Sensitivity to Landscape Features: A Spatial Analysis of Field Geoscientists on the Move

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ABSTRACT

Intelligent behavior in everyday contexts may depend on both ability and an individual's disposition toward using that ability. Research into patterns of thinking has identified three logically distinct components necessary for dispositional behavior: ability, inclination, and sensitivity. Surprisingly, sensitivity appears to be the most common bottleneck to achieving quality outcomes. Using global positioning system data taken when field geologists ($n = 66$) performed a bedrock mapping task, we assess sensitivity to landscape and its relationship to expertise, content knowledge in the discipline, thoroughness of route, and quality of outcome. A discipline-specific concept inventory served as a proxy measure for participant knowledge and ability. Thoroughness in the field served as an indicator of a participant's inclination to employ abilities critical to the success of the task. To assess sensitivity to opportunities in the landscape, we identified relatively small areas frequently visited by experienced geologists, then quantified the frequency with which participants across a continuum of mapping experience placed themselves in these areas. Results showed clear spatial differences in landscape use across scales by expertise level, suggesting that sensitivity to physical locations for quality thinking is less pronounced among inexperienced field geologists and correlates strongly with quality of outcome. These results are significant for the education of field researchers because cultivation of sensitivity to opportunities in the landscape for higher-quality thinking presents a different sort of instructional challenge than that of directly teaching discipline specific content or traditional mapping skills. [DOI: 10.5408/15-110.1]

Key words: dispositional thinking, problem solving, expertise, spatial analysis, GIS

INTRODUCTION

The abilities to think critically and solve problems lie at the heart of most educational goals and are particularly emphasized in science education. For example, reform efforts in the U.S. (e.g., AAAS, 1993; NRC, 1996, 2012) call for developing students' skills in making observations, analyzing and interpreting data, constructing and testing explanations, and evaluating arguments from evidence—all skills critical in scientific problem solving. Does developing these skills depend on students' intellectual abilities or on how students choose to use those abilities in solving particular problems?

Traditionally, views of intelligent behavior focused solely on ability—whether an individual had the capacity, generally in terms of possessing particular intellectual traits or behaviors, for success at a particular task. Several researchers, however, propose that intelligent behavior "in the wild" (cf. Hutchins, 1996) depends not only on raw ability but also on how the individual is disposed toward using that ability. Simply put, dispositions are "behavioral tendencies" (Perkins et al., 1993, p. 5) that account for how people invest their abilities, such as open-mindedness, curiosity, being methodical, etc. This dispositional view of intelligent behavior can account for variations in performance in everyday contexts beyond ability-centric measures alone (Perkins et al., 1993, 2000).

Perkins et al. (1993, 2000) proposed a three-part model of dispositional intelligence. First, the authors used the term *ability* in reference to an individual's capacity to carry out a particular behavior. Second, *inclination* was used to refer to whether an individual is motivated to engage in the behavior. Third, *sensitivity* was used to refer to whether the individual noticed opportunities to engage in the behavior. A series of studies on critical thinking with U.S. 5th- to 8th-grade students (children ages 10–14 y) demonstrated that sensitivity was most often the bottleneck to effective performance (Perkins et al., 2000). In other words, missed opportunities to engage in particular types of effective thinking, rather than lack of ability or inclination, led to decreased task performance.

The notion of dispositional thinking gained momentum in the cognitive science literature in the late 1980s (e.g., Baron, 1987; Ennis, 1987; Siegel, 1988), although, as noted by Perkins et al. (1993), it has its roots in the Dewey (1930) concept of good habits of the mind. In Table I, we explore how the Perkins et al. (1993, 2000) triadic model of dispositional thinking may be related to other psychological constructs. In particular, we note that dispositional thinking appears to be distinct from the affective and cognitive components of the human mind (cf. Huitt, 1999) because it is not limited to feelings and emotions or to the attainment and processing of knowledge, respectively.

The activity of geologic mapping provides an opportunity to examine problem-solving behavior, as well as the role of dispositional thinking, quite literally in the "wild." During mapping, the geoscientist is typically outdoors for extended periods, often in rugged terrain, and must form and test hypotheses while moving through an unfamiliar landscape.

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TABLE I: An exploration of Perkins triadic model of dispositional intelligence (as defined in Perkins et al., 2000, pp. 272–273) and potentially related psychological constructs.

