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Key to Freshwater Algae: A Web-based Tool to Enhance Understanding of Microscopic Biodiversity

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The Freshwater Ecology Laboratory at Connecticut College has developed an interactive, Web-based identification key to freshwater algal genera using the Lucid Professional and Lucid 3 software developed by the Centre for Biological Information Technology at the University of Queensland, Brisbane, Australia. The *Key to Freshwater Algae* was funded by the National Science Foundation (Award #CCLI-0229531) to encourage awareness of microscopic diversity through a creative, investigative approach to learning. Users may answer questions in any order to quickly and efficiently narrow down the list of taxa to only those that match the characteristics they have chosen. All characters and terms are clearly explained for ease of use by those unfamiliar with the algae. This non-hierarchical, user-friendly key is linked to Web pages containing a wealth of resources, including images, movies, and information about the morphology, ecology, and reproduction of each organism. These materials are especially well suited for classroom use in conjunction with cultures purchased from the Carolina Biological Supply Company, a popular distributor of biological materials. Cultures from the Carolina Biological Supply Company representing nearly 75 freshwater genera from a variety of algal groups were observed and photographed using high resolution digital imaging to fully document cellular structure and highlight distinguishing features. High quality video footage of each taxon incorporating titles, diagrams, and structural terminology was outputted as QuickTime movies, on DVD, and on VHS cassettes. The *Key to Freshwater Algae* and supplemental materials are available online at http://silicasecchidisk.conncoll.edu to provide an innovative alternative to traditional dichotomous keys that is particularly appropriate for introducing students in undergraduate life science courses to the algal groups and genera.

KEY WORDS: algae; microscopic biodiversity; science education; taxonomic key; Web-based learning.

INTRODUCTION TO MICROSCOPIC DIVERSITY

The microscopic world is often perceived as intimidating and inaccessible to the novice. Indeed, it is difficult for those lacking equipment and experience to investigate the world hidden from the unaided eye. It is, therefore, important that those with scientific expertise share their knowledge through the development of learning tools to make the microscopic world accessible to the educational community and to inspire a new generation of passionate learners. Once the barrier of scale is overcome, educators and students alike are dazzled by the array of cellular forms, adaptations, and processes that characterize microscopic diversity. The *Key to Freshwater Algae* provides educators with much-needed tools and information to easily incorporate studies of microscopic diversity into science curricula.

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Algae are found throughout the biosphere inhabiting the world's oceans, lakes, ponds, wetlands, streams, rivers, and estuaries (Graham and Wilcox, 2000; Wehr and Sheath, 2003). Other taxa are found in more unexpected or extreme environments and exert important ecological influences. Desert-dwelling algae aid in soil formation; others fix nitrogen in rice paddies, forge symbiotic partnerships with fungi to create lichens, or live in animals such as tropical corals or within the hollow hairs of polar bears (Graham and Wilcox, 2000). Still other species are found in hot springs, brine lakes, ice, snow, and the polar oceans (Graham and Wilcox, 2000). These microbes are critical to the functioning of the global ecosystem. Tiny cells sequester carbon and nutrients that then radiate throughout the food web to sustain higher trophic levels, and photosynthetic phytoplankton convert carbon dioxide to the oxygen that is vital for life—contributing approximately half of the total global primary production (Dodds, 2002; Graham and Wilcox, 2000; Wehr and Sheath, 2003).

Many taxa are highly valued economically for a broad range of commercial and industrial applications (Borowitzka, 1992; Graham and Wilcox, 2000; Radmer, 1996). The vast species diversity of microscopic organisms also provides an unparalleled source of genetic variability for biotechnology and biomedical research efforts (Borowitzka, 1992; Graham and Wilcox, 2000; Patterson *et al*., 1994). Many algal genera are useful indicators of environmental change; diatoms and scaled chrysophytes are especially valuable paleolimnological tools due to their elaborately sculptured siliceous cell walls and scales that remain preserved after the cells' demise (Siver, 1999; Wehr and Sheath, 2003). Single- and few-celled microscopic organisms also provide useful insights into the form and function of larger, multicellular organisms. Microbes elaborately showcase the colorful diversity and intrinsic beauty of life from a wide variety of habitats across the globe and provide a fascinating look at the complex interactions that connect organisms to each other and to the environment (Dodds, 2002; Graham and Wilcox, 2000; Lee, 1999; Wehr and Sheath, 2003).

