Through Their Eyes: Tracking the Gaze of Students in a Geology Field Course

Adam V. Maltese,[1,a] Russell N. Balliet,[2] and Eric M. Riggs[3]

ABSTRACT

The focus of this research was to investigate how students learn to do fieldwork through observation. This study addressed the following questions: (1) Can mobile eye-tracking devices provide a robust source of data to investigate the observations and workflow of novice students while participating in a field exercise? If so, what are the strengths and limitations of mobile eye tracking? (2) If these devices offer a unique source of data to investigate student work, what findings might be helpful for improving field instruction? To address these questions, we used mobile eye-tracking devices in a pilot study to collect video from students completing mapping exercises during a geology field course. Data were collected from six students participating in two different parts of an exercise where they were asked to create geological maps of an area based on their field observations.

From this study, we learned that conducting eye-tracking research in field conditions is technically demanding and operationally difficult. We found that most of our analysis was based on reviewing the scene video and did not require the eye-tracking information. In reviewing the scene videos, substantive features of students' observational practices were exposed. We found that students struggle with foundational mapping practices, miss opportunities to collect key data, and are often distracted or disengaged during direct instruction. We observed instances of swarm behavior where students tend to group around outcrops even when nominally working independently. We also noted key differences in student behavior working individually compared with group mapping. We believe these findings provide data for geoscience educators to consider when thinking about ways in which to develop the observational skills of their students and to design appropriate field course instruction. © *2013 National Association of Geoscience Teachers*. [DOI: 10.5408/11-263.1]

Key words: field learning, mapping, instruction, eye tracking

PROBLEM

Both *America's Lab Report* (Singer et al., 2006) and the *National Science Education Standards* (NRC, 1996; NRC, 2011) discuss the importance of "observation" as a critical skill provided by laboratory and field science at all educational levels. However, Roth et al. (2001) commented that in most educational work, visual observation is seen as "unproblematic and taken for granted." Roth et al. concluded that in science education, there is an implicit assumption that students extract understanding from their tactile and visual experiences of natural phenomena (e.g., laboratories, science museums), and yet the validity of this assumption and the mechanisms by which this occurs are rarely discussed in the research literature.

Despite the goal of training students to observe and understand natural phenomena, research indicates that laboratories are often disconnected from real-world experiences (Maltese et al., 2010), and instruction is often designed to routinize inquiry experiences (Luft et al., 2004). Findings about learning from observations overwhelmingly indicate that information is not extracted in the form, or to the degree, that is intended (e.g., Driver, 1983; Eberbach and Crowley, 2009). Research has shown that the *depth of knowledge* held by the observer plays an enormous role in what is observed and gleaned from that observation (e.g., Chase and Simon, 1973; Lindwall and Lymer, 2008). As a result, novice students are unclear about the purpose of observations (Haslam and Gunstone, 1998) and often fail to grasp the connection between observed phenomena and deeper scientific concepts (e.g., Ford, 2005; Lehrer and Schauble, 2004).

Duschl and Osborne (2002) argue that observation is a foundational element of scientific practice, but the research indicates that students are not receiving educational experiences that encourage development of these skills. Given that many geology field courses focus on teaching students to make interpretations of their observations of natural phenomena, and given the general lack of understanding on how this observational learning occurs, the focus of this research was to investigate how students make observations of natural phenomena during a geology field course. Specifically, this study addressed the following questions:

1. Can mobile eye-tracking devices provide a robust source of data from which to investigate the general observational practices and workflow of novice students while participating in a field exercise? If so, what are the strengths and limitations of mobile eye tracking in investigating student workflow and observational skills?
2. If the data from these devices offer a unique source of data for which we can study the observational practices and workflow of students, what do these

Received 15 September 2011; revised 25 April 2012; accepted 29 August 2012; published online 21 February 2013.

[1]School of Education, Indiana University, Room 3054, 201 North Rose Avenue, Bloomington, Indiana 47405, USA
[2]Independent Researcher.
[3]College of Geosciences, Texas A&M University, Room 202 Eller O&M Building, 3148 TAMU, College Station, Texas 77843, USA
[a]Author to whom correspondence should be addressed. Electronic mail: amaltese@indiana.edu.

data indicate that might be helpful for improving field instruction?

Our experiences as science instructors with students ranging from middle school through graduate school, along with our discussions with science colleagues, confirm that many students are deficient in their observational skills. We are interested to know if students follow any type of ''workflow'' or repeating pattern of observational practices as they investigate a field area. The goal of this study was to determine if there is evidence for these deficiencies and to test the capabilities of mobile eye-tracking technologies for collecting data on students in a field setting.