Dispositional Thinking Component	Definition	Related Constructs
Ability	• Capacity to carry out a behavior	• *Knowledge* and *skill* components of intelligence, as commonly used in the literature.
Inclination	• Motivation or impulse to engage in a behavior	• *Conation*, which broadly includes the "intentional and personal motivation of behavior" (Huitt, 1999, p. 2). Conation, in turn, includes constructs such as volition (e.g., Donagan, 1987), self-regulating behavior (e.g., Bandura, 1991), mindset (e.g., Dweck, 1991), and persistence (e.g., McClelland, 1985), more recently popularized in the K–12 literature as *grit* (e.g., Duckworth et al., 2007).
Sensitivity	• Likelihood of noticing occasions to engage in the behavior	• *Professional vision*, defined as distinctive ways of "seeing and understanding" within a social group (Goodwin, 1994, p. 606).
		• *Perceptual learning*, which refers to "experience-induced changes in the way information is extracted" (Kellman, 2002, p. 259). In particular, experienced individuals may be more likely to note affordances, or characteristics of the environment that offer opportunities to engage in a specific behavior or action (Gibson, 1977).

The goal of this task is to produce both a spatially accurate map of the surface distribution of rock types (the bedrock geology) and an accurate interpretation of the three-dimensional relationships of these rocks beneath the earth's surface (the structural geology). Furthermore, mapping is an example of a relatively ill-defined problem (cf. Reitman, 1965) in which the desired outcome is clear—successfully interpreting the landscape through creating an accurate map of the rock distribution and geologic structure(s)—but the process by which the solution is attained is not prescribed.

Both abilities and learned skills clearly have a role in mapping. For example, the geoscientist must be able to correctly identify the types of rocks encountered, take measurements of the rock orientations, interpret those measurements in three dimensions, infer what rocks are present in areas lacking surface exposure, and plan a route through an unfamiliar landscape. Although success certainly depends, to a certain extent, on the skills of the individual, we have found differences in patterns of landscape use and dependence on visuospatial ability among novice and expert geoscientists (Petcovic et al., 2009; Baker et al., 2012, 2016; Hambrick et al., 2012). A task analysis of behaviors that are central to success in field mapping, e.g., collecting measurements of rock orientation, could incorporate components of dispositional thinking. In this example, the geoscientist needs to be inclined to take these measurements when the opportunity presents itself. The geoscientist must know how to identify a bedding plane, know how to use a compass to record strikes and dips to have the ability to take measurements, and must be sensitive to recognizing locations in the landscape in which it would be advantageous to take those measurements as a step toward the goal of forming a plausible interpretation of the landscape.

Our study examines evidence of dispositional thinking in the context of an in situ landscape encounter. Bedrock geologic mapping is an environmental experience, as described by Ittelson et al. (1976), in which experience and purposeful action cannot be separated. Although other types of human-movement studies focus on urban environments or on tasks that rely on efficiency (Yan et al., 2008; Cornell, et al., 2009), unconstrained human movement is much less studied and more difficult to quantify (Turner and Penn, 2002) because it is not driven by the same attractors as animal movement. However, because our participants are involved in an intellectual-performance task during the landscape encounter, we were able to investigate ways in which aspects of dispositional thinking and its influence on movement patterns might be quantified in an outdoor field situation. Our analysis differs from some of the classic landscape-encounter literature (Brunswick, 1944; Hull and Stewart, 1995) because participants were driven by a broad purpose, with few constraints on spatial movement or time use.

In this study, we examined the relationships among the three logically distinct components necessary for dispositional behavior (ability, inclination, and sensitivity), as well as the relationships among these behaviors and success in the bedrock-mapping task. In other words, we hypothesized that geological knowledge and skills relevant to mapping (ability), motivation to map a field area (inclination), and a likelihood to notice occasions for collecting field data (sensitivity) must be present for an individual to correctly interpret the landscape to produce an accurate geologic map. This study follows in the classic tradition of expertise research (e.g., Chase and Simon, 1973; Chi et al., 1981) because both experts (in our case, geoscience professionals) and novices (undergraduate students) performed a novice-level task. The research literature clearly establishes that experts have acquired a body of knowledge and skills (in Perkins et al. [1993, 2000] terms, *ability*), which affects what they perceive, how they store and recall information, and how they reason and solve problems (e.g., Chase and Simon, 1973; Larkin et al., 1980; Chi et al., 1981; de Jong and Ferguson-Hessler, 1986; Ericsson and Lehman, 1996; Heyworth, 1999; Anderson and Leinhardt, 2002; Hmelo-Silver and Nagarajan, 2002). Thus, we examined the relationships among ability, inclination, sensitivity, and expertise.

