Application of Tablet PCs to Lecture Demonstrations on Optical Mineralogy

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ABSTRACT

Learning optical mineralogy requires students to integrate a complex theory with microscope manipulations and image interpretation. To assist student learning, we performed lecture demonstrations during which digital photomicrographs were taken and delivered to students using Tablet PCs, whereupon they were imported into note-taking software and annotated with digital ink by both instructor and students. We tested two different methods for delivering images: (1) images were delivered via an ad hoc wireless network using the file transfer capability of NetSupport School, using the instructor's computer as the hub, and (2) images were saved to a shared folder that could be accessed by students via the regular campus wireless network. Students loaded the images into either Microsoft OneNote or PowerPoint, and then annotated them with digital ink using the stylus pen as the instructor lectured. Use of the campus wireless network resolved issues of slow image delivery encountered with the ad hoc wireless network. Summative assessment revealed that most students thought the Tablet PCs helped them to understand the complex visualizations. The degree of acceptance among students of using Tablet PCs for note-taking during lectures improved considerably when the issue of slow image delivery was resolved. In addition, students commented that it was helpful to have the images close up and that the colors were highly accurate.

INTRODUCTION

Optical mineralogy is one of the most challenging subjects taught within undergraduate geology programs. Students must learn to integrate a complex theory, microscope manipulations, and image interpretation in order to identify minerals in thin section or to narrow the possibilities. In recent years, many geology programs have reduced the time allocated to optical mineralogy within their undergraduate programs, in spite of contrary justifications (Gunter, 2004), challenging instructors to find more efficient and effective ways of teaching these skills. Modern methods of pedagogy were incorporated into a textbook on mineralogy and optical mineralogy (Dyar and Gunter, 2008). One technique, in common usage, is to incorporate demonstrations into lectures using a digital camera attached to a microscope and directing the live video feed from the camera to a projector. This method carries both advantages and disadvantages. Advantages include (1) the lecture content is well illustrated, possibly leading to enhanced comprehension, and (2) in response to questions and discussion, the instructor may expand on particular points with more demonstrations. The main disadvantages are (1) students observe passively and consequently may suffer a loss of engagement during the demonstration, and (2) note taking during lecture demonstrations is difficult due to the complex color images that must be rapidly sketched and labeled.

In an effort to overcome the disadvantages, we proposed that the learning effectiveness of lecture demonstrations might be improved if students could take notes directly on their own copies of the displayed images. Learning improvement would result from greater student engagement due to working directly with the images. In addition, by removing the need for sketching the images, students would have more time and mental energy to focus on learning the skills. Furthermore, the high accuracy color of the images would assist learning because they would realistically represent the subtle color changes that students must learn to interpret.

Tablet PCs come equipped with a hand-held stylus pen that writes with digital ink on digital paper in pen-capable programs such as Microsoft Word, PowerPoint and OneNote, analogous to using a conventional pen to write on conventional paper. The user writes with the stylus pen directly on the computer screen and the software responds by creating vector objects containing the digital ink lines and placing them in a layer that superimposes over the digital paper and over any embedded objects such as images. Lines drawn in digital ink may be specified as to width and color, and may be easily modified, moved, or erased.

The electronic delivery of digital photomicrographs taken during a lecture to students using Tablet PCs was achieved with two different methods, an ad hoc wireless network and the campus wireless network. We used an ad hoc wireless network in fall 2007 and the campus wireless network in fall 2008. We made the change in an effort to resolve issues of slow image delivery encountered with the use of the ad hoc network. We report on the use of both methods in this paper.

In geoscience education, Tablet PCs have been used for field mapping applications, effectively replacing conventional paper maps and writing tools (pens, pencils and erasers) with digital maps and digital ink (Brimhall et al., 2002; De Donatis and Bruciatelli, 2006; Clegga et al., 2006; Knoop and van der Pluijm, 2004, 2005; Manone et al., 2003, 2006, 2007). Using Tablet PCs, GPS locations may be displayed in real time on georeferenced maps inside programs such as ArcGIS (Manone et al., 2003, 2006, 2007), MapIT (De Donatis and Bruciatelli, 2006) and GeoMapper (Brimhall et al., 2002), which may also be used to construct maps while in the field in real time. Tablet PCs have also been used to aid instruction in computer science courses

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(e.g., Anderson et al., 2003, 2004; Berque et al., 2004; Subhlok, et al., 2007). This study appears to be among the first to report the use of Tablet PCs in any natural science classroom setting.

Tablet PCs can be used to facilitate the development of expert performance consistent with the literature on learning. In the meta-analysis of research on learning, Bransford et al. (2000) claimed that two of the six characteristics that distinguish experts from novices is that "experts notice features and meaningful patterns of information that are not noticed by novices," and "experts' knowledge cannot be reduced to a set of isolated facts or propositions but, instead, reflects contexts of applicability: that is, the knowledge is 'conditionalized' on a set of circumstances." One essential activity in moving students along the trajectory from novice to expert is to give them opportunities to encounter, recognize, learn, and internalize patterns essential for understanding a subject. Giving students access to microscope images during lectures promotes both of these characteristics of expert performance: the expert (instructor) draws attention to salient features on images while explaining their origin and interpretation, and using the stylus pen, students are able to mark the salient features and their interpretation.

Hearing the expert think aloud engages students in legitimate peripheral participation, a learning process proposed by Lave and Wenger (1991). In their theory, Lave and Wenger (1991) identify a novice-expert trajectory that includes acquiring the language, procedural skills, and claims-substantiation requirements characteristic of a community of practitioners. Students of optical mineralogy fill the role of apprentice learners by marking up the microscope images on their own Tablet PCs, the same way the expert marks the projected image. As the instructor marks the images, he is also explaining why he is marking particular features, justifying how these images assist in mineral identification, and also describing the origin of particular features. Through the coupled actions of annotating images and listening to the lecture, students are acquiring the language and thought process of applying optical mineralogy.

TECHNICAL SETUP

Hardware

In general, the hardware needed to perform the required tasks is not specific to particular brands, rather specific capabilities are required of certain components. The essential components consist of a polarizing light microscope, digital camera, adaptor that mounts the camera onto the microscope (if needed), digital projector, and Tablet PCs for the instructor and each student (Fig. 1 shows the hardware setup used by the instructor for the lecture demonstrations).