While we are aware of others pursuing similar research on fieldwork (e.g., work by Petcovic and Libarkin [e.g., Petcovic et al., 2009; Callahan et al., 2010] and work by the University of Rochester/Rochester Institute of Technology group [Choi, 2010]), most other studies take the approach of looking for differences between experts and novices. While this approach is quite common and valuable in attempts to understand the differences in cognitive processing between the two groups (e.g., Chase and Simon, 1973), the pedagogical implications from these studies are often much more difficult to surmise. In contrast, we collected data from students, who can generally be classified at the novice end of the spectrum, participating in actual learning experiences as part of a geological mapping course.

THEORETICAL BACKGROUND

Guiding our work is the belief that science knowledge and observational skills are developed through observing particular phenomena—a form of what Goodwin (1994) termed *professional vision*. According to Goodwin, expertise is about more than having greater depth of knowledge in a discipline. Instead, echoing findings from Chase and Simon (1973), he claimed that expert practice involves a way of seeing and interpreting the world, and documented how experts pass on their way of ''seeing'' to their students through three steps: coding, highlighting, and by creating and interpreting graphical representations. Taken together, these three processes help attune an observer to relevant aspects of a situation; aspects that a novice might not notice or understand. *Coding* involves learning to use a common language with which to make and discuss observations in a given discipline. Goodwin discusses how coding ''structures perception'' but notes that this does not guarantee accurate judgments. *Highlighting* is the process by which a person versed in a field makes an object stand out from the background noise, often providing salience to that object. This is significant because research shows that salience is a key feature in making observations of natural phenomena (Roth et al., 2001; Lindwall and Lymer, 2008). Finally, *graphical representations* are a critical means of sharing and describing information that would be difficult to understand as spoken or written word. In this way, interpreting graphical representations becomes another form of literacy that is central to a discipline, and it provides a means of communicating specific information. As Goodwin notes, in expert practice, these three processes are often intertwined (making representations involves coding and highlighting) and are frequently passed on to novices through apprenticeship (or cognitive apprenticeship; Roth, 1995).

We believe that these skills are at the core of what instructors try to teach students in many geological field courses, where students: are taught the common language used in creating geologic field notes, maps, and interpretations; take part in activities to develop their skills at separating signal from noise while making field observations; and create geologic maps and cross sections to share their interpretations with their classmates and instructors. These activities reflect the coding, highlighting, and creation of graphical representations discussed by Goodwin (2004) and therefore provide the framework for the current study.

DESIGN/PROCEDURE

Setting

The setting for data collection was the Indiana University Judson Mead Geologic Field Station (IUGFS), located in the Tobacco Root Mountains near Cardwell, Montana. The IUGFS is situated in close proximity to the three major structural styles of the Western Cordillera of North America—basement-involved block uplifts of Laramide-style deformation, fold and thrust shortening of the Sevier orogeny, and the Basin and Range style of deformation. Students are involved in the study of stratigraphic sections ranging from 3.2 Ga metamorphic complexes to <65 Ma (Cenozoic) stratigraphic packages that reflect a variety of depositional environments and tectonic influences (for greater detail, see Douglas et al., 2009). The IUGFS has been in operation for over 60 y and hosts a number of field classes for geology students, educators, and geology enthusiasts.

Courses at the IUGFS are 6 weeks long and are intensive (i.e., 6 d/week, 10–12 h/d). Students generally are introduced to a new topic and area for a few days (*coding and highlighting*), complete a project within that area, and then complete an ''independent'' exercise as a summative assessment for that unit. The independent exercises involve taking students to an area they have not worked in before, where they then complete a geologic map detailing the structure of that area (*graphical representation*).

Data Collection

As stated, the goals of this study were to explore the feasibility of collecting data from students in the field environment using mobile eye-tracking devices (Fig. 1a) and to collect data on the observational behaviors of students during field exercises. To accomplish these, we collected video from students participating in a long-established summer field course on geologic mapping. Data were collected from six student volunteers (five undergraduates and one MS student) participating in two different parts of a mapping exercise near the beginning of a field course. The entire exercise comes approximately 7–10 d into the field course. By this time, students have visited various geologic sites, where they have learned some of the basic conventions of structural mapping, such as locating themselves on a map, data collection and navigation strategies, and how to use geologic tools to collect this data.