We did not plan to directly measure ability, inclination, and sensitivity at the outset of our larger study but had developed proxy measurements for each of those components (the limitations of this approach are discussed later). A discipline-specific concept inventory served as our evaluation of participant ability. We assume that a greater knowledge of geology would enable a participant to use the knowledge and skills required to make a successful map. In fact, in prior work, we found a strong correlation between participant knowledge and success on the mapping task (Baker et al., 2012). This is in contrast to the traditional use of the term *ability* as a generally fixed psychometric measure of intelligence. Thus, we will use the term *knowledge* to refer to this part of the Perkins et al (1993, 2000) model. Thoroughness in the field, as measured by global positioning system (GPS) tracks obtained as participants were mapping, was considered a good indication of inclination to use knowledge and skills required for the task. Here, the assumption was that a more-thorough path through the field area indicated a greater motivation to use the knowledge and skills required for the task. Finally, sensitivity to opportunities in the landscape for collecting quality field measurements was measured by investigating participants' tendency to visit relatively small areas in the field that were frequented by experienced geologists. Our assumption was that experts were more sensitive to opportunities present in the landscape in which they could employ geologic knowledge to the greatest possible advantage.

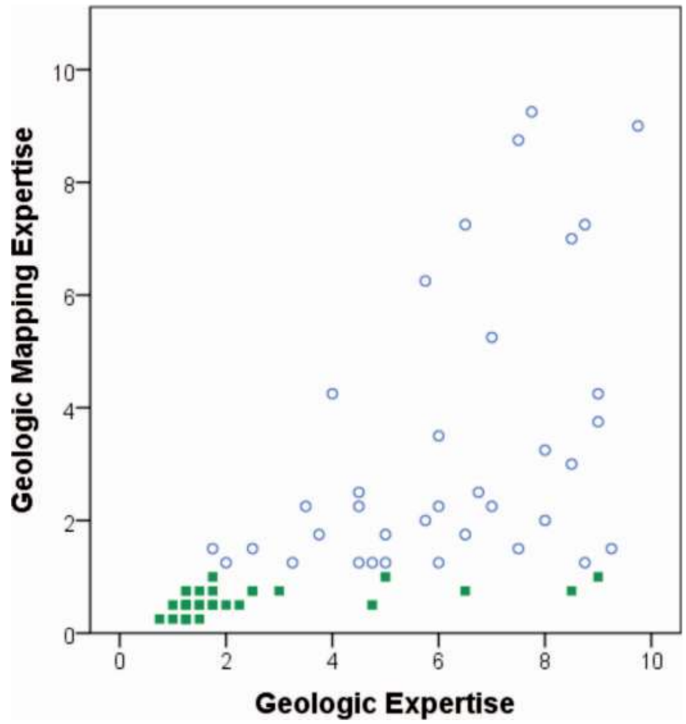

FIGURE 1: Among participants, geologic mapping expertise correlated strongly with general geologic expertise ($r = 0.789$, $n = 66$, $p < 0.01$, as reported in Baker et al., 2012). A maximum score of 1 was chosen as the cutoff between inexperienced mappers (filled squares, $n = 37$) and experienced mappers (open circles, $n = 29$) because this was the highest score that an undergraduate student with field experience could achieve on the instrument. For reference, a graduate student with fieldwork experience and no professional work experience can achieve a maximum score of 3, and most professional geoscientists with $\geq$10 y of career experience, which includes $\geq$10 d in the field per year score 6 or higher. Color version can be found online.

METHODS

Geologists with a range of geologic and mapping skills were recruited to participate in a multiday research experience in the Rocky Mountains of Montana. As part of a related study (Hambrick et al., 2012), cognitive measures, such as visuospatial ability, perceptual speed, working memory capacity, and domain-specific knowledge, were assessed on the first day via paper-and-pencil or computerized tasks. The second day of the study consisted of the full-day bedrock geology mapping task, during which participants' use of time and space were tracked with GPS units (Baker et al., 2012). Research took place in the summers of 2009 and 2010.

