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A tutorial for sandstone petrology: architecture and development of an interactive program for teaching highly visual material☆

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Abstract

We have developed an interactive computer-based tutorial in sandstone petrology for undergraduate-level students. The goal of this tutorial is to provide students exposure to the highly visual subject matter of petrography outside the confines of organized laboratory exercises. This paper describes the architecture and development procedures of the current version of the sandstone petrography tutorial, and offers a possible model for similar development approaches in other fields of petrography or in any other field that utilizes large quantities of visual material such as remote sensing image interpretation or seismic interpretation.

The tutorial is an interactive photomicrograph archive with sufficient content and flexible architecture that functions as a virtual laboratory instructor as well as a stand-alone reference. The current tutorial was programmed using Macromedia Authorware v.6.0 and supports both Windows-based and MacOS personal computers. The tutorial is constructed around the Folk sandstone classification scheme (quartzarenite, arkose, and litharenite), and an additional section addresses grains other than quartz, feldspar, and lithic fragments and sandstones dominated by these grains. The user interface is designed to take minimal portion of the screen area so that the screen can closely mimic the type of view seen by a student peering down a microscope. Each photomicrograph in the tutorial is basically unadorned until the user actively calls up information that is temporarily displayed over the image, inducing the user to search for information and actively "ask" to be informed with a mouse click. The structure of the tutorial permits multiple strategies of program use, as a linear tutorial, tutorial driven by thumbnail browser, and as a searchable reference.

Keywords: Petrography; Sandstones; Sedimentary petrology; Interactive multimedia; Digital imaging

1. Introduction

The last decade witnessed the exciting emergence and adaptation of information technology in Earth Science education. An early product, 'The Virtual Microscope' (http://met.open.ac.uk/vms/vms.html; http://www.ouw.co.uk/products/S260_CDR_E.shtm), originally designed to provide simulated microscope experience for physically handicapped students, demonstrated the potential for combining digital media with petrography instruction (Robinson, 1994).

The inauguration of United Kingdom Earth Science Courseware Consortium (UKESCC, http://www.man.ac.uk/Geology/CAL/index.html) in 1992 and subsequent development (1992–1995) and revision (1996–2000) of 21 digital coursewares was a major spearhead in Earth Science digital educational material development

☆Code available from http://www.aapg.org/index.html

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during the last decade (Bryon and Sowerbutts, 1996; Sowerbutts and Bryon, 1996; Sowerbutts, 1999). Modules developed by UKESCC typically require about 4 h of student time to complete and are designed in a way that effectively supports traditional lecture and practical classes (Edwards et al., 1996; Sowerbutts, 1999). Two modules created by UKESCC address microscopy for lower-level undergraduates: 'Optical Mineralogy' (Emley et al., 2000; Browning, 1996) and 'Basic Petrography' (Emley et al., 1996).

One of the key features repeatedly used in these digital teaching materials in geosciences is 'interactivity' (Sowerbutts, 1999). Notable examples of interactive geoscience educational materials, in addition to the 21 UKESCC coursewares, are: elementary optical mineralogy and petrography (Blaylock and Christiansen, 1999; Christiansen, 2001), virtual field trip (Hurst, 1998), digital geologic map presentation (Condit, 1995), structural geology training (Shen et al., 1997; Kluth and Wilbur, 2000), and mineral identification (Smith and Abley, 1996; Magloughlin, 1998; Murray and Yavine, 1998). It has been realized also that digital media can partially replace fragile sample collections for undergraduate laboratory exercises and can act as a virtual database and archive of thin sections and mineral specimens (Browning, 1996; Smith and Abley, 1996; Magloughlin, 1998; Milliken et al., 2003).

We have developed an interactive digital tutorial in sandstone petrology for undergraduate-level students. The goal of this tutorial is to provide students with exposure to the highly visual subject matter of petrography outside the confines of organized laboratory exercises. This program allows students to gain high levels of expertise with description and interpretation of sandstones. This paper describes the architecture and development procedures of the current version of the sandstone petrography tutorial, and offers a possible model for similar development approaches in other fields of petrography or in any other field that utilizes large quantities of visual material such as remote sensing image interpretation or seismic interpretation.