The polarizing light microscope used for this application needs only to be adaptable to a digital camera. The best results are obtained if the microscope has a C-mount, which is commonly the third port on a trinocular microscope, the other two being ocular lenses. Many models of digital cameras, including good quality consumer grade cameras, are suitable for mounting to a C-mount with the appropriate adapter. The advantages to using this type of system are that the user may use the ocular lenses of the microscope for viewing the image while the camera is in use, and the zoom on the camera may be used to narrow the field of view to the evenly illuminated part in the center, which is useful if the images are to be montaged or publication quality images are desired. A suitable camera is one that can be powered by plugging into an electrical outlet because battery power will not be sufficient to operate the camera over the length of time generally needed for lectures or labs. The camera must also possess a port for outputting a live video signal. Cables that connect to camera video ports are normally terminated by an RCA plug, which cannot be directly connected to most computers; however, adapters are available that accept the RCA connection and output to a USB connection. The video signal can then be viewed on the computer using the adapter's software.

Recently, inexpensive (<$200) digital cameras have become available that replace the ocular lens on a monocular microscope and supply a live video feed to a computer via a USB connection. The video is displayed on the computer inside the camera software or within a PowerPoint plug-in. The diameter of microscope eyepiece tubes is generally standard in the industry, so these cameras fit most if not all monocular polarizing light microscopes. The disadvantages of this type of camera include the loss of the ability to look into the microscope through the eyepiece, the inability of some models to zoom in, which leads to noticeable shadowing along the margins of the camera's field of view, and inaccurate color representation. Nevertheless, this is a good option for people seeking an inexpensive alternative.

Any computer projector will work for this application. Its function is to project the computer that displays the video stream from the microscope camera. Both cable and wireless options are available for connecting projectors to computers.

Numerous makes and models of Tablet PCs are

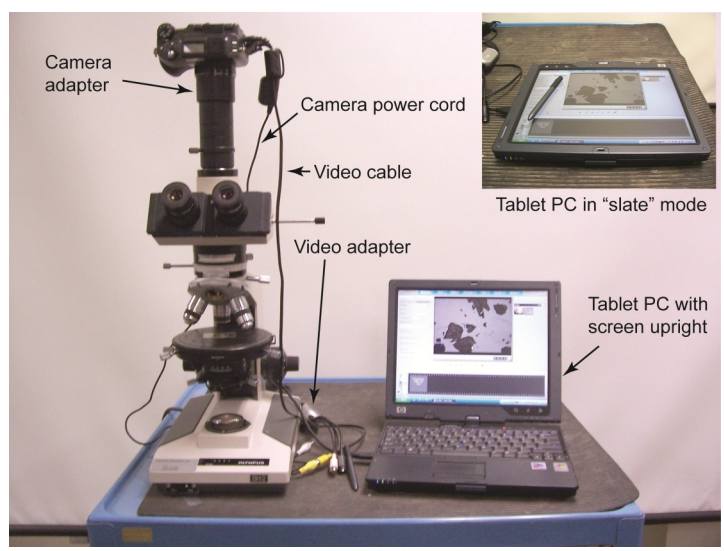

FIGURE 1. Instructor's station for the lecture demonstrations. Inset shows tablet in "slate" mode, with stylus pen sitting on the screen.

available and all will work for this application. We used HP 4200 Tablet PCs running the Windows XP Tablet PC operating system. This model comes equipped with a convertible display that may be rotated and clipped over the keyboard to make a true (slate style) tablet, or setup with the keyboard horizontal and the display upright, like an ordinary laptop. The advantage of this type of Tablet PC is that, when set up like an ordinary laptop, both the keyboard and stylus pen are available at the same time. To type text on a slate tablet, one is limited to using the stylus pen to either tap the keys on the virtual keyboard displayed on the screen or to create characters using the Tablet PC Input Panel in handwriting mode. Use of the stylus pen is easiest in slate mode because the screen is more stable as a writing surface when it has been clipped over the keyboard.

Software

There are two essential software components: video adapter software and software for taking notes. One optional software component is classroom teaching software. For setups that use a camera attached to a C-mount, the video adapter software is used to capture and save images from the video stream. For setups that use a camera to replace the ocular lens on a monocular microscope, that camera's software is used to capture and save images.

We used two different set-ups to affect the transfer of image files from the demonstration computer to computers being operated by students. We used an ad hoc wireless network in fall 2007 but changed to the campus wireless system in fall 2008 to address issues that arose with the ad hoc system. With the ad hoc system, we used an interactive classroom software package called NetSupport School to distribute files from the instructor's computer to the students' computers. However, simultaneous file transfers to multiple computers via an ad-hoc wireless network was slow due to bandwidth issues, taking 3-4 minutes to complete a transfer of several images to all computers. The use of the regular campus wireless network to save and retrieve images to and from a shared folder was much faster – students could retrieve images within seconds after they were saved to the shared folder, and there were no bandwidth limitations.

There are several widely available pen-capable programs that easily embed images and may be used for taking notes. These programs include Microsoft OneNote, Word and PowerPoint. Our goals in choosing a program were to select one that has a shallow learning curve and to maximize the ease of note-taking. Our mineralogy class is taught at the junior level - most students at this level arrive already familiar with Word, and some arrive already familiar with PowerPoint, but few arrive already familiar with OneNote. If familiarity were the only factor to consider, then Word would be the program of choice; however, the way images are formatted inside Word documents can quickly lead to complications that distract students from the primary goal of learning optical mineralogy. Also, Word does not allow typing over embedded images. For these reasons, we chose not to use Word for note-taking during class.

We considered OneNote to be a better choice than Word because it embeds images without formatting complications and allows typing over embedded images. OneNote is a comprehensive note taking program with broad capabilities designed to replace all aspects of conventional note taking. It includes a system for organizing notes and for making audio recordings of lectures; however, some parts are not intuitive at first. For instance, there is no "save" operation – everything is automatically saved. Additionally, notes taken in OneNote flow onto to a single page that continually expands in size, which can lead to a very long page that must be scrolled to see all of the information on the computer screen, unless the user changes the default from an auto-sizing page to a fixed-size page and learns to create new pages as needed. In addition, students in the mineralogy class needed to be able to view and possibly modify their notes after class, when the Tablet PCs were no longer available to them. This required saving the notes in a format that could be read by a program on a pen-absent computer. Two "save as" options are provided in OneNote, the standard Word document format and a web-page (MHTML) format. Pages saved as Word documents did not display correctly inside Word where embedded images had digital ink lines written over them. Pages saved as a web page displayed correctly inside web browsers, but no further modification of the notes is possible from within web browsers. Pages may also be saved by printing to a PDF file using a PDF print driver, whereupon they may be viewed but not modified in readily available applications like Adobe Acrobat Reader.