Participants

Of more than 200 applicants, 67 participants were chosen to create age- and gender-matched groups that varied by prior geologic experience (see Hambrick et al., 2012, for a detailed description of participant-selection procedures). For this study, 66 participants were included because of an error with one participant's GPS track. All participants completed an experience questionnaire that catalogued a wide variety of coursework, research, and paid-work experiences in both geology and geologic mapping. Prior experience was quantified using a scoring rubric that awarded points based on the type and duration of key experiences, with a possible score range of 0–10. Psychometric properties and validation of this instrument are described in Baker et al. (2012). Overall, participants ranged in experience from undergraduate students with a single completed course in geologic field methods, to professionals with >20 y of experience in geologic mapping.

Participants ranged in ages from 20 to 68 y, with a mean age of 36.4 y. There were 36 men and 31 women. Because we sought to cover a wide range of age and experience, most participants had completed their education and, overall, had a mean of 7.6 y of work experience since earning their highest degree. The project paid for participants' travel expenses, and participants received a monetary stipend of $300–$700, depending on their experience level.

General experience in geology was found to be significantly correlated with experience in geologic mapping ($r_s = 0.789$, $p < 0.01$). Breaks in how the instrument calculates mapping experience were used to assign individuals to categories of expertise (Fig. 1). Because the study was originally designed to capture the full continuum of experience from advanced undergraduate student to career professional, these categories were admittedly arbitrary but were still useful in terms of differentiating between the extremes in experience levels. For purposes of this article, only geologic mapping expertise (the vertical axis in Fig. 1) was used to classify individuals with regard to map accuracy and structural interpretation outcomes. Because so few true experts in mapping participated in the study ($n = 7$), those