METHODS

Cultures from the Carolina Biological Supply Company representing nearly 75 freshwater genera from a variety of algal groups were photographed and filmed using high resolution digital imaging on a Leica DMRD light microscope fully equipped with transmitted and reflected optical capabilities, high resolution plan apo lenses, and a Sony DKC-ST5 digital camera. Each organism was documented at both low and high magnification and using different optical techniques to fully characterize cellular structure and highlight distinguishing features. The original images were modified as necessary using Adobe Photoshop. High quality video footage of each taxon was outputted as QuickTime movies, on DVD, and on VHS cassettes using Adobe Premiere 6.5, Media Cleaner 6, and DVD Studio Pro 3.0 software packages. The movies incorporate titles, diagrams, and structural terminology to further familiarize students with the morphology and taxonomy of the algal groups and genera. Adobe PageMill 3.0 was used to develop Web pages with images, movies, and information about each genus that can be accessed either via the key or separately. The key, descriptive pages, images, and QuickTime movies were available online in spring 2005. The Freshwater Ecology Laboratory at Connecticut College has developed an extensive interactive Website at http://silicasecchidisk.conncoll.edu. In addition to these educational aids for the study of freshwater algae, this site provides research tools for diatoms and scaled chrysophytes and an extensive limnological database. The Freshwater Ecology Laboratory is currently promoting the distribution of the DVDs as complements to the interactive key and to offer an alternate means of viewing the movies when Internet access is not available.

The key itself was constructed using the Lucid software package developed by the Centre for Biological Information Technology at the University of Queensland, Brisbane, Australia to provide the framework for constructing multimedia, non-hierarchical identification keys for any taxonomic group or object set. This type of key offers an alternative to the traditional hierarchical, dichotomous keys that are notoriously difficult for beginner use. Such keys require that questions be answered in a certain order, frequently resulting in a frustrating dead end, often use difficult terminology, and require the observation of structures that may not always be present. The Lucid Professional software package consists of the Builder, which is used to construct the keys, and the Player, which may be downloaded at no cost at www.lucidcentral.com. Completed Lucid Professional keys are thus easily deployed and accessed via the World Wide Web for use by students and educators in facilities across the globe. The newest ver-

sion of the software, Lucid 3, allows the keys to be viewed directly via the World Wide Web without requiring a Player download. The *Key to Freshwater Algae* is available in both software versions.

Using the Builder software, the developer compiles a series of questions and associated characters that are linked with the list of available taxa to create the user interface (Figure 1). The questions are designed so that the user may efficiently and accurately narrow down a list of available organisms. The questions are arranged in a logical order but may be answered in any order, and any question may be skipped. Character pages provide helpful hints for a given question (Figure 2a, b), while organismal pages provide high-quality images and information about the morphology, ecology, and reproduction of each genus (Figure 3). The QuickTime movies, accessed from the organismal pages within the key, are enhanced by captions and diagrams noting important characteristics and allow the user to experience a microscopic investigation firsthand, progressing from low to high magnification as though they are looking over the shoulder of a skilled microscopist.

The taxa are scored for each question to create a database of characteristics. Each time a user answers a new question, the program discards any taxa that do not have the selected characteristic. The characteristics may also be scored as ''rare'' or as ''likely to be misinterpreted'', allowing the user to make common mistakes and still successfully identify the specimen.

