaying information and images about the winter mushroom for comparison with our specimens. The rapidity and accuracy with which they, as beginning students, were able to identify this unknown fungus was a powerful demonstration to the students of the importance of understanding characteristics of organisms and the value of digital imaging in classification and identification. Subsequently, I posted images of the winter mushroom to my web site (http://www.fhsu.edu/biology/thomasson/SpringcreekS01/velvet.html) for student review.

In summary, the Spring Creek experience was ideal for showing organisms in our environment and demonstrating how terminology, description, classification and identification are keys to understanding and communicating about biodiversity, and that digital imaging was an outstanding method for enhancing and reinforcing the learning processes involved in both the field and laboratory.

Selecting A Digital Camera & Microscope Adapter

Although numerous digital cameras with a wide array of remarkable and exciting capabilities are now available, knowing exactly which camera to select for
classroom use can be a daunting task, especially if you're relatively new to digital imaging. While the rather primitive features of early digital cameras gave the consumer limited choices, features of more recent models rival those of film cameras (Lawrence 2000; Dale 2000). The capabilities, type of controls (manual or automatic), and what price to pay, among others, are all considerations in making the final choice for a piece of equipment that you should reasonably expect to use for several years.

Camera prices range from a few hundred to thousands of dollars, but any number of excellent cameras in a $600 to $900 range work well for imaging biological organisms in both the field and laboratory. Regardless of the manufacturer, I would suggest a digital camera have four main features:

1. The camera should have a macro mode that allows focusing to within 2.5 cm. With my first digital camera I was continually frustrated because it would not focus any closer than 15 cm; even after I purchased a set of screw-on, close-up lenses, the macro images were still not satisfactory. My current camera, a Nikon Coolpix 950, has excellent macro capability, and I regularly photograph specimens as close as 2 cm (Figures 4 & 5) both in the laboratory and field. During my search for a camera, I found it

valuable to research specifications of the macro capabilities from manufacturers’ web pages and to read professional reviews of each camera, but I found especially helpful sites on the web where actual camera users posted images they had taken.

2. The camera should have at least a 2 megapixel CCD. Digital cameras capture images on a sensor called a charged coupled device (CCD), and the number of pixels that these chips includes determines the final resolution of an image. The more pixels the better, because, for example, images that are captured
for producing 8 x 10 prints are going to require more resolution in the form of pixels than images that are going to be displayed on a website. Thus, while even 1-megapixel cameras are adequate for capturing images for display on a website, high resolution 8 x 10 prints for classroom use require 2 to 3 and even higher megapixel cameras (Sawalich 2000). This has been especially true in my experience when photographing the details of biological specimens in the macro mode.

3. The camera should have at least a 64 MB, removable storage card. Cameras store images recorded from the CCD on these cards in either JPEG (in several modes) or TIFF formats that can be either compressed or uncompressed. These image files can be rapidly downloaded to a computer using either a USB port (found on newer computers and cameras) or a card reader (my preference). In most cases, I have found that recording the images in a JPEG format (fine mode) produces a file size of approximately 800 to 900 K and allows me to get about 27 pictures on a 30 MB card. Since it is not unusual for me to take as many as 50 to 100 photographs on a field trip, I carry a minimum of at least 128 MB in cards into the field. To free space on the cards in the field, I also have carried a laptop into the field and downloaded the images from the cards to the laptop. Portable, palm-sized, battery-operated storage devices to which thousands of high resolution images could be downloaded in the field or laboratory are also available for around $400 (Lawrence 2001).

4. The camera should be capable of attaching to a universal microscope adapter. Our biology department purchased a universal microscope adapter (model MMCool, Columbia Instruments Inc., Trussville, AL 35173) that threads onto the lens of the Nikon camera and then inserts into any microscope eyetube with a standard 23 mm or 30 mm diameter (Figure 6). Similar adapters are available for a number of different digital cameras. The image is viewed on the camera's LCD screen and focused using the microscope's focus controls. The adapter allows images to be captured in the laboratory with the digital camera using almost any available dissecting or compound microscope (Figures 3, 7).

Laminations – Protecting & Preserving Your Digital Images for Classroom Use

One of the most exciting aspects of bringing the digital world into the classroom is being able to quickly produce high quality color images of biological subjects. These color images in the form of computer files can be used in numerous ways that do not require printing and handling (e.g., overhead projection, on the Web, etc.). Allowing students access to color prints, either in the field or in the laboratory, is one of the more powerful methods for reinforcing the learning experience. However, unprotected color prints used in this manner will rarely survive a single class period unless they are afforded some level of protection. I have found that heat laminating them is an excellent, low cost method for preserving them for repeated handling.

Laminations of images have several significant advantages in the classroom:

1. Laminated images are extremely durable. Laminations can be handled repeatedly by
of the laminator, costs of the laminating pouches and color prints are the principal expenditures for producing laminations. We purchase 8 x 10 laminating pouches through a national discount chain at a cost of 50 for $14.95, or about 15 cents each. Because a lamination could be made from any number of color print media and printers (i.e., inkjet, laserjet, dye-sublimation, etc.), the cost of the print used for lamination could be quite variable. In my own experience using a photo quality inkjet printer and photo quality glossy paper, I can produce an 8 x 10-inch color print for about 70 cents, including paper and ink. Thus, my cost is approximately 85 cents for a high quality, laminated image that will last many years in the classroom.

3. Laminated images can be produced quickly. Although I generally plan for a reasonable period of time for assembling laminated images for classroom use, in several instances I have decided to produce one only shortly before (i.e., within one hour of) the class, or actually while the class was in session. For example, in a recent botany laboratory class we actually used a student-prepared epidermal peel of

students and instructors in a variety of ways with little or no degradation of quality. For example, in the laboratory I regularly use erasable markers on laminations to temporarily label features of the figured organisms for student review or quizzes and tests. When finished, the marks are easily and completely removed. Because water does not affect the laminations, I and a colleague teach an aquatic biology course in which we have carried laminated images of insects and fish into the field (Figure 5). As we collected live organisms from the stream, we laid them directly on the laminations for comparison and identification purposes. Laminations I produced on a color ink jet printer three years ago from photo quality inkjet jet prints retain their quality and vibrant color despite repeated use in the classroom.

2. Laminated images can be produced at a reasonable price. The moderate duty, heat laminating device (Royal Sovereign, Model BD-1200, Royal Centurian, Inc., Englewood, NJ 07631-4809) we purchased for our department of 13 instructors cost approximately $300. Beyond the purchase of:

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Kalanchioe, mounted in water, to obtain digital images of epidermal features (Figure 7) during the class period using the microscope adapter described previously on a student grade microscope similar to those found in many beginning laboratories. From the time the digital picture was taken, until I was able to provide them with a laminated color plate (and un laminated color prints for each student), less than 20 minutes elapsed. This was certainly an exception, but with many biological samples, taking a digital image and processing it through the computer, ink jet printer, and laminator can be reasonably accomplished within two to three hours.

Summary

With the advent of reasonably priced, high resolution digital cameras and associated equipment, the ability of any instructor or student to capture stunning color images of specimens in the classroom has become a reality. The versatility of digital imaging and the flexibility with which the results can be handled and displayed to students in the classroom either during the initial learning experience or for later reinforcement are unparalleled. Digital imaging presents a significantly enhanced paradigm for teaching in situations where specimens are routinely studied as an integral aspect of a course having both indoor and outdoor activities. Based on the positive response of students to the application of digital imaging in my classes, I expect its use to be expanded significantly in classes I teach, and I would recommend its adoption in any classroom where specimen imaging is an important consideration for learning the subject matter.

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