For this study, we focus on data from six students collected during two parts of the first ''practice'' independent exercise. The first part of the practice independent is designed to acclimate students to the goals, rules (i.e., no verbal communication with other students), and general

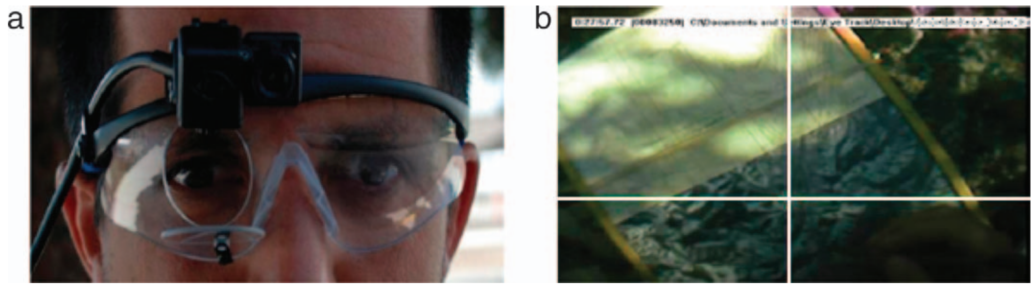

FIGURE 1: (a) Image of mobile eye goggles. Scene camera is located closest to the bridge of the nose and is pointed forward. Eye camera is centered over the pupil and points downward to capture reflection of the eye off of detached monocle. A wire leads from the cameras to a video recorder worn in a small hip-pack. (b) Snapshot from mobile eye video. The image was captured when the student was seated and working to reconcile location on a topographic map (top left of frame) and aerial photo (lower right of frame). The crosshairs indicate the current point of gaze.

logistics of these exercises and to give students a half-day warm up for the full-day independent exercises that students experience later in the course. The independent practice begins with students receiving a brief introduction to the field area and the conventions for marking the boundary of the area with flags. After receiving a set of materials including a topographic map and a pair of stereophotos, the students set out to make observations and map the defined area. Students generally take a few hours to traverse out and back across the area in the morning, and they rendezvous for lunch and to turn in their maps and cross sections. After lunch, the second part of the learning exercise begins. Students are split into groups based on the number of instructors, and they spend the next few hours completing a walkthrough of the field area with a faculty member, who discusses data collection strategies, the rock units encountered, and general interpretation of the stratigraphic package being studied. We will use the terms *independent* and *walkthrough* to differentiate between these two activities throughout the paper.

Eye-Tracking Devices

To collect the gaze data, participants wore a pair of Applied Science Laboratories (ASL) Mobile Eye[1] glasses fitted with two cameras (Fig. 1a). In this design, one of the cameras looks out from the glasses and captures the scene from the viewpoint of the student, while the other camera looks inward and tracks the movement of the participant's right eye. These two recordings (scene and eye) are interleaved, frame by frame, to produce a video that indicates both where the student was looking within the environment (e.g., rock face or field notes) and where the student was specifically fixating (e.g., notes or hand sample) (Fig. 1b). The glasses units are generally lightweight (<100 g), and the recording time on the devices we used was mostly limited by the mini-digital video media required by the recorder. The cameras were connected to a recorder and rechargeable battery pack, which can be worn as a hip pack (<1 kg) or placed in a backpack during use.

To achieve accuracy, it is necessary to calibrate the units in the field with each new user. We employed a basic calibration where volunteers stood approximately 3–4 m away from the researcher. Students were asked to keep their head centrally aligned with the researcher while moving their eyes to fixate on an orange field book held at different locations. While it is also possible to calibrate the unit at different distances to improve accuracy when a student is close to an object or very far away, we did not find these secondary calibrations very helpful when it came to processing the data.

If robust data are collected after these calibration efforts, it is possible to construct fixation durations to obtain a quantitative measure of period of time during which students are attending to particular features, which can provide a relative measure of their mental expenditure during the activities (Rayner, 1998). Additionally, the videos provide an audio track that allowed us to investigate how verbal cues, nonlinguistic utterances, and incidental, momentary, permitted verbal interaction with classmates and instructors influenced behavior.

Sample

For this research, we rented three mobile eye-tracking devices to collect eye-tracking data from a set of three student volunteers during the morning independent exercise, and from three different students taking part in the afternoon walkthrough. Each student wore the tracking device for approximately 45–60 min (Fig. 1b). As an additional piece of data, one of the students volunteered to review her video with the researcher and an instructor to discuss what she was thinking/doing while traversing the field area.

While we originally intended to record students while they spent hours in the field, the equipment limitations noted previously and minor student complaints caused us to rethink this strategy. Student complaints included having a bit of a headache from wearing the goggles, sweat running into their eyes while hiking through the field area, and difficulty in using a hand lens. Given these issues and an overall objective to collect data from multiple students, we sought different volunteers for the two parts of the independent exercise and walkthrough.

Analytical Methods

The coding we describe here focused on the videos collected from the three students who wore the eye-tracking

[1] Readers interested in learning more about the technical features of the devices are directed to asleyetracking.com. The units we used have been upgraded to improve recording time and mobility.

TABLE I: Description of codes used to analyze student video data.