2. Background

Ever since Henry C. Sorby, the 'father of petrography', introduced microscopy in geological research and published the first paper based on such work in 1851 (Folk, 1965), the teaching methods of petrography have remained practically unchanged. In conventional practice, an instructor having extensive petrographic experience, conducts a laboratory through demonstrations to a small group of students. After watching the demonstration on how to locate and identify a given feature, the student is called upon to make such an identification independently, and to have the correctness of their interpretation confirmed by the instructor. Typically, petrographic laboratory activities proceed through repeated exchanges in which students locate features with the microscope, question the instructor about them, and in turn are interrogated about other features located by the instructor. In sandstones, as in all natural materials, tremendous heterogeneity exists across features of equivalent classification. Hence, expertise with identification of rock components requires repeated exposure to a wide range of examples. Extensive practice outside of the laboratory is a key element for gaining petrographic expertise. Especially at the beginning of this process, however, individualized guidance from the instructor is indispensable.

In order to supplement the labor-intensive nature of petrography teaching, traditional hard copy image atlases (e.g., Scholle, 1978, 1979; MacKenzie et al., 1982; Adams et al., 1984) as well as image archives on Photo CD (Carozzi, 1996) have been used in undergraduate petrography laboratory exercises. In addition, since the mid-1990s, from the advent of the Internet as a viable medium for conveying educational resources (Butler, 1998, 2000), web pages have been constructed to provide petrographic images and related information (e.g., Perkins and Hartman, 2001; Choh et al., 2002, Table 1). Though convenient sources of information, the biggest shortcoming of these traditional hard copy and electronic atlases is that identification of individual components within a complex image can be troublesome for the novice user. These existing archives do not deliver effective pedagogy for learning petrography because they do not provide a substantial informational content keyed to specific areas of the image. In order to overcome these obstacles, we have initiated the construction of an interactive photomicrograph archive with sufficient content and flexible architecture that it functions as a virtual laboratory instructor as well as a stand-alone reference.

3. Technical aspects of the tutorial

3.1. Development platform and system requirements

The current version of the tutorial is made with Macromedia Authorware 6.0 on a Microsoft Windows-based PC, and supports both Windows and MacOS platforms. We chose Macromedia Authorware over Macromedia Director, Visual Basic (e.g., Smith and Abley, 1996; Murray and Yavine, 1998), and HTML (e.g. Thum, 1998) because it is easier to learn and program the very simple types of navigation and interactions we wanted to implement, and it allows us to package the tutorial as a single application program that can be delivered on a CD-ROM for both Windows and MacOS personal computers. In addition, it also comes with the capability to deliver the final product via Local Area Network (LAN) or the internet as needed by means of a free Authorware Web Player plug-in for the Microsoft Internet Explorer web browser (http://www.macromedia.com/software/authorware/download/).

The current tutorial program is about 20 MB in size and is delivered on a CD-ROM disc as a stand-alone application. We chose CD-ROM as the delivery medium for the current tutorial program because the relatively timeless nature of the content that does not need frequent revisions and to assist the users without access to high-speed internet connection (Kluth and Wilbur, 2000). The program can be executed from the CD-ROM without installing any component to the user's local hard disk. Additional supporting files and photomicrographs used throughout the tutorial, about 70 MB in size, are also stored on the same CD-ROM in separate folders.

Minimum hardware and operating system requirements for running the tutorial are a Pentium 120 MHz processor or better, 64 MB of RAM or better, a CD-ROM drive, 800 by 600 screen resolution, and Microsoft Windows 95 or later for the Windows personal computers, and a PowerPC 120 MHz processor or better, 64 MB of RAM or better, a CD-ROM drive, 800 by 600 screen resolution, and MacOS® 8.1 or later for the MacOS personal computers. Recommended hardware specifications are Pentium II 350 MHz processor, 128 MB of RAM, 24 × speed CD-ROM drive, and 1024 by 768 screen resolution with 16 bit color for the Windows-based personal computers, and PowerPC G3 350 MHz processor, 128 MB of RAM, 24 × speed CD-ROM drive and 1024 by 768 screen resolution with 16 bit color for the MacOS personal computers.