Of the three programs, PowerPoint seemed to lend itself best to note taking on images. Both digital ink and typed text may be placed over images, and the slides provide convenient breaks similar to pages. In addition, there is no difference in working with notes in

PowerPoint on a pen-absent computer, except for the lack of the stylus pen as an input device; digital ink lines remain correctly displayed over embedded images and students can continue to work on their notes, using the mouse in place of the stylus pen.

In fall 2007, for the first lecture demonstration the instructor used OneNote and for the second and third used PowerPoint. Students were asked to do the same as the instructor for the first two lecture demonstrations in order to provide a basis for comparison, and then given a choice for the third, whereupon all but one student chose PowerPoint. Assessment of student and instructor opinions on the software choice verified that PowerPoint was preferred; hence it was adopted for use in fall 2008 without further exploration.

LECTURE DEMONSTRATIONS USING TABLET PCS

At Northern Arizona University, optical mineralogy is taught within the course GLG309 titled "Mineralogy, Introduction to Earth Materials." The optics portion of the 15–week class occupied about one third of the course and was taught in weeks 5-9. Lectures in this class were 75 minutes long and occurred twice each week. The course

was taught in a lecture hall that seats 48. Class enrollments were 24 in 2007 and 17 in 2008. Tablet PCs were used for three of the lectures for the classes taught in both years as described in detail below. For all other lectures, students took notes using conventional methods. For the lectures that involve the use of the Tablet PCs, the course instructor (TDH) was supported by two assistant instructors.

The course instructor, who was previously unfamiliar with Tablet PCs, prepared for the lecture demonstrations by setting up a practice session in the empty classroom and running through a portion of the first lecture demonstration with the help of the assistants, one of whom had extensive experience with Tablet PCs, pen-capable software, NetSupport School, and networking (co-author MM). It took the instructor about one hour to develop the necessary skills. The instructor operated a microscope and camera that was connected to a Tablet PC and projector to display images on a screen in front of the class. During the lecture demonstrations, images were captured and delivered to the students' Tablet PCs, generally in groups of three or four at a time. Each student loaded the image files into note-taking software, and then annotated the images following the example of the instructor. Students could see how the instructor used the Tablet PC by watching the instructor's computer desktop projected onto a screen at the front of the room. This process was repeated throughout each lecture demonstration.

On the days of the lecture demonstrations the students arrived to find the Tablet PCs set up at their desks, switched on, and fully booted, which required setting up about 15 minutes before the class. At the first lecture demonstration the course instructor introduced the two assistants, who then took about 15 minutes to instruct the students on how to retrieve the image files, how to import them into note-taking software, and how to annotate them with the stylus pen and typed text. The procedure for retrieving image files was different depending on whether the ad hoc or campus wireless systems were used to distribute the images. For students to receive files via Netsupport School on the adhoc system, as done in 2007, the NetSupport School client had to be pre-installed on their computers. The instructor could then connect to all of the students' computers using the instructor's computer as a hub, and push images out to the students' computers and into a desktop folder named "GLG309 Pentab Photos." For students to connect to the campus wireless system, as done in 2008, they had to undertake several steps including logging into the campus network, accepting initial agreements, and mapping the network drive. The instructor saved the images to a folder "GLG309 Pentab Photos" hosted on the shared network drive, which could then be accessed by the students from a short-cut to the folder located on their desktops. The complexity of connecting to the shared network drive was challenging for some students, so a written procedure was distributed with the Tablet PCs in subsequent class periods. Technical questions were answered as they arose. The assistant instructors provided support to individual students as needed throughout the lecture. Students initially configured the Tablet PCs with the screen in the upright position (Fig. 1), which allowed both the keyboard and stylus pen to be used; however, through the course of the three lecture demonstrations, most students clipped the screen over the keyboard ("slate" mode, Fig. 1), which made it easier to use the stylus pen. In 2007, at the end of each lecture demonstration, the file saving utility of NetSupport School was used to save all of the students' notes to the instructor's computer, whereupon they were resaved to a network-accessible class folder where students could access their notes out of class. In 2008, students were shown how to save their notes over the network to their own university-provided space. Students were shown how to annotate images in PowerPoint on a pen-absent computer to allow them to make additional annotations out of class if they desired.

Each lecture demonstration took one class period and addressed aspects of optical mineralogy that require students to integrate image interpretation with optics theory and microscope manipulations. Classes prior to the first lecture demonstration had covered the basic properties of light (wavelength, waveform, propagation direction versus vibration direction), refractive index, Snell's Law, relief, polarization, color in transmitted light, refractometry using Becke line tests, cross polarization, birefringence, the interference color chart, and the uniaxial indicatrix. Lecturing involved writing key equations and brief explanations on the chalkboard combined with a variety of demonstrations using a pad cam illuminated from below (like a light table) together with polarizing filters, cellophane (which is doubly refracting), and calcite and halite crystals. Snell's Law was demonstrated using a laser pointer and a large jar of water containing a suspension of fine particles. By this point in the course students had completed a laboratory exercise using Becke line tests and relief to estimate the refractive index of unknowns, a laboratory exercise involving calcite crystals and polarizing filters to demonstrate the properties of polarization, cross polarization and double refraction, and one homework exercise involving the use of Snell's Law to predict ray paths passing through isotropic substances.

The three lecture-demonstrations were given over a period of four consecutive lecture periods. The class between the second and third lecture demonstrations was a conventional lecture that covered biaxial theory. The figures accompanying the descriptions of the lecture demonstrations (Figs. 2, 3 and 4) came from the fall 2007 class. Similar lecture demonstrations were given in fall 2008, the main differences being the use of the campus wireless network rather than an ad hoc network to transfer images from the instructor to the students, and the use of PowerPoint for note-taking in all lecture demonstrations rather than just during demonstrations two and three. There were also slight differences in content and in the photographs that were taken. Examples of notes taken by two students in the 2008 class are provided in electronic Appendices A and B.