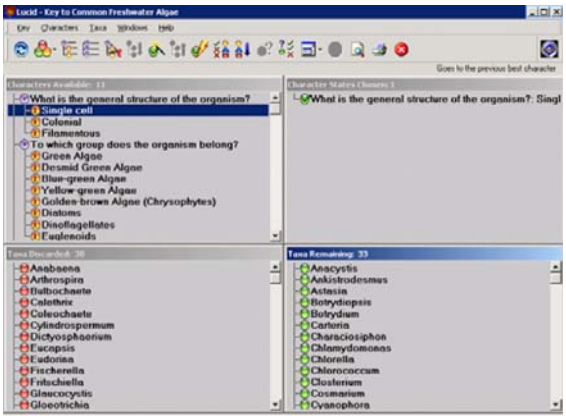
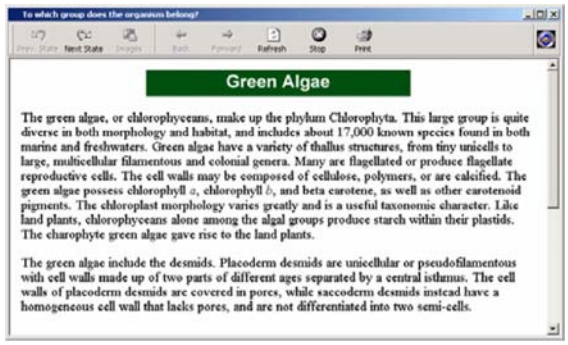


Fig. 1. User interface in the Lucid 2.1 Player for the *Key to Freshwater Algae*. The user chooses a response to a question from the top-left quadrant and drags it to the top-right quadrant. Any taxa that do not possess that trait are moved to Taxa Discarded (bottom-left quadrant) so that the Taxa Remaining (bottom-right quadrant) shows only the taxa possessing the chosen characteristics.



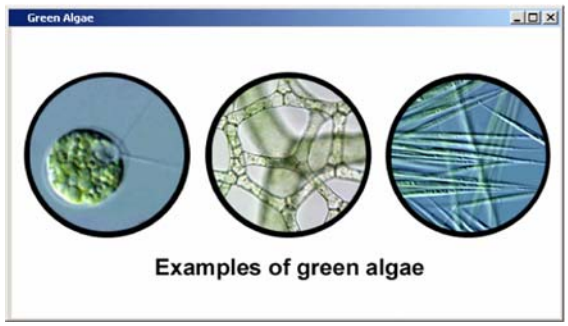


Fig. 2a, b. Character pages from the *Key to Freshwater Algae* provide the user with more information as they answer questions.

Descriptive text guides the user through the decision-making process, and offers information such as an explanation of the features common to a particular algal group.

Illustrative images showcase important features or traits, such as the morphological range of a particular algal group.

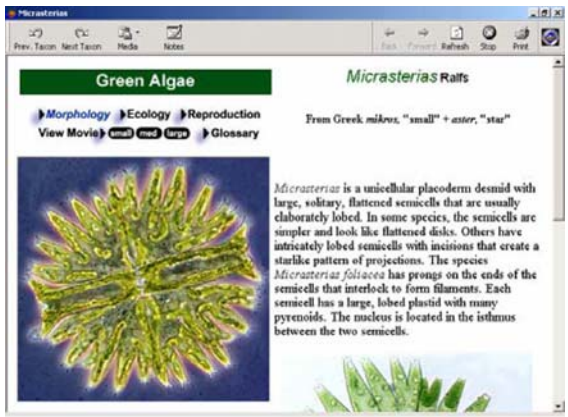


Fig. 3. Example of the organismal pages linked to the taxonomic lists in the *Key to Freshwater Algae*. Pages for each genus supply images, links to QuickTime movies and a glossary, as well as information about the morphology, ecology, and reproduction of that organism.

The character pages are linked to the appropriate question and response within the Lucid Player.

COLLABORATIONS

Our project has established a strong base of logistical and institutional support over the course of the funding period. The Freshwater Ecology Laboratory at Connecticut College is fully equipped to digitally image and film all specimens, both microscopic and macroscopic. A digital media specialist at Connecticut College has coordinated access to instructional technology facilities and equipment and provided hours of technical support in the development of the QuickTime movies and DVDs. The Centre for Biological Information Technology at the University of Queensland has provided technical support for the Lucid software platforms throughout the key development process. The Carolina Biological Supply Company donated live cultures and other supplies for the filming and imaging process, and may become an instrumental partner in distributing and marketing our learning materials.