3.2. Image acquisition and formats

Photomicrographs used in the tutorial are 800 by 600 pixels in dimension, 8-bits per channel RGB color images. Over 430 images were collected by either scanning 35 mm color slides taken with a microscope-mounted film camera (approximately 70% of images used in tutorial), or with a digital camera mounted on a polarizing microscope (approximately 30% of images used in tutorial). The Minolta Dimage Scan Multi 35 mm film scanner was used to scan 35 mm color slides at the resolution of 1344 by 896 pixels. These scanned images, each 3.4 MB in size, are archived as TIFF format files. A Polaroid DMC-1 digital microscope camera attached to Olympus BH-2 polarizing microscope was used to capture photomicrographs directly from thin sections. Images were captured either at 1600 by 1200 (5.5 MB in size) or 800 by 600 (1.4 MB in size) pixels then archived as TIFF format files. Each image file has a unique serial identifier number depending on the type of information the image conveys. An Excel database containing the date of image acquisition, file name, objective lens magnification, image type (cross polarized or plane-polarized), sample number, geologic unit name, age, locality, and source of image was constructed. The archived TIFF format images were subsequently retouched for color, brightness and contrast, reduced or cropped to 800 by 600 pixels for the main tutorial and 100 by 75 pixels for thumbnail browser sections, and converted to medium-high JPEG compressed files using Adobe Photoshop before incorporation into the tutorial. The resultant JPEG files are typically between 90 and 390 KB and 9 and 24 KB in size for main images and thumbnails, respectively.

4. Tutorial design

4.1. Architecture

The goal of providing undergraduates a balanced and full exposure to the major topical areas of sandstone petrology provides the framework around which the program is constructed (Fig. 1). The architecture of the program directly reflects the organization of the topic as it is currently taught to undergraduate students. Hence, the top-level page is constructed largely around the tripartite Folk sandstone classification (Folk et al., 1970; Folk, 1980). An additional section addresses grains other than quartz, feldspar, and lithic fragments and also sandstones dominated by these exceptional grain types. For each of the four major sandstone 'clans', there are tutorials containing petrographic images related to both provenance and diagenesis. Within each sub-section of the tutorial, there are introductory text describing the major learning goals for the particular section ('Goals'; Fig. 1); thumbnail browser pages for easy preview and access of tutorial materials ('Browse'; Fig. 1); and tutorial sections that contain the interactive, "live" images ('Tutorial'; Fig. 1). In addition to the tutorial sections for the sandstone clans mentioned above, the main page provides entry to the following subtopics: "How to use the tutorial", "Heroes of Petrography", "Sandstone Architecture and Classification", "Compaction", and "Texture". A full-text search engine and a page-tracking function that records previously visited pages can be opened from the main page as well as from all tutorial pages. Also, focused on the novice-level expertise of the intended user, a 70-term glossary that is hyperlinked throughout the tutorial as well as an annotated reference list is provided.

4.2. User interface

The principal design concept of the tutorial user interface is the creation of non-intrusive and intuitive user experience (Hurst, 1998; Greaves and Heideman, 2000) that reproduces as closely as possible the learning