First lecture demonstration

The first lecture demonstration illustrated the following points: (1) in cross polarized light, anisotropic

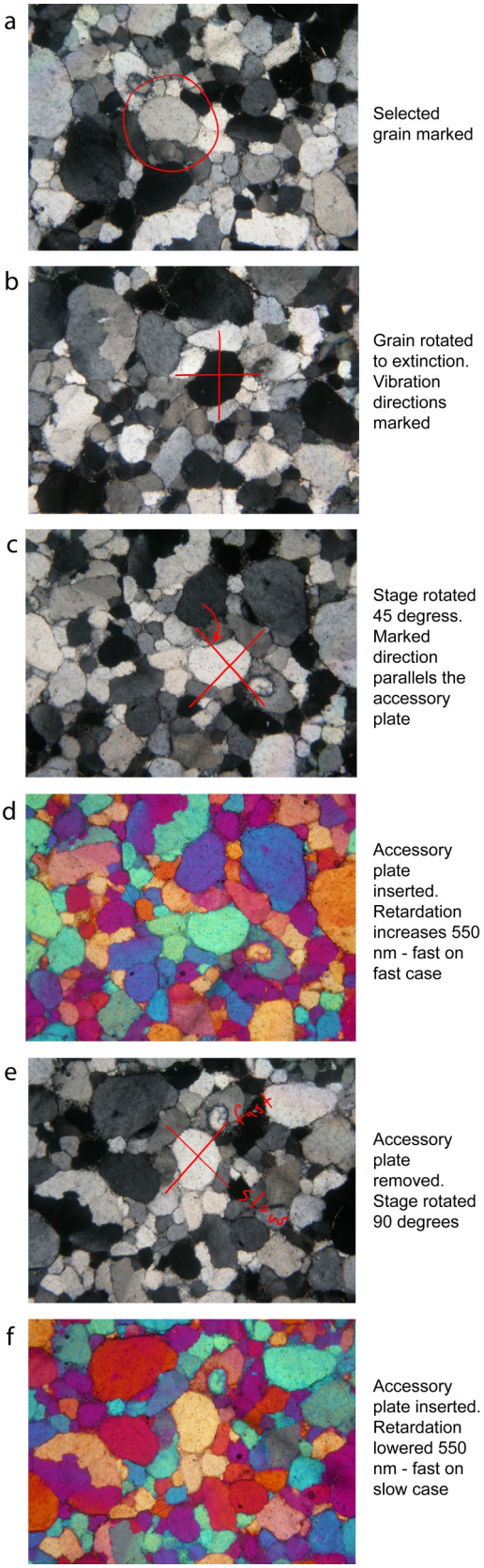

FIGURE 2. Photomicrographs and annotations for the first lecture demonstration. Images were loaded in the order shown, top to bottom (a to f), into OneNote and annotated with digital ink and typed text, as described in the text. The long strip depicts the appearance of a single page in OneNote.

grains display extinction as the stage is rotated every 90°, (2) different grains of the same mineral display different values of retardation as judged from the interference color, (3) in the extinction position, the vibration directions parallel the crosshairs, and (4) the accessory plate may be used to distinguish the fast and slow vibration directions when grains are rotated 45° from extinction. First, a series of photos of a thin section of a quartz sandstone was captured and delivered to students (Figs. 2a-d). The first image captured a randomly selected field of view in cross-polarized light. The second image captured a selected grain within that field of view rotated into its extinction position. The third image captured the same grain rotated 45° clockwise from extinction, and the fourth image captured was the same as the third with the accessory (one wave) plate inserted. The instructor (TDH) and students pulled the images into OneNote, and then used the stylus pen to label color shifts and fast and slow directions. Then two more images were captured of the same grain rotated 90° (Figs. 2e-f), the first without the accessory plate and the second with the plate inserted. As before, the images were delivered to students and then incorporated into OneNote by both students and instructor. Notes were then taken on the images using digital ink and typed text to illustrate how the color shifts changed as a result of the 90° rotation.

Second lecture demonstration

The second lecture demonstration was targeted at illustrating several points: (1) how birefringence varies depending upon the crystallographic orientation of grains in thin section, (2) how to choose a correct grain for getting a centered optic axis figure, and (3) determination of optic sign using the accessory plate. First, a series of three photos of a quartz grain mount in cross-polarized light were captured and delivered to students (Figs. 3a-c). Each photomicrograph was taken after rotating the stage to show that varying degrees of retardation are displayed by different grains, and that all grains fade to extinction through rotations of 90° except for grains with a retardation of zero. One grain in the field of view displayed a retardation of zero, and so was identified as the optimal choice for obtaining a centered optic axis figure. The instructor (TDH) placed the images into PowerPoint, and then annotated several grains using the stylus pen to illustrate variations in c-axis orientations and retardation as students took notes on their copies of the same images, also in PowerPoint. The purpose of switching from OneNote to PowerPoint was to determine student preferences, as well as the advantages and disadvantages of the different programs.

To demonstrate the method of determining optic sign, two more photos were captured and delivered to students (Figs. 3d-e). The first image was of the interference figure obtained on the one grain displaying zero retardation, which turned out to be almost perfectly centered. The second image was of the interference figure after insertion of the l-plate. After loading the images into PowerPoint, one per slide, the instructor labeled the parts of the uniaxial figure and the color shifts using digital ink and typed text as students took notes on their copies of the

images.

To conclude the second lecture demonstration, a series of three more photos (Figs. 2f-h) were captured on a calcite grain mount. These images served to reiterate the points illustrated earlier in the lecture, this time using a mineral of very high birefringence. The first image captured grains displaying both comparatively high and low retardation, the second captured an interference