We will continue to cultivate relationships with the educators and students that form the target audience for our materials. We have established collaborations with our colleagues at the Northeast Algal Society and have obtained comments and suggestions for improvement through discussions generated from oral presentations and through an online planning evaluation. Society members represent a significant part of the targeted user group and are most knowledgeable about the subject material; their constructive feedback and support is, therefore, vital to the success of the *Key to Freshwater Algae* as a useful and appropriate educational tool. Many of these educators have expressed great interest in utilizing our curricula, and several have already done so at both the undergraduate and graduate level.

We have also received excellent feedback from several pilot programs currently in use in elementary, middle school, and high school classrooms in Connecticut. Dr. Siver has presented select DVD movies and other educational materials to a third grade class at Jack Jackter Elementary School in Colchester, CT. The content was well received by both the students and the teacher; the school is interested in exploring microscopic diversity in future curricula. Additionally, a fifth grade teacher at E.O. Smith School in Storrs, CT is currently using the QuickTime movies available via our Website as part of a cell learning module. Our Website and materials are also being used by an educator in a high school biology class, and are slated for use in New Fairfield, CT at Candlewood Lake for the educational initiative Project CLEAR.

EVALUATION

In spring 2005 at Connecticut College, students from both introductory and intermediate level botany classes identified two different sets of cultures: one with the Lucid *Key to Freshwater Algae*, and the other with a very thorough and up-to-date dichotomous key titled *Common Freshwater Algae of the United States* (Dillard, 1999). We selected the Dillard (1999) key for comparison because it is one of the most complete and easy to use hierarchical algal keys available. Each student completed a written survey after finishing the activity that allowed them to compare, contrast, and critique their experiences with both keys. The introductory level class, Botany 115: Classical and Current Topics in Botany, consisted of 10 students, while the intermediate level class, Botany 205: Plants, Protists, and Fungi, consisted of 13 students. The evaluation results summarized below assessed the experiences of both science and non-science majors.

Both the introductory and intermediate botany classes found the Lucid key significantly easier to use to identify the algal cultures. Students especially liked the numerous color images (which replaced the black and white line drawings found in many dichotomous keys), and found it very helpful to be able to answer questions in any order and skip any questions for which they were uncertain of the answer. Several students also noted that they appreciated how the redundant questions were eliminated each time they answered a question. Overall, the key was preferred by the students and described as "very user-friendly, especially for beginners."

The introductory botany class unanimously agreed that all types of specimens were more easily identified with the Lucid key, even though this group received significant help from their instructor in using the Dillard (1999) dichotomous key to identify their cultures. The students from the intermediate level class also agreed that their key of preference, the Lucid key, was more useful in identifying cultures from the variety of algal groups in their culture set, which included green algae and desmids, blue-green algae, euglenoids, and chrysophytes. The students were in agreement that the

Lucid key was strongly preferred overall, and that "all organisms were easily identified with the Lucid key." One student noted that the Lucid key was especially efficient "when you could determine the color, structure, and one other trait" of a particular culture. Another student noted that colonial and filamentous organisms were harder to identify, which is likely attributed to the atypical characteristics of the particular cultures used. Indeed, it is important for the instructor to note that organisms frequently do not exhibit typical morphologies under natural or laboratory growth conditions—this is often particularly apparent in cultured populations. For this reason the *Key to Freshwater Algae* includes a list of recommended organisms (i.e., those genera that do not take on other forms in culture).

All students from both classes used the character pages (Figure 2a, b) as they answered questions and needed more information, and utilized the organismal pages (Figure 3) at the end of the exercise to verify that they had in fact identified the specimen correctly. The students found the images to be particularly helpful throughout the activity and used these more frequently than the written information. It was noted that "some of the images were identical to the view under the microscope," emphasizing that it is especially appropriate for instructors to use the Carolina Biological Supply cultures from which the images and movies were produced. Due to time constraints, most students did not view the movies for this exercise. However, one student in the introductory class did comment that the movies are a great way to observe the movement of the algal cells and to better equate the key materials with the dynamic view of the live cells under the microscope.