Code Name	Description
Notes	Student is writing notes or referring to field book
Outcrop	Student is working at an outcrop taking samples, measurements, or just looking at the rock
Mapping	Student is working on map drawing contacts, looking at aerial photos, or just looking at map (not clearly locating)
Location	Student trying to find themselves on the map or in three-dimensional space
Moving and searching	Student actively moving and searching for outcrops

units during the morning practice independent exercise. Erickson (2006) points out that while video provides more potential information than can be recorded by other qualitative means, the amount of detail can overwhelm analysts. Finding salient features within the video records takes multiple passes through the data and an iterative process of hypothesis building and refinement. Macrolevel analysis began with our first viewing of the videos. The goal here was deconstruction—finding small parts of video or audio that showed significant events. For this study, we define significant events to be any activity related to students completing their mapping exercise or moving through the field area. While there was a brief episode (~45 s) in one video where a student was swatting away mosquitoes, overall, we saw no evidence of students eating, daydreaming, or becoming involved in other distractions during the independent exercise. Audio records of a single student were also extracted from the original video, as well as from the follow-up review. We analyzed these data using a "progressive refinement of hypotheses" (Engle et al., 2009), an iterative approach where multiple passes through the data lead to refinement and development of robust hypotheses. At the start, coding was emergent; no pre-established coding scheme existed. Each video was broken down and coded for significant events, dialogue, and nonverbal interactions. Pertinent sequences were transcribed and coded, with data handled in the *NVivo* (ver. 8) and *ELAN* (ver. 3.9) software packages. After completing this for each video, comparison (recomposition) began. This process was iterative as ideas were constructed and deconstructed with each pass through the data. The coding presented in this analysis was initiated by the lead author and then reviewed and refined by the other authors. During the revision of codes, the authors communicated back and forth about the definition of codes and identification of representative video samples. We also discussed the timing and coding of passages until there was complete agreement. This cycle was ongoing as we continued to develop a robust coding scheme and as we generated, tested, and refined various hypotheses with each review of the data. The codes used for this analysis are described in Table I.

LIMITATIONS

As with most exploratory studies, our results cannot be readily generalized to the population of geoscience students until we are able to collect data from a larger and more diverse sample of students. Additionally, both technological (recording time) and research (access to student work) limitations led to incomplete data records for each student involved in the research. We were only able to capture a snapshot of what occurred during these field exercises based on the recording limitations of the devices. While we were not able to capture the full amount of time students were in the field, we did capture the time when they were interacting with the key outcrops in this particular field area. Review of the associated global positioning system tracks for each student indicated that none of the students completing the independent exercise ventured back into this part of the field area when they were not wearing the eye-tracking devices.

FINDINGS AND ANALYSIS

The results we present are directed toward answering our stated research objectives. First, we mention the benefits and difficulties of using mobile eye-tracking data to shed new light on these practices. Next, we present the findings for the range of workflows observed as students participated in the independent practice. Finally, we discuss the videos captured from students during the walkthrough exercise.

First, we want to make mention of our "findings" regarding using the eye-tracking devices in this context. We feel that the overwhelming strength of these devices was the recorded scene image and audio tracks that they provided. While we originally believed the ability to determine exactly the point of gaze for each participant was critical, the tracking accuracy was spotty on nearly all student volunteers, and we found more value in the overall scene camera information, because it did well in capturing all the movement and most of the activities the student was performing in the field (capturing writing/drawing is dependent upon how students work in the field). There were a number of issues that made tracking difficult. First, to obtain precise and accurate gaze points, the devices need proper calibration. However, since students are making observations at dramatically different scales, from studying an object up close (e.g., notebook or hand sample) to taking in outcrop-scale features or the overall landscape, the device needs to be calibrated for each of these situations to produce valid results across contexts. Other factors such as the brightness of the intense alpine sun and student readjustment of the goggles (to use a hand lens or stereoboard; to climb over/under fences) certainly hampered our tracking accuracy. One student, who was wearing a hat with a wide brim to shield himself from the sun unknowingly shifted his hat down during his recording and cut off part of the scene from the camera's view. Also, upon returning the goggles some students commented on feeling a bit dizzy or having sweat or wind blow into their eye (through the opening in the lens) and temporarily impact their vision. In sum, given these limitations to the eye-tracking devices, we plan to use