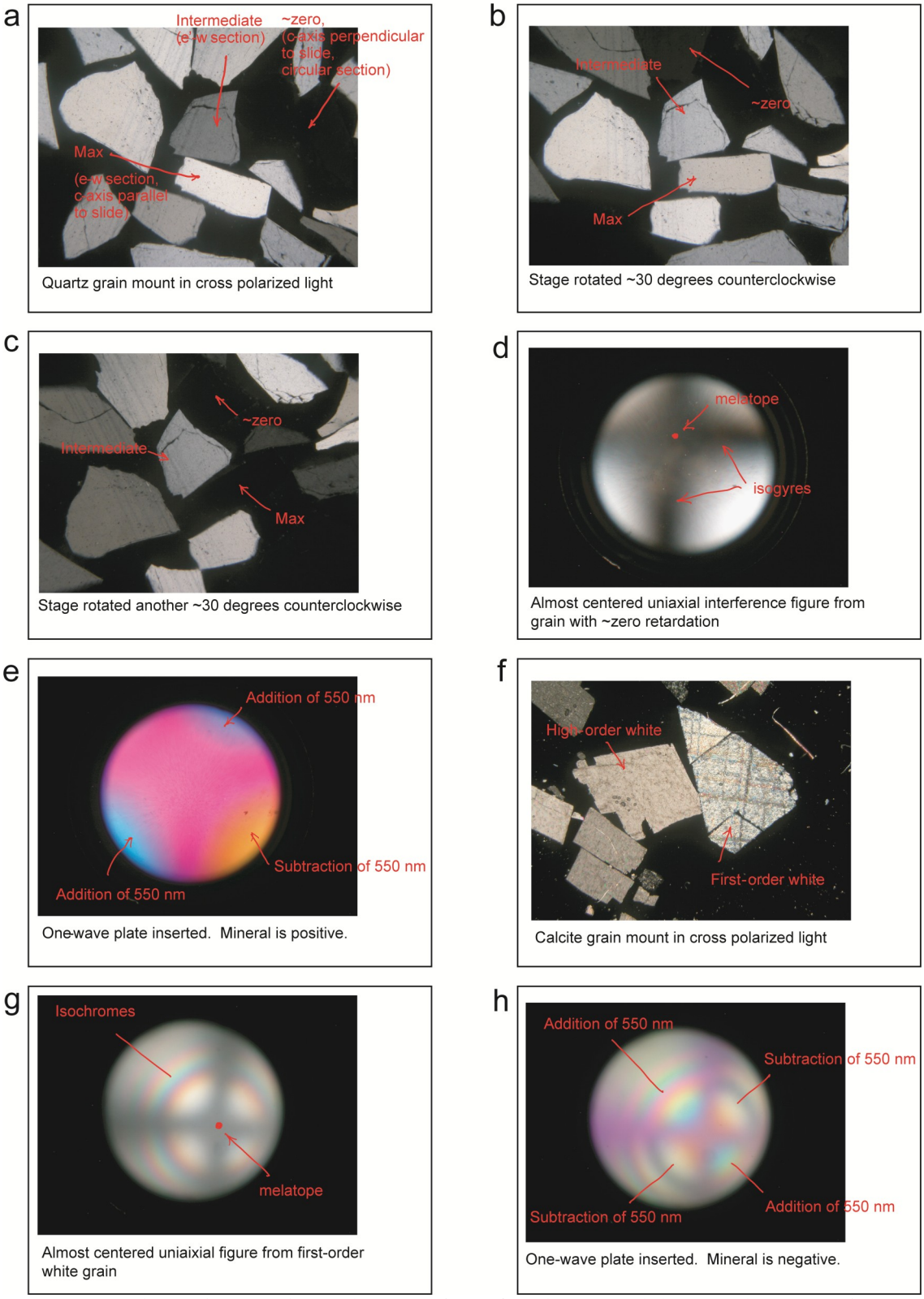

FIGURE 3. Photomicrographs and annotations for the second lecture demonstration. Images were loaded into PowerPoint, one image per slide, in the order shown (a to h), and annotated with digital ink and typed text, as described in the text. On a-c, relative retardations are indicated with the labels "max" (maximum), "intermediate," and "~zero."

figure obtained on the grain displaying the lowest retardation, and the third captured the interference figure of the latter grain with the l-plate inserted. After the images were transferred to students and pulled into PowerPoint, one per slide, the instructor annotated them in digital ink using the stylus pen and typed text, as students took notes on their copies of the same images.

Third lecture demonstration

The third lecture demonstration was aimed at illustrating the interpretation of acute bisectrix figures and

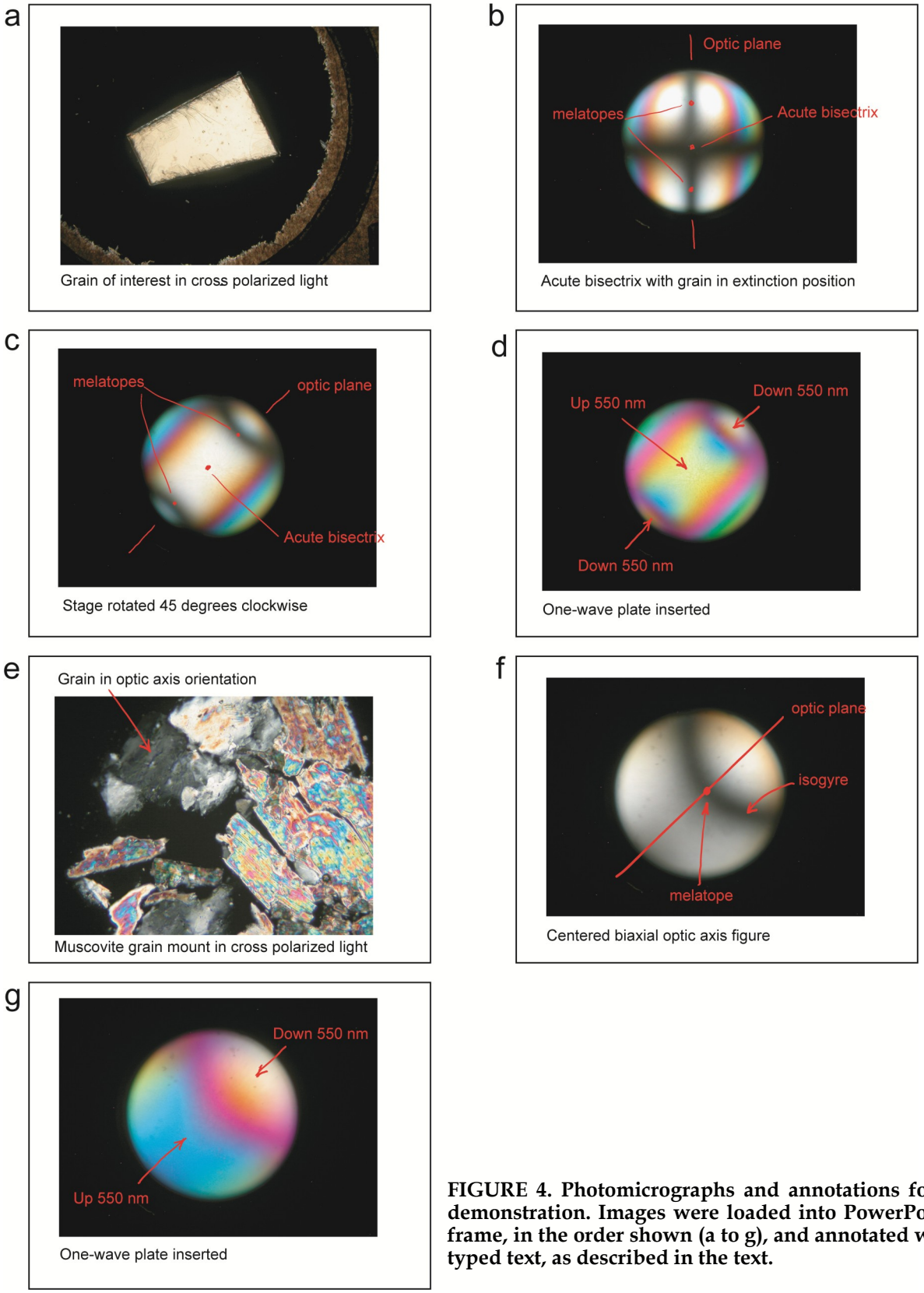

FIGURE 4. Photomicrographs and annotations for the third lecture demonstration. Images were loaded into PowerPoint, one image per frame, in the order shown (a to g), and annotated with digital ink and typed text, as described in the text.