If required to view the specimens in class and subsequently use the *Key to Freshwater Algae* at a later time from a different location, many students noted that in this situation it would be critical to take good notes and to draw a picture of the specimen or, preferably, capture a digital image. Another student noted that in this situation "helpful hints" suggesting which features would be most important to look for would be appropriate as well. Students also indicated a strong preference for a program that could be installed on a home computer, which is indeed one of the main advantages of the Lucid software package.

The students nearly unanimously preferred the Lucid *Key to Freshwater Algae* to Dillard's (1999) dichotomous key, *Common Freshwater Algae of the United States*. We do not dispute the value and necessity of producing such keys for the professional audience; instead, we emphasize the appropriateness of a non-hierarchical, multi-media key for use in an educational setting. Many students were visibly excited and enthusiastic about the idea of using a computer key, and seemed very comfortable with the Lucid software user interface—most quickly learned to navigate the screen efficiently. One student noted that she found the Lucid software to be very accessible, even though she does not consider herself to be very proficient with computers. The students rapidly learned to trouble-shoot their answers by trying different combinations of responses to the questions that they were the least confident about. Most students intuitively learned to apply this strategy immediately. Overall, the introductory class stated that "The Lucid key was extremely helpful for a beginner, and was surprisingly easy to use" and that "The Lucid key was very simple and straightforward." The intermediate class concurred, commenting that "The Lucid key was amazing. It made it really hard to go back to the dichotomous key, because the black and white pictures were hard to identify. I love the Lucid Key!" and, "All in all, it is a really fantastic program."

EXPECTED CONTRIBUTIONS

The *Key to Freshwater Algae* takes full advantage of digital media to provide a useful and efficient alternative to traditional dichotomous keys that is particularly appropriate for introducing students to the morphology, ecology, and biodiversity of the algae. The questions in traditional hierarchical keys must be answered in a certain order, and often use difficult terminology or ask about structures that may not always be present. Our key allows the student to answer only the questions that they feel confident about and understand fully. The user-friendly key is linked to a wealth of information and resources to provide students with high-resolution, highly magnified views of algal cells to supplement their own investigations, is freely available online at http://silicasecchidisk.conncoll.edu, and includes simple instructions for use.

Our key is not designed to replace the use of cultures and investigative microscopy during laboratory sessions. Instead, the images and movies allow students to quickly and easily see high-quality views of each organism at a greater level of detail and clarity than is typically possible during a single lab-

oratory or classroom session. The students are encouraged to learn about the algae by observing live organisms, identifying their specimens using the interactive key, and researching each genus using the many images, movies, and informational pages associated with the key. The *Key to Freshwater Algae* will fully equip students to overcome the difficulties imposed by time constraints, the limited capabilities of teaching microscopes, and by their own limited experience to more quickly become comfortable with the basics of freshwater ecology.

The *Key to Freshwater Algae* was created as a teaching tool to spark student interest in microscopic biodiversity. Those students that continue to explore this area through advanced study will also become experienced with a variety of standard identification keys, field collection techniques, and culture procedures. Our interactive key is designed to be used in undergraduate courses introducing students to the algae, but could easily be used by high school and graduate students or professionals. We are also investigating ways to incorporate freshwater ecology materials into elementary and middle school curricula. The *Key to Freshwater Algae* incorporates all needed information and therefore, requires no prior knowledge of the subject matter, making it suitable for educators in a wide variety of formal and informal settings. The key also provides a practical, self-contained identification tool that is appropriate for researchers and professionals. The World Wide Web provides an efficient and powerful means of disseminating educational materials to students across the globe and is especially suited to a self-guided, investigative learning approach (Hackbarth, 1997; Owston, 1997). These learning materials will stimulate interest in microscopic biodiversity in a way that is innovative, enlightening, and fun for students and educators alike, and will greatly enrich learning in the life sciences and environmental education.

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