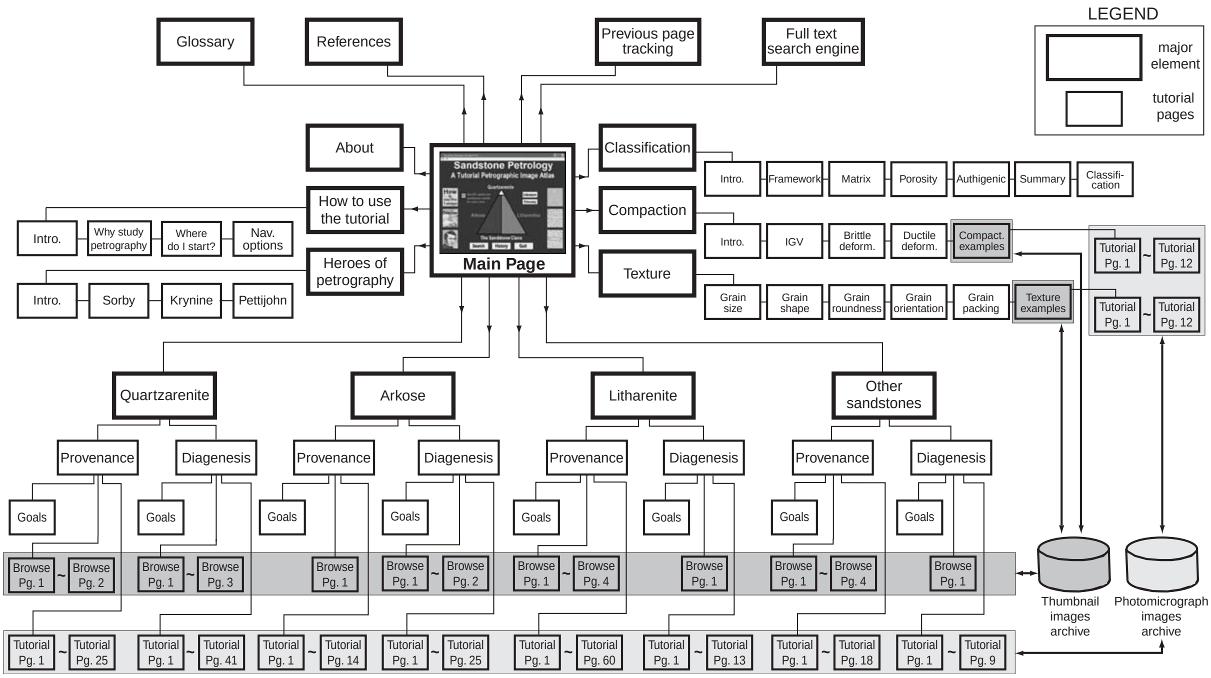

Fig. 1. Structure of interactive tutorial for sandstone petrology.

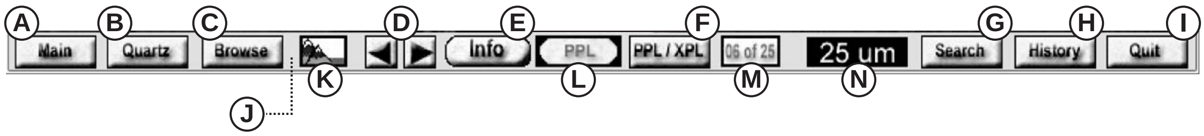

Fig. 2. (A–N) User interface cluster of tutorial.

environment of a traditional instructor-directed, 'hands-on' petrographic laboratory exercise. Elements of the traditional approach that we sought to preserve include:

1. a sense of exploration that engages the user's initiative to seek out information;
2. immediate access to information on the identity of features 'discovered' by the user; and
3. a high degree of repetition so that the user learns the complex variations of features by repeated encounters with differing examples of similarly classed features.

Inside the four sandstone clan tutorials, the window is mostly filled with the photomicrograph, with the user interface cluster located toward the bottom of the window occupying a minimal portion of the screen area (e.g., Choh et al., 2002, their Figs. 6 and 7), thus mimicking as closely as possible the type of view seen by a student actually peering down a microscope. Buttons on the user interface cluster allow the user to:

1. go back to the main page (Fig. 2A);
2. go back to the top of sandstone clan page (Fig. 2B);
3. go back to the thumbnail image browser page (Fig. 2C);
4. go to the previous or the next interactive image (Fig. 2D);
5. trigger general information text box about the sample (Fig. 2E) such as age, stratigraphic unit, and locality;
6. toggle between different image types of the same field of view (Fig. 2F). It is possible to switch between plane- and cross-polarized views of about 40% of images used in the tutorial; and
7. activate the search engine (Fig. 2G) and history function (Fig. 2H).

In addition, there are several other indicators that display the current state of the tutorial: the background color of the user interface cluster (Fig. 2J) indicates which section the user is currently in (quartzarenite, yellow; arkose, blue; litharenite, pink; and other sandstones, orange), provenance and diagenesis section indicators (mountain icon indicates provenance section, Fig. 2K; a crystal icon represents diagenesis section), an image mode indicator (plane-polarized light (PPL) view vs. XPL; cross-polarized light view; Fig. 2L), an image counter that shows how many additional similar images there are in the current section (Fig. 2M), and a scale bar (Fig. 2N).