centered biaxial optic axis figures to determine optic sign. First, a series of four images were captured on a muscovite grain oriented with one acute bisectrix perpendicular to the slide (Figs. 4a-d). The first image captured is of the grain in cross-polarized light – it displays a high order white interference color. The second displays the interference figure with the grain in its extinction position, the third displays the same interference figure with the grain 45° from extinction (optic plane in the NE-SW orientation), and the fourth displays the same view as the third with the l-plate inserted. The images were delivered to students and loaded into either PowerPoint or OneNote, whichever was preferred by each student. Only one student used OneNote. The instructor loaded the images into PowerPoint. Both students and instructor then annotated the images using digital ink and typed text.

A second set of images of a muscovite grain in a grain mount of standard (30 µm) thickness was then captured to show a centered optic axis figure (Figs. 4e-g). The first image is in cross-polarized light and shows the grain selected for determining optic sign - the one displaying the lowest retardation as judged from the interference color (low 1° grey). The second shows the optic axis figure, almost perfectly centered, with the optic plane in the NE-SW orientation, and the third shows the same view as the second with l-plate inserted. The images were delivered to students, whereupon both students and instructor annotated them using digital ink and typed text.

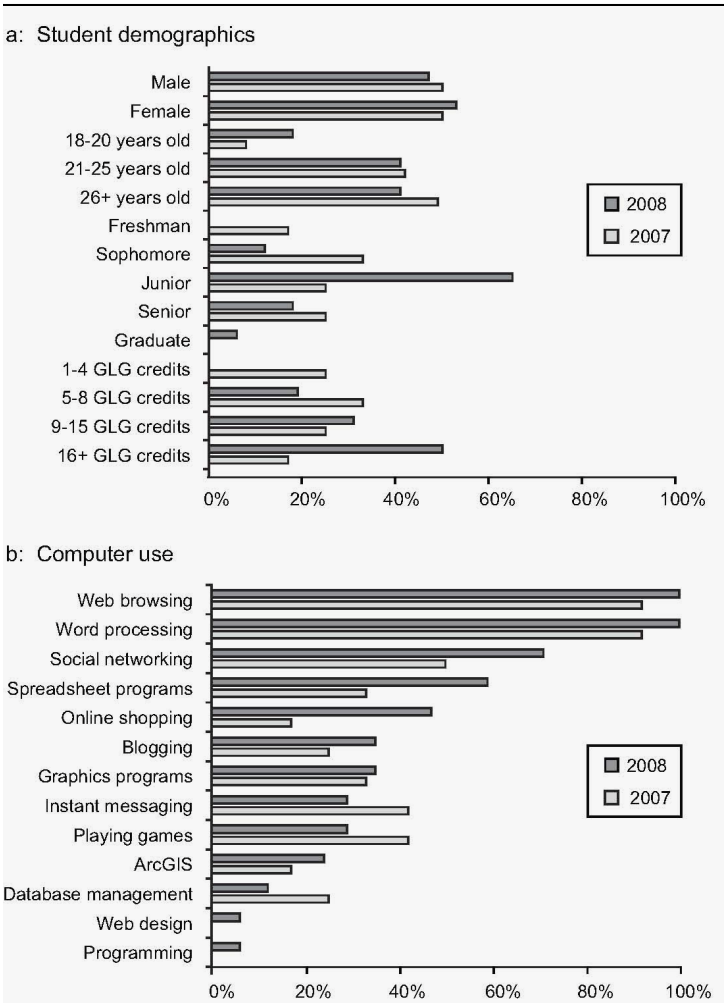

FIGURE 5. Data on demographics and computer use for both 2007 and 2008 classes. a. GLG credits refers to the numbers of geology credits taken at Northern Arizona University prior to taking the mineralogy class. b. The data show the percentage of students who say they routinely use computers to perform the task indicated.

ASSESSMENT

Evaluation data were collected through student surveys, instructor interviews, and in-classroom observations. In both fall 2007 and fall 2008, students were asked to complete surveys before the first lecture demonstration involving Tablet PCs and after the last one. The evaluator performed on-site observations for the first and second lecture demonstrations in 2007 and for the second lecture demonstration in 2008. Survey responses were gathered from 18 students out of 24 enrolled in 2007 and 14 students out of 17 enrolled in 2008. Surveys were conducted on-line, and participation was both voluntary and anonymous.

Figure 5a compares student demographics from 2007 and 2008. In general, students in 2008 were slightly younger than in 2007, but with more geology experience as shown by overall higher class standing and a greater number of geology credits. In both 2007 and 2008, most students used computers regularly for a variety of activities, indicating a familiarity with computer technology in general. Students in 2008 were slightly more experienced with computers than those surveyed in 2007 (Fig. 5b). Nearly two-thirds (68%) of the 2008 students spend more than 10 hours per week using computers (Fig. 6a). About three-quarters (76%) had not used a Tablet PC prior to the lecture demonstrations (Fig. 6b). The 2008 students were slightly more experienced with computers and Tablet PCs prior to working with the Tablet PCs than the 2007 students.

Figure 6c compares student familiarity with Tablet PC technology before and after the lecture demonstrations using a 1 to 5 scale (1 = not at all familiar and 5 = very familiar). Average values greater than 2.5 indicate some familiarity with Tablet PCs. Although they rated themselves as less familiar with Tablet PCs prior to using them, the 2008 students on average reported more familiarity with the Tablet PCs after using them than the 2007 students did.