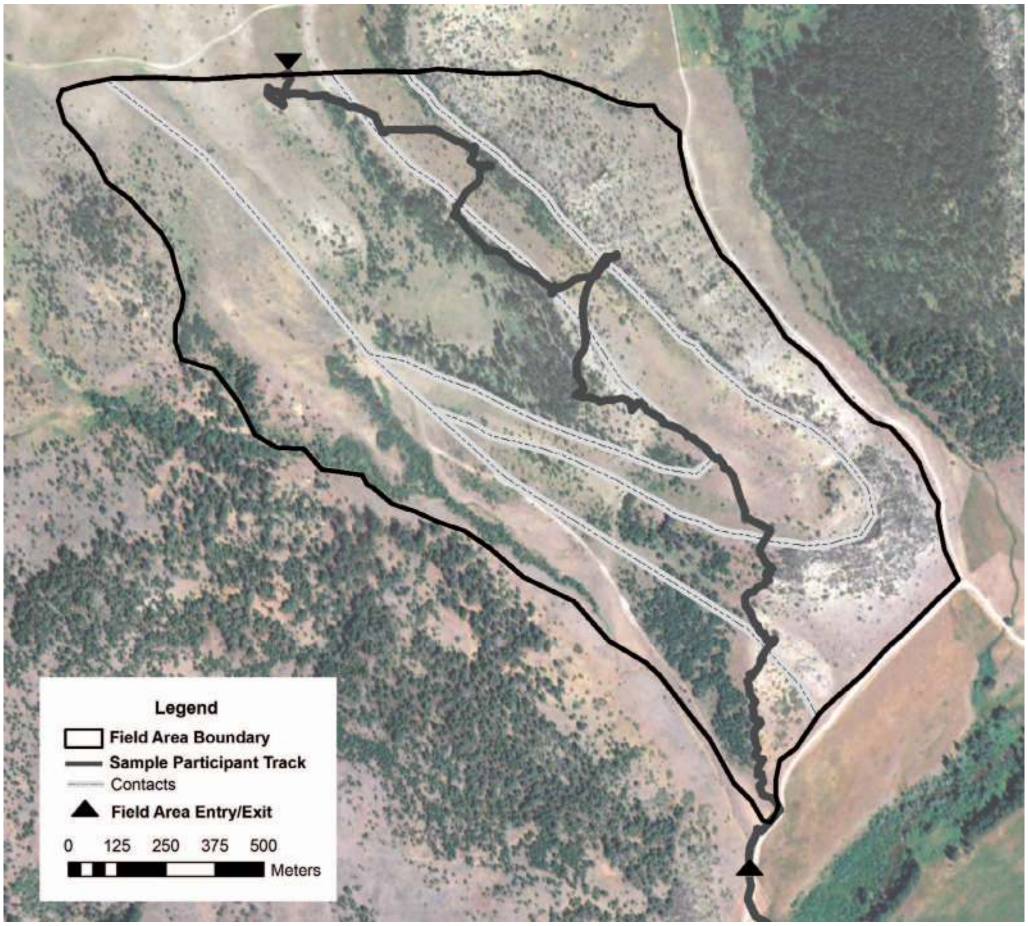

FIGURE 2: Aerial photograph of the field area overlaid with an example participant track. The photograph has been distorted to disguise the exact location of the field site; thus, a north arrow is not given on the map, and geologic features are not described in the text using compass directions. The boundary of the field area was clearly marked by flagging, roads, or barbed-wire fencing. Three conformable Paleozoic units (in stratigraphic order from oldest to youngest: dolostone, shale, and limestone) form a plunging syncline. A gneissic, Precambrian basement is uplifted over one limb of the syncline (the left side of the image) by a low-angle thrust fault. Sparse, gabbroic intrusions can be found within the limestone unit at the nose of the syncline.

individuals were combined with somewhat-experienced mappers into an "experienced" category ($n = 29$), as opposed to "inexperienced" mapping novices ($n = 37$).

The Mapping Task

The field task was designed to simulate a typical undergraduate-level geological bedrock-mapping task of an area in which the geology is relatively well known. The map area (Fig. 2) was 70 ha, with approximately 700 ft (213 m) of elevation change from the top of the area, where participants began the task, to the bottom of the area, where participants exited the mapping task. At this location, three Paleozoic sedimentary units form a plunging syncline, one limb of which is cut by a thrust fault that uplifts the crystalline Precambrian basement. Good outcrops with discernable bedding were located throughout the study area (with the exception of the shale unit), although observable contacts among units were rarely exposed.

Participants completed the mapping task individually; however, on each mapping day (7 d total), a cohort of 8–10 participants were in the field area at the same time. Within each cohort, participants were individually released into the field area at 5-min intervals and were instructed not to speak with one another about topics related to the task. Most participants completed the mapping task in 4–5 h. Research team members were present in the field area during the mapping task as a safety precaution but did not interact with participants.

To ensure consistency of participant preparation for the task, scripted information was read to each cohort of participants about rock types, study area, field-mapping boundaries, safety information, and conditions of the task during a 2-h introduction to the local rock types before the mapping task began. All participants, therefore, had seen the rock types they were to encounter in the field area before the task. Participants were given two copies of an aerial photograph (Fig. 2) and one copy of a topographic map of the study area on which to draw their maps, but were instructed to complete their final map on one of the photographs, for consistency in data processing.

The field area contained only a single two-track, leading about a third of the way into the study area from the exit point (visible as a white scar on the landscape in Fig. 2). Similarity in participant tracks was influenced by abrupt