4.3. Interactive images

Each photomicrograph (Fig. 3A) in the tutorial is unadorned until the user actively calls up information that is temporarily displayed over the image. This interactivity is achieved by placing transparent polygons on the features to be clicked by the user (Fig. 3B). These polygons were hand drawn in Authorware using the polygon tool, then set to transparent mode. Each polygon is programmed in a way that in passing the cursor over the invisible polygon, the

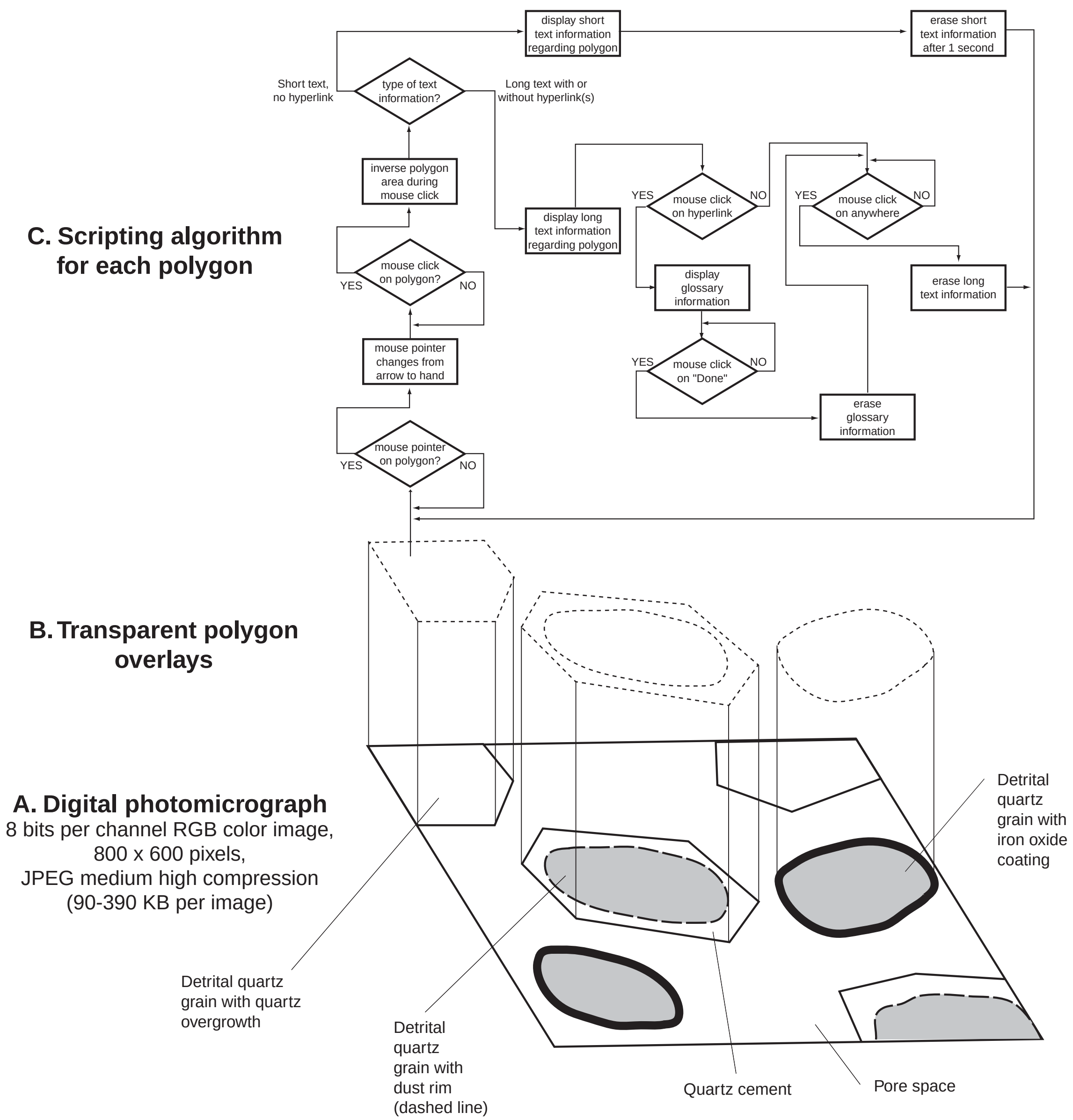

Fig. 3. (A–C) Interactivity is achieved by drawing transparent scripted polygons on top of features to be explained in digital photomicrograph.

cursor changes from an arrow to a hand, which is the only clue in the tutorial that hints the user that the particular feature has linked text. The transparent polygons are further scripted so that clicking on the region inverts the color of the area inside the transparent polygon for the duration of a mouse click. If the user clicks and holds the mouse button, it is possible to clearly discern the area of the photomicrograph described in the text box. On releasing the mouse button, either a small amount of text that identifies the feature or a larger box of text that expounds upon the key concepts conveyed by the feature will be displayed. The small text boxes disappear after 1 s. The larger text boxes disappear on clicking the mouse again, and the user can continue to explore the image or move to another (Fig. 3C). In effect, the user must search for information and actively "ask" to be informed with a mouse click. There are about 300 interactive images in the current tutorial, and each photomicrograph has from 1 to over 15 such "hidden" scripted polygons.