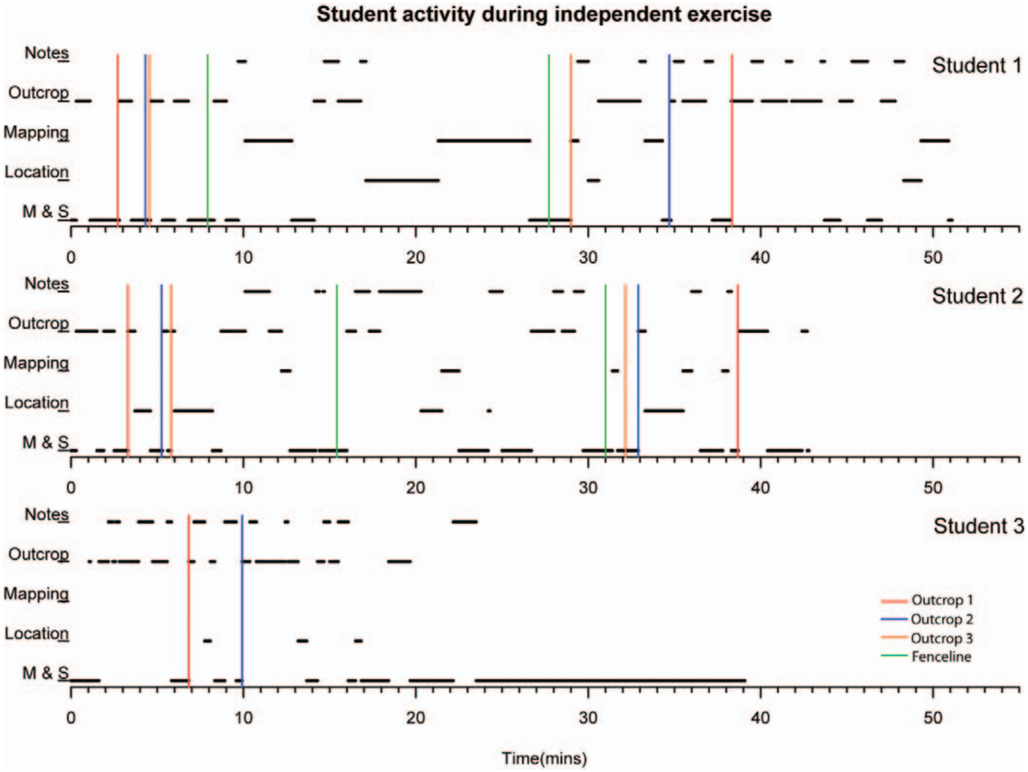

FIGURE 2: Student activity graphs for three students who completed independent practice exercise while wearing eye-tracking devices (black horizontal line segments). X-axis represents minutes since start of tracking (at same location). Y-axis indicates activity categories based on coding discussed in text. Vertical lines indicate times when students reached notable outcrops or boundaries along their paths through the field area. Students 1 and 2 made it out beyond the fence to the edge of the field area before returning on a similar path to the start. There are only two lines for student 3, since she never reached the final few outcrops, and she did not make a return trip.

more standard video equipment for future research until access to better tracking instruments is readily available.

Review of the gaze videos from the independent exercise provides interesting insight into how students make observations and interpretations in the field setting, skills critical in understanding geologic structures (Kastens et al., 2009). At a basic level, the videos revealed technical difficulties that students were having, such as improper or inefficient use of compass and rock hammers, and overall difficulty in locating themselves in three-dimensional space.

Independent Exercise

In attempting to synthesize the field strategies of students, we found it difficult to draw concrete comparisons between styles because each student seemed unique in their approach to data collection and interpretation. To give the reader a sense of how students spent their time in the field, we created activity graphs to indicate the timing, duration and sequence of activities as three students moved across the same terrain in the heart of the field area (Fig. 2).

We present the data in a different format in Table II, which shows the proportion of time spent by each student by coded activity. There are distinct differences in the ways in which each student worked during the time captured on video. While all students spent approximately the same amount of time interacting with the outcrops, this can be misleading, since student 3 only visited a portion of the outcrops in the area before heading to the rendezvous, while the other two students passed by or worked at each of the outcrops twice during their trip out to the boundary and back to the starting point. Students 1 and 2 spent much less time at each outcrop collecting data and instead spent more time working with their maps and aerial photos. From what the videos demonstrate, this time was spent both locating themselves and key stations, and in drawing units/contacts on their maps. Student 1 selected to focus efforts on constructing a map of the area, while student 2 preferred to "download" information into notes first and potentially put off mapping until the field portion of the exercise was complete. Student 3 spent a good portion of her time at each outcrop she encountered and in taking notes, but little to no

TABLE II: Percentage of time coded for each activity, by student.

Code	Student 1	Student 2	Student 3[1]
Moving and searching	26.1	37.5	36.5
Location	11.4	15.6	5.0
Maps	21.4	6.0	–
Outcrop	30.0	23.4	34.6
Notes	11.0	17.5	23.9
Total time (min)	51.1	42.8	23.5

[1]Values for student 3 are adjusted to account more properly for the time spent in the field area. For these calculations, we removed the time at the end of the video spent hiking cross-country.