Overall, students in both years enjoyed using Tablet PC technology (Figure 6d). Comparing pre- and post-lecture responses illustrates that students enjoyed using the technology more than they anticipated. The 2008 students on average had a more enjoyable experience than the 2007 students. All students in both years reported a preference for writing notes by hand prior to the lecture demonstrations. After the lecture demonstrations, however, the preference for using the Tablet PCs increased to increased to 14 percent in 2007 and 43% in 2008 (Figure 6e). In 2008, 93% of students reported an improvement in their ability to use the Tablet PC (Figure

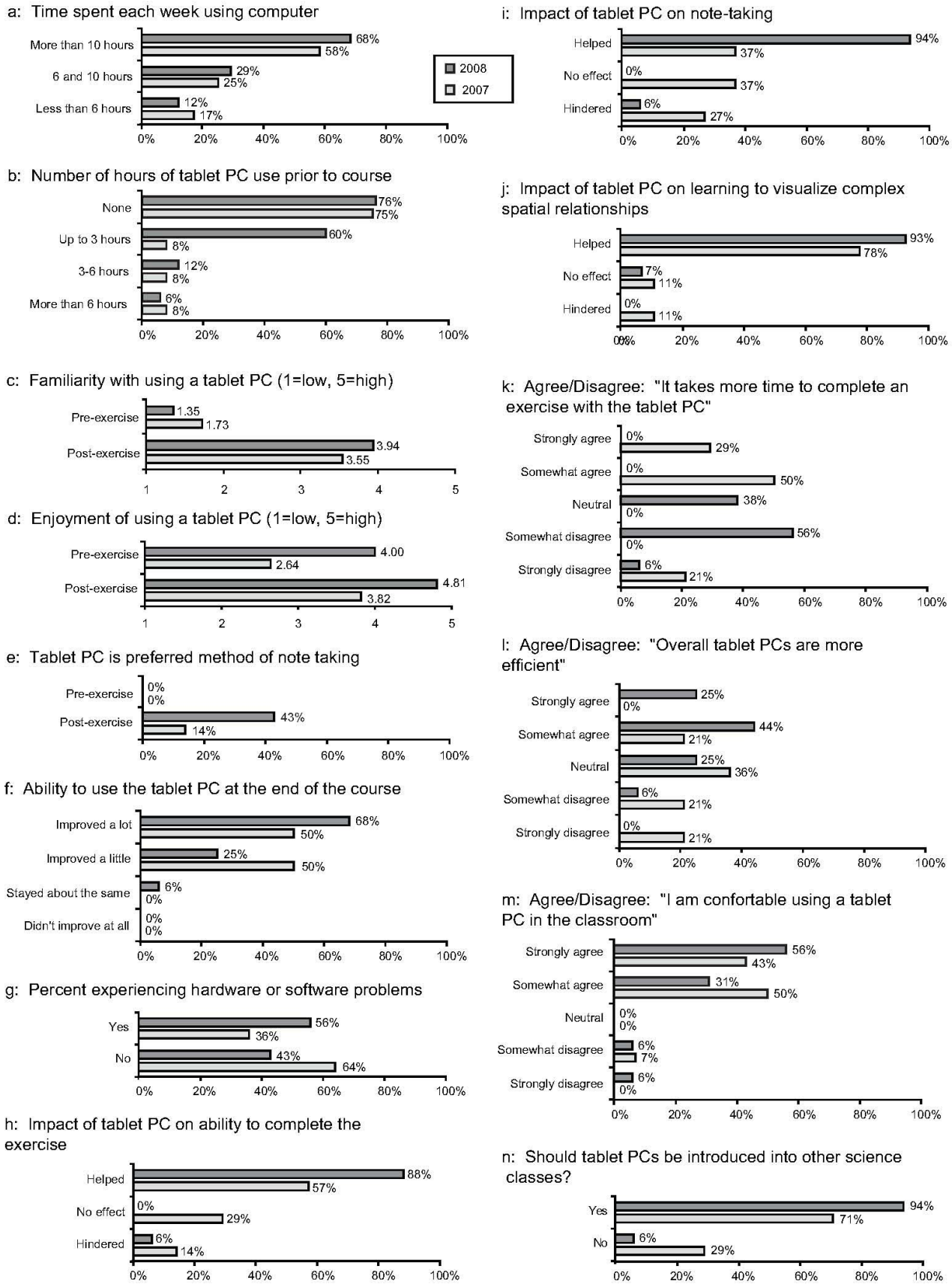

FIGURE 6. Survey responses from 2007 and 2008. a and b: Responses from surveys administered before the lecture demonstrations. c-e: Comparison of responses from surveys administered both before and after the lecture demonstrations. f-n: Responses from surveys administered after the lecture demonstrations.

6f). Many students who reported they improved a lot said that they went from not knowing how to use a Tablet PC to proficiency over the three class periods. "I had no idea how to use a Tablet PC before and now I prefer it more. It saved time from trying to draw, and I could very easily add more notes later." Another student commented "I became aware of how easy it is to multi-task using different programs on the Tablet PC." Students who reported improving a little said they would like more time with the Tablet PCs to become proficient.

Over half (56%) of the students in 2008 reported experiencing a hardware or software problem during the lecture demonstrations (Figure 6g), 20 percent more than in 2007. As in 2007, many of the software problems reported were networking issues. Some students reported problems logging on (2008 only), calibrating the pen for left-handed use, power loss due to battery failure, and difficulty mapping network drives (2008 only). Even though 2008's students experienced more technical problems than in 2007, students reported that the Tablet PCs helped them learn the material covered in the lecture by enabling them to visualize complex relationships and effectively take notes that they could easily update and refer to later (Figs. 6h, 6i, and 6j). Students' comments in 2008 included "It helped to visualize the concepts involving optical mineralogy as they appear in thin section," "The notes taken on microscope slides were very useful when studying and when working in lab," "Couldn't have done it without the colored visuals," and "I was surprised at… how much they helped me understand the lesson better, both in class and out of class."

In 2008, majority opinions on how Tablet PCs compare to traditional note-taking methods reversed compared to 2007 (Figs. 6k and 6l). In contrast to 2007, most students in 2008 (62%) thought that Tablet PCs take *less* time than traditional methods and were *more* efficient. This can be attributed to the improvement made to the method of image delivery, which was slow in 2007 due to using an ad hoc wireless network, and fast in 2008 due to using the campus wireless network. Students overwhelmingly said they were surprised at how easy the Tablet PCs were to use: "It's so much easier, faster, and more organized. Plus notes can be added on as I study later." One student noted that she could move at the speed of the instructor. Another said simply, "I was able to get better notes."