4.4. Navigation

The overall structure of the tutorial permits multiple strategies of program use. Because each sub-module is designed to gradually add information at the user's own pace, the first-time user may view the tutorial images sequentially (Fig. 4A). The user who wants to review what he/she has learned by quickly glancing through the program may use the thumbnail browser pages. Each browser page contains 16 thumbnail images of the interactive photomicrographs and provides a short description of each image. Each thumbnail image is hyperlinked to the actual photomicrograph. Clicking on the thumbnail brings the user to the corresponding interactive page within the tutorial (Fig. 4B). The user may return to the previous thumbnail browser page by clicking the 'Browse' button (Fig. 2C), or may continue to navigate inside the tutorial section using the arrow buttons (Fig. 2D). Alternatively, for those using the tutorial as a reference, the tutorial can be entered by using the search engine. The search engine allows the user to generate a list of images referring to a given term. The user can then access each image in the search result by double-clicking the image identification number (Fig. 4C). All images contain a unique alphanumeric identifier that can allow instructors wishing to utilize only a small portion of the tutorial images (e.g., in introductory-level courses) to assign a list of specific images to be viewed. The 'history' function (previous page tracking) allows the user to generate a list of pages visited and to return immediately to any of them with double-click on the image name.

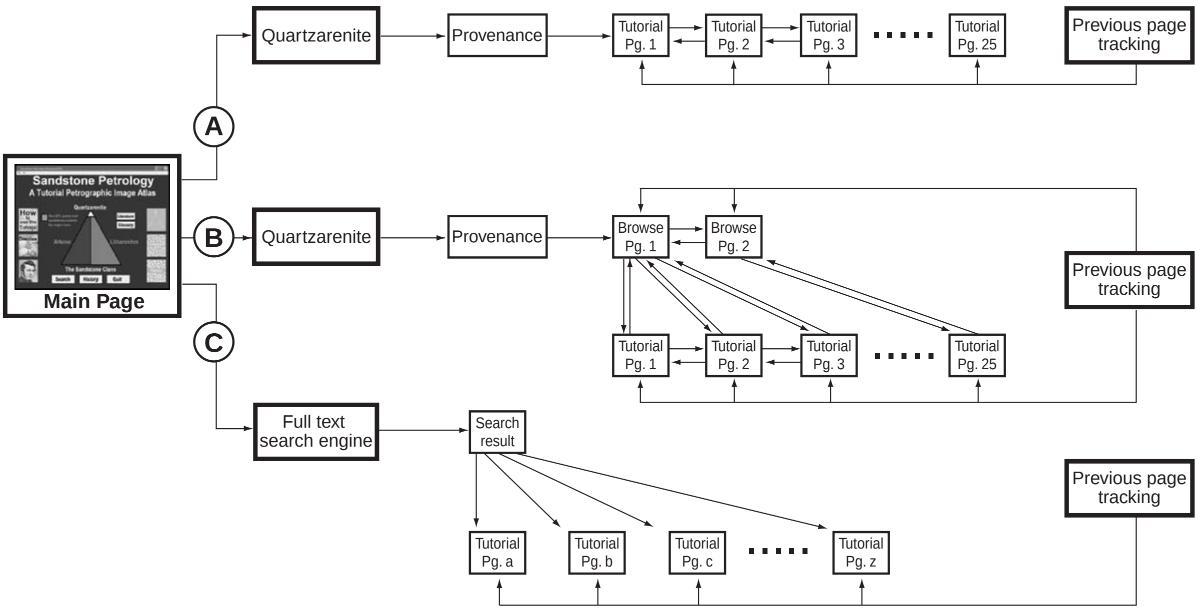

Fig. 4. Three possible strategies of using interactive sandstone petrology. (A) For the first-time, user will sequentially visit each image inside each tutorial section. (B) An experienced user, or a user who wants to skim through tutorial, will scan image browser then select an image from browser for detailed view. User can go back to browser by means of 'Browse' button (Fig. 2C) or may navigate further inside tutorial section using navigation arrow buttons (Fig. 2D). (C) Tutorial can be used as a reference by selecting search engine from main page or from any tutorial pages, and then typing in search criteria. Search engine generates a list of images that contain search criteria. User double clicks image identification number to be directly transported to image.