TABLE III: Concurrent conversations during independent walkthrough within the same instructional group.[1]

Timing	Student Conversation with Teaching Assistant	Instructor to the Group
46 min	SS A: Hey {TA}, are we up in this little thing?	SS B: So we go down a hill, a little flat spot and…
	TA: So let's see you go down a hill, flat spot...so 1st ridge, 2nd ridge, then we came down to this drainage and worked our way around...so we should be somewhere in here.	IN: ...a big hill, a big flat spot and then a little hill.
	SS A: 'cause we're not very far up from that drainage down there—if this is the main one that comes out. But this is the main one isn't it?	SS C: Is this roughly right?
	TA: Yes	IN: Put your dip ticks in.
	SS A: With the blue stream line?	SS C: Oh, dip ticks.
	TA: So why are you saying we're up here?	IN: The reason for putting the dip ticks in is so you remember the orientation. So, would that help you predict the orientation of bedding behind it? Some units are notoriously bad to find the bedding, but if you start where...again, you don't want to be biased, you don't want to force something but if you know what the regional is, you can start to look there first and that may help you a little bit rather than just dropping in from the moon [and thinking] Where am I? Ok, what's the other possibility? Let's just say we didn't see the fossils and we have a shale and a limestone. Give me another option?
	SS A: Wouldn't this little thing that dips in be this...	
	TA: Where?	
	SS: Like that little shark-fin looking thing?	
	TA: (Looking at location on map where student is pointing)	
47 min		

[1]On the left is a conversation between a student and the teaching assistant (TA); on the right is the dialogue of the instructor to the entire group of students. SS = student; TA = teaching assistant; IN = instructor.

time working to locate herself in the terrain or to make note of features/stations on the map or aerial photographs. A note of clarification: Student 3 spent the greatest amount of time moving and searching but "saw" the least amount of the field area. This occurred because this student was spending so much time at each outcrop that she arrived in the main field area late and rather than hurry through the area, she decided to hike back to the rendezvous point on a ridge above the main field area to begin her map construction.

Given our limited data set, it is impossible for us to determine which of these strategies is an optimal method for working through the field area, assuming one actually exists. However, after multiple passes through the videos, we suggest that some "average" between students 1 and 2 would be best, with a good mixture of observation, mental modeling, working on notes and maps, and moving efficiently between outcrops, but we cannot definitively support this assertion until more data are collected for analysis.

Other observed factors are worth noting. First, the videos provide evidence for a "swarm" behavior during independent field examinations, where students moving through the field area may be more likely to investigate an outcrop simply because they notice other students working there. Students seemed to spot other students located at or moving around an outcrop before they notice the outcrop, and so this may highlight for them key areas to investigate. Depending on the nature of the field area, this activity may strongly influence how a student progresses through the area, and although we did not observe any students trading information, this likely impacts the "independent" nature of the exercises, especially in field areas with complex and/or subtle features.

While the videos from the independent exercise are mostly silent, a few snippets from those videos provide helpful information regarding why students were not taking notes (e.g., left notebook behind, lost pencil). The audio also revealed the physical exertion put forth by some students hiking cross-country, leading to higher than normal breathing rate (50+ breaths/min) while traversing slopes of the 5,000′+ elevation field area.

In one case, we were able to review the gaze video with a student who participated in the morning independent exercise. She revealed that she entered into the exercise with a mental model for how the rock units should be organized. During the video, it was clear that she made observations that contradicted this model, and upon questioning, she admitted that during the exercise she neglected to use her observations and accept that her original model might be flawed. Following the ideas of conceptual change (Posner et al., 1982), it seems that this is an instance demonstrating that when students have preexisting or newly created models for phenomena they are observing, they often find ways to fit contradictory observations into those models rather than changing their models to fit the data (e.g., Roth, 1995; Penner and Klahr, 1996).

Walkthrough Exercise

Quite different from the video of solitary students completing the morning independent exercise, the videos captured during the afternoon walkthrough provide a sense of how three different students participated in a key learning/review activity. The most striking thing from these videos is evidence that determining location was the most significant learning hurdle for these students. Repeatedly, students would ask one another "Do you know where we are?" or look for guidance from the lead instructor or teaching assistants. As a result, this difficulty created a secondary issue where students often missed important pieces of instructional information while they attempted to locate themselves. This is demonstrated in one instance when a student was working with a TA to figure out location, while the instructor was talking to the group about bedding features (Table III).