In the post-surveys for both 2007 and 2008, most students said they were comfortable with using the technology in the classroom (Fig. 6m). In 2008, 94% of the respondents said they would recommend introducing Tablet PCs in other science courses (Fig. 6n), a notable increase over 2007. Students specifically noted that understanding three-dimensional concepts requires good visuals, commenting for example: "It might make it easier to explain difficult concepts with pictures, graphs, maps, etc. that can be customized by each student." They also mentioned the advantage of not having to make quick hand drawings in their notes, how color helps with note-taking, and the ability to easily fix mistakes with the Tablet PC. Several comments highlighted the benefits of learning current technology that students will encounter when working in the 'real world'. One student commented "With certain material, it really helps to get involved while learning instead of just watching the instructor."

CONCLUSIONS

The main objectives of this work were to develop, test and refine methods that use Tablet PCs in lecture demonstrations to assist the learning of complex visualizations in optical mineralogy. Most students felt that the Tablet PCs helped them with the complex visualizations. Student opinions were more favorable the second time they were used (fall 2008), when the setup was modified to expedite the transfer of photomicrographs to the students from the instructor during the lecture. The use of the campus wireless network in 2008, instead of the ad hoc wireless network in 2007, reduced the distraction of the transfer time for images from several minutes to seconds. In both classes, students felt more comfortable with the technology after using it and felt that the technology would be of benefit to other science classes. Other advantages mentioned by students included that it was helpful to have the images close up and helpful that the colors were highly accurate.

This study broadens the application of Tablet PCs in geoscience education beyond its previously established role of field mapping and data collection. Tablet PCs also provide advantages for instruction in the classroom setting, where they may be used for note-taking on digital photographic images that are delivered to students electronically during lectures. Working directly with the images leads to greater student engagement and peripheral participation in the lecture. Furthermore, the high accuracy color of the images assists learning because the subtle color changes that students must learn to interpret are realistically depicted. Although there is a learning curve associated with the technology and software for both instructors and students, this is compensated by eliminating the time-consuming task of sketching into notes images displayed on a screen in the front of a classroom and replacing with digital photographs, giving students more time and mental energy to focus on learning the skills.

Acknowledgments

Grants from the Hewlett-Packard Charitable Foundation funded the acquisition of the HP 4200 Tablet PCs. Additional support came from Northern Arizona University's E-learning Center and a grant from Science Foundation Arizona. Reviews by M. Gunter and an anonymous reviewer greatly improved the paper and are much appreciated.

APPENDICES

Electronic Appendix A. First example of notes taken by a student in the 2008 class using PowerPoint.

Electronic Appendix B. Second example of notes taken by a student in the 2008 class using PowerPoint for the same lecture as Appendix A.

REFERENCES CITED

Anderson, Ri., Anderson, Ru., Simon, B., Wolfman, S.A., VanDeGrift, T., and Yasuhara, K., 2003, Classroom presentation from the Tablet PC, ACM SIGSCI Bulletin, v. 356, p. 238.

Anderson, Ri., Anderson, Ru., Simon, B., Wolfman, S.A., VanDeGrift, T., and Yasuhara, K., 2004, Experiences with a Tablet PC Based Lecture Presentation System in Computer Science Courses, ACM SIGSCI Bulletin, v. 36, p. 56-60.

Berque, D., Bonebright, T., and Whitesell, M., 2004, Using pen-based computers across the computer science curriculum, ACM SIGCSE Bulletin, v. 36, p. 61-65.

Bransford, J. D., Brown, A. L., and Cocking, R. R., 2000, How People Learn: Brain, Mind, Experience, and School. Washington, D.C., National Academy Press, 374 p.

Brimhall, G.H., Vanegas, A., and Lerch, D., 2002, GeoMapper Program for Paperless Field Mapping With Seamless Map Production in ESRI ArcMap and GeoLogger for Drill-Hole Data Capture: Applications in Geology, Astronomy, Environmental Remediation, and Raised-Relief Models. U.S. Geological Survey Open-File Report 02-370.

Clegga, P., Bruciatelli, L., Domingosa, F., Jonesc, R.R., De Donatisb, M., and Wilson, R.W., 2006, Digital geological mapping with Tablet PC and PDA: A comparison, Computers & Geosciences, v. 32, p. 1682-1698.

De Donatis, M., and Bruciatelli, L., 2006, MAP IT: The GIS software for field mapping with Tablet PC, Computers & Geosciences, v. 32, p. 673-680.

Dyar, M.D. and Gunter, M.E., 2008, Mineralogy and Optical Mineralogy. Mineralogical Society of America, Chantilly, Virginia, 708 pp.

Gunter, M.E., 2004, The polarizing light microscope: Should we teach the use of a 19th century instrument in the 21st century? Journal of Geoscience Education, 52, 34-44.

Knoop, P.A. and van der Pluijm, B., 2004, Field-based information technology in geology education: GeoPads, Eos, v. 85, p. 47.

Knoop, P.A. and van der Pluijm, B., 2005, GEOPAD: GIS-enabled field science education, Geological Society of America Abstracts with Programs, v. 37, p. 445.

Lave, J., and Wenger, E., 1991, Situated Learning: Legitimate Peripheral Participation. Cambridge, UK, Cambridge University Press, 134 p.

Manone, M.F., Umhoefer P.J. and Garcia, P., 2006, Integrating emerging technologies throughout the geology undergraduate curriculum: Using Tablet PCs, wireless networks, and digital geospatial data in the classroom, lab, and field. In Berque, D., Prey, J.C., and Reed, R.H., editors, The Impact of Pen-based Technology on Education: Vignettes, Evaluations, and Future Directions, Purdue University Press, p. 123-130.

Manone, M. F., Umhoefer, P. J., and Hoisch, T. D., 2003, A digital field camp: applying emerging technology to teach geologic field mapping, Geological Society of America Abstracts with Programs, v. 35, p. 411.

Manone, M.F., Umhoefer, P.J., Springer, A., Hoisch, T., Newell, S., and Solop, F., 2007, An incremental approach for teaching field mapping using rugged tablet computers and GIS, Geological Society of America Abstracts with Programs, v. 39, p. 623.

Subhlok, J., Johnson, O., Subramaniam, V., Vilalta, R., and Chang, Y., 2007, Tablet PC video based hybrid coursework in computer science: report from a pilot project, ACM SIGCSE Bulletin, v. 39, p. 74-78.