5. Development history and team

5.1. Development timetable

The first phase of development (September 2000–May 2001) focused on the creation of interactivity, the navigation scheme, and a user interface for effective pedagogy, and resulted in a collection of 90 scripted images focused on sand grain identification. This prototype was demonstrated at the 2001 AAPG meeting (Choh et al., 2001a, 2002). A second phase of development (June 2001–May 2002) focused on enlarging the scope of the content to 300 interactive images and testing the educational effectiveness of the digital tutorial (Choh et al., 2001b; Milliken et al., 2003).

The tutorial was field tested by about 180 students of GEO 416M ''Sedimentary Rocks'' during Spring and Fall 2002 semesters at the University of Texas at Austin. Students were encouraged to report errors and suggestions. A questionnaire on student attitudes toward the tutorial also proved to be a valuable source of user input. End user suggestions were used for debugging, enhancing standard navigation buttons (Fig. 2), and refining navigation options. It has been found that students indicated a high level of approval of the digital tutorial, and subject matter attainment appears to improve with tutorial use (Milliken et al., 2003).

5.2. Development team

The development team consists of sandstone petrographers (KLM and EFM) and a geology graduate student software developer (SJC) who is a carbonate petrographer. The subject authors acquired and provided original images in 35 mm slide and digital form, text, and graphical contents for the tutorial and subtopic modules. The software developer was in charge of content digitization and programming. Two undergraduate geology majors, under the supervision of the developer, were added to the team in the second phase of development in order to accelerate content digitization and programming. These upper-division undergraduates had completed the course for which the tutorial is intended. An important point is that all members of the development team have experience in petrography laboratory exercises as students; three team members have experience as petrography instructors.

Once the overall user interface, interactivity, and navigation schemes are devised during first phase of development, an assembly line approach was employed during the second phase of development. The sandstone petrographers, guided by the desired content for laboratory exercises in sandstone petrology, selected images from digitized photomicrographs. Content authoring was carried out using hard copies of these photomicrographs: the authors manually drew features to be programmed as 'live' portions of the images (transparent polygons) and wrote texts to be attached to those fields, typically incremented by a few 10 s of images each week. Insertion of the hand-drawn content into Authorware was carried out by the developer and undergraduate assistants, again, at an incremental rate of a few 10 s of images each week. Progressive construction of the hierarchical programming framework into which the 'mapped' images were inserted was carried out by the developer.

6. Discussion

The way we programmed interactive images turned out to be highly effective for introducing complex images to novice students (Milliken et al., 2003). Though labor intensive to program, this type of interactive learning style has the potential to be widely used for teaching highly visual materials, not only petrography but also remote sensing and geophysical image interpretations in the future. This type of simple interactivity could be implemented by using any of a variety of multimedia programming tools or computer languages available today. It appears that having a flexible navigation scheme that can act as a linear tutorial, a thumbnail browser image driven tutorial, as well as a stand-alone searchable reference significantly enhances the usefulness of the tutorial.

Each team member contributed from multiple vantage points and filled multiple roles in program development. All the team members have the perspective of someone who would actually use the materials, either as an instructor or a student, or both. The sandstone petrographers and the programmer all share extensive knowledge of the content as well as experience with acquisition and processing of digital photomicrographs. Knowledge of detailed capabilities of Authorware is primarily the purview of the programmer, but all members of the team are cognizant of the broader possibilities of multimedia authoring software. Such shared skilled sets across the development team has lent a degree of efficiency and quality to the development process that would likely be difficult to achieve using programmers unfamiliar with the content and goals of the program.

7. Future plans and software availability

The next phase of development will focus on expanding content, especially for more complete coverage of lithic and non-QFL components. A greater diversity of petrographic images such as cathodoluminescence (CL), backscattered-electron (BSE), and X-ray maps will be incorporated into the tutorial.

A self-assessment (quiz) section is also planned. The current version of tutorial (Milliken et al., 2002) is available through the American Association of Petroleum Geologists (http://www.aapg.org/index.html). A limited demonstration version of the tutorial can be downloaded from ftp://ftp.geo.utexas.edu.

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