Other segments of video reveal that, during the walkthrough, there were often points where students appear to be completely disengaged. During one sequence, the instructor asked students if anyone located fossils in the formation they were standing near. One of the students began scanning the outcrop and jotted down some notes, while another looked out toward the valley, paying no heed to the rock at his feet. A similar case of this occurred toward the end of the walkthrough (and video), when the instructor spent 20 min providing an overview of the area and some guidance on mapping. During this stretch, one of the students spent most of the time observing her surroundings and classmates while making little reference to her notes, maps, or other materials. Finally, discussions among students on the audio tracks from these videos clearly reveal the general frustration—in the form of expletives—that students felt with being expected to notice geological minutiae.

While this may paint a bleak picture for the ways in which some students behave during a learning exercise, we get a different picture from the student who completed the postexercise video review mentioned earlier. Although we did not record video from this student during the walkthrough portion of the exercise, the student indicated that the afternoon activity was critically important; she had done quite poorly during the practice exercise, but based on the recommendations and guidance received during the walkthrough, she changed her observational strategies and completed the subsequent independent exercise (a few days later in a new field area) with a high level of success. Instructional interventions such as the faculty walkthrough may offer a concrete way to help students improve their skills and will be investigated further in future work.

In summary, the two most striking things we take from review of these videos is the critical nature of basic skills that we, as experts, take for granted; and we are reminded that students often are distracted by other tasks (e.g., locating themselves in space) while receiving instruction and are thus likely to miss important content. Prior work by Riggs et al. (2009a, 2009b) and by Petcovic, Libarkin, and others (Petcovic et al., 2009, 2010) offers us a foundation from which to think about the ways in which students approach mapping tasks while in the field. These studies provide a sense of the temporal flow of work in the field, linking navigation with field notes and observations of geologists constructing their maps, sometimes in near real-time. However, while this evidence affords useful clues and insights, the finer details of temporal and spatial scale of work and observation, specific attention directed to geologic features, and time on task remain ambiguous. The results and coding framework we present here provide first steps toward understanding the workflow of novice students in the field at a detailed temporal and spatial resolution.

CONTRIBUTION TO TEACHING AND LEARNING OF GEOSCIENCE FIELD COURSES

Students in geology field courses are traditionally evaluated on their submitted notes and geologic maps, and their performance on associated assessments. The question has rarely been "how" do students learn, the focus has mostly been on "how much" do they learn. The videos we captured with mobile eye-tracking devices allowed us, for the first time, to see the field from the perspective of the students as they participated in learning activities. While we found it difficult to produce reliable data using the mobile eye-tracking devices, we did find the scene camera video to be very insightful. Even our limited set of data provides insights about the myriad ways with which students approach a field mapping exercise, their difficulties in obtaining accurate data from outcrops, and the common distractions in attention while they are expected to be engaged in what we—as educators—feel is critical instruction.

Based on our review of the extant literature, we believe that the level of resolution on task and workflow resolution available in the video data is fundamentally new. Data from our videos most strongly suggest that foundational issues (e.g., navigation, map reading) need to be addressed before adding to the cognitive complexity of tasks for students in the field. The navigational difficulties seen in the video suggest that instructors may benefit from dedicating time at the beginning of their courses to improve related skills. If a key element of the course involves using maps and aerial photos, we suggest including activities and assessments to build student proficiency in map reading before embarking on serious field mapping exercises. Additionally, we recommend that instructors employ a form of "wait time" (Row, 1974) during walkthrough exercises to allow students to orient themselves in space and on their maps before continuing with procedures or explanations.

In 2010, Steven Breckler, executive director for science at the American Psychological Association sent a letter to the director of the Institute of Education Science (IES) regarding the newly proposed priorities of IES. In the letter, Breckler (2010) wrote, "Research that focuses on the key processes of attention, memory, motivation and reasoning are essential for learning and are likely to produce substantial gains in academic achievement" and recommended that the IES priorities include these processes. Toward this objective, we believe that this paper presents research, albeit limited in breadth, using cutting-edge technologies to study the observational behavior of students in a geology field course. While this paper is directed toward college educators, we believe the findings have application in any setting where students are required to make observations of natural phenomena.

REFERENCES

Breckler, S. 2010. Sept. 7. Letter to Director of Institute of Education Sciences. Available at: http://www.regulations.gov/#!documentDetail;D=ED-2010-IES-0008-0024 (accessed 24 April 2012).

Callahan, K., Petcovic, H., and Baker, K. 2010. Getting the inside track: Head-mounted cameras give new perspective on process of bedrock mapping. *Geological Society of America Abstracts with Programs*, 42(5):191.

Chase, W.G., and Simon, H.A. 1973. Perception in chess. *Cognitive Psychology*, 4:55–81.

Choi, C. 2010. Expert education. *Scientific American*, 302:17–18.

Douglas, B.J., Suttner, L.J., and Ripley, E. 2009. Indiana University geologic field programs based in Montana: G429 and other field courses, a balance of traditions and innovations. *In*

Whitmeyer, S.J., Mogk, D., and Pyle, E., eds., Field geology education: Historical perspectives and modern approaches. Boulder, CO: Geological Society of America, p. 1–14.

Driver, R. 1983. The pupil as scientist?. Philadelphia, PA: Open University Press.

Duschl, R.A., and Osborne, J. 2002. Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, 38:39–72.

Eberbach, C., and Crowley, K. 2009. From everyday to scientific observation: How children learn to observe the biologist's world. *Review of Educational Research*, 79:39.

Engle, R.A., Conant, F.R., and Greeno, J.G. 2009. Progressive refinement of hypotheses in video-supported research. *In* Goldman, R., Pea, R., Barron, B., and Derry, S., eds., Video research in the learning sciences. Mahwah, NJ: Lawrence Erlbaum Associates.

Erickson, F. 2006. Definition and analysis of data from videotape: Some research procedures and their rationales. *In* Green, J.L. Camilli, G., and Elmore, P.B., eds., Handbook of complementary methods in education research. Mahwah, NJ: Lawrence Erlbaum Associates, p. 177–191.

Ford, D.J. 2005. The challenges of observing geologically: Third graders' descriptions of rock and mineral properties. *Science Education*, 89:276–295.

Goodwin, C. 1994. Professional vision. *American Anthropologist*, 96:606–633.

Haslam, F., and Gunstone, R. 1998. The influence of teachers on student observation in science classes. Presentation. National Association for Research in Science Teaching, San Diego, CA.

Kastens, K.A., Agrawal, S., and Liben, L. 2009. How students and field geologists reason in integrating spatial observations from outcrops to visualize a 3-D geological structure. *International Journal of Science Education*, 31:365–393.

Lehrer, R., and Schauble, L. 2004. Modeling natural variation through distribution. *American Educational Research Journal*, 41:635.

Lindwall, O., and Lymer, G. 2008. The dark matter of lab work: Illuminating the negotiation of disciplined perception in mechanics. *Journal of the Learning Sciences*, 17:180–224.

Luft, J.A., Kurdziel, J.P., Roehrig, G.H., and Turner, J. 2004. Growing a garden without water: Graduate teaching assistants in introductory science laboratories at a doctoral/research university. *Journal of Research in Science Teaching*, 41:211–233.

Maltese, A.V., Tai, R.H., and Sadler, P.M. 2010. The effect of high school physics laboratories on performance in introductory college physics. *The Physics Teacher*, 48(5):333–337.

National Research Council (NRC). 1996. National science education standards: Observe, interact, change, learn. Washington, DC: National Academies Press.

National Research Council (NRC). 2011. A framework for K–12 science education: Practices, crosscutting concepts, and core ideas. Committee on a Conceptual Framework for New K–12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Penner, D.E., and Klahr, D. 1996. The interaction of domain-specific knowledge and domain-general discovery strategies: A study with sinking objects. *Child Development*, 67:2709–2727.

Petcovic, H.L., Libarkin, J.C., and Baker, K.M. 2009. An empirical methodology for investigation of geocognition in the field. *Journal of Geoscience Education*, 57(4):316–328.

Posner, G., Strike, K., Hewson, P., and Gertzog, W. 1982. Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, 66:211–227.

Rayner, K. 1998. Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, 124:372–422.

Riggs, E.M., Balliet, R.N., and Lieder, C.L., 2009a. Effectiveness in problem solving during geologic field examinations: Insights from analysis of GPS tracks at variable time scales, invited paper. *In* Whitmeyer, S.J., Mogk, D.W., and Pyle, E.J., eds., Field geology education: Historical perspectives and modern approaches. Boulder, CO: Geological Society of America, Special Paper 461, p. 323–340.

Riggs, E.M., Lieder, C.C., and Balliet, R.N. 2009b. Geologic problem solving in the field: Analysis of field navigation and mapping by advanced undergraduates. *Journal of Geoscience Education*, 57(1):48–63.

Roth, W.M. 1995. Authentic school science: Knowing and learning in open-inquiry science laboratories. Boston: Kluwer Academic Publishers.

Roth, W.M., Hawryshyn, C., Haimberger, T., and Welzel, M. 2001. Visual perception: More than meets the eye. Paper presented at the European Association for Research on Learning and Instruction: Fribourg, Switzerland. Available at http://education2.uvic.ca/Faculty/mroth/PREPRINTS/Perception.pdf.

Row, M.B. 1974. Wait-time and rewards as instructional variables, their influence on language, logic, and fate control: Part one-wait-time. *Journal of Research in Science Teaching*, 11(2):81–94.

Singer, S.R., Hilton, M.L., and Schweingruber, H.A. (Eds.). 2006. America's lab report: Investigations in high school science. Washington, DC: National Academy Press.