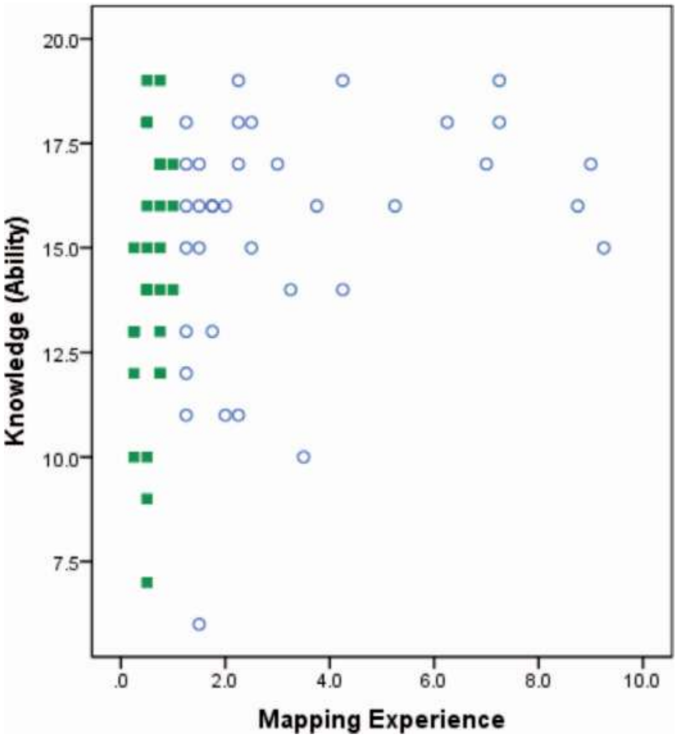

FIGURE 3: Participant ability, as measured by the geologic concept inventory (GCI), varied across levels of mapping expertise (filled squares, inexperienced mappers; open circles, experienced mappers). A significant correlation was found between ability and mapping experience ($r = 0.321$, $n = 66$, $p < 0.01$).

changes in topography and vegetation, which rendered several areas inaccessible to all but the most enthusiastic participants (in addition to one area of grazing cattle that participants were asked to avoid). Participants did often follow "cattle paths" that crisscrossed the remaining accessible areas, but these were too numerous and undefined to warrant documentation.

Measure of Participant Ability—Geologic Knowledge

The Geoscience Concept Inventory (GCI; Libarkin and Anderson, 2006, 2007) is a valid and reliable measure of domain-content knowledge in the geosciences. A modified version of the GCI, containing 17 multiple-choice items and two open-ended items related to bedrock mapping, was used to assess participants' general knowledge of geology. The open-ended items asked participants to plot the strike and dip of a plane on a stereonet and to interpret a topographic map.

As expected, experienced mappers had relatively high GCI scores (Fig. 3) because knowledge is gained through longer experience in a domain. Less-experienced mappers displayed variable knowledge, as measured by the GCI. We found in prior work (Baker et al., 2012) that there is a positive correlation between participant GCI scores and success at the mapping task, both in terms of correctly identifying the distribution of rock types ($r = 0.671$, $n = 66$, $p < .01$) and in identifying the geologic structures ($r = 0.547$, $n = 66$, $p < 0.01$). These correlations suggest that the GCI is an appropriate proxy measure for knowledge (e.g., *ability* in the Perkins et al. [1993, 2000] model) in the context of this task.

TABLE II: Loadings obtained during principal components analysis (varimax rotation) of participant's fieldwork characteristics measured during the bedrock mapping and structural interpretation task.

Input Variables	Factor 1 "Thoroughness"	Factor 2 "Speed"
Total participant time in field (h)	0.816	−0.541
Total distance walked (m)	0.961	0.186
Percentage of field area seen within 5 m	0.914	0.256
Elevation change of field track	0.928	0.076
Total stops during field task	0.279	−0.857
Number of fast segments during the task	0.253	0.808
Distance walked during the first hour in the field	0.316	0.754

Measure of Participant Inclination—Thoroughness of Field Track

Garmin (Schaffhausen, Switzerland) eTrex Legend HCx GPS receivers were tied or clipped to participant's backpacks or belts during the field task. Receivers took a waypoint at 10-s intervals. GPS track files were downloaded from the receivers after each cohort of participants completed the field task. Initial analysis of GPS track data (Baker et al., 2012) revealed patterns in the sequence used by participants in traversing the area. When principal component analysis (PCA) was used to consolidate general track variables, two orthogonal extracted components accounted for 84% of the variability (Table II). Component A reflected thoroughness in the field and accounted for 50% of total variability. Time in the field, distance walked, percentage of the field area seen, and elevation change of the track heavily were loaded on the thoroughness component. In other words, a more-thorough participant spent more overall time in the field, walked a greater distance, and/or physically visited more of the field area. Component B reflected speed and accounted for 34% of total variability. The speed component correlated positively with the percentage of time that the participant spent moving quickly and the distance covered during the first hour of mapping and correlated negatively with the number of stops and the time in the field. In other words, faster participants covered more area in less time with less-frequent stops. In the current analysis, we use the thoroughness component as a quantitative measure of each participant's inclination to spend time and energy understanding the field area.

Measure of Participant Sensitivity—Landscape Analysis

During the exploratory data-analysis phase of the research, we noticed that groups of individuals across cohorts and years appeared drawn to some particular locations in the landscape. We interpreted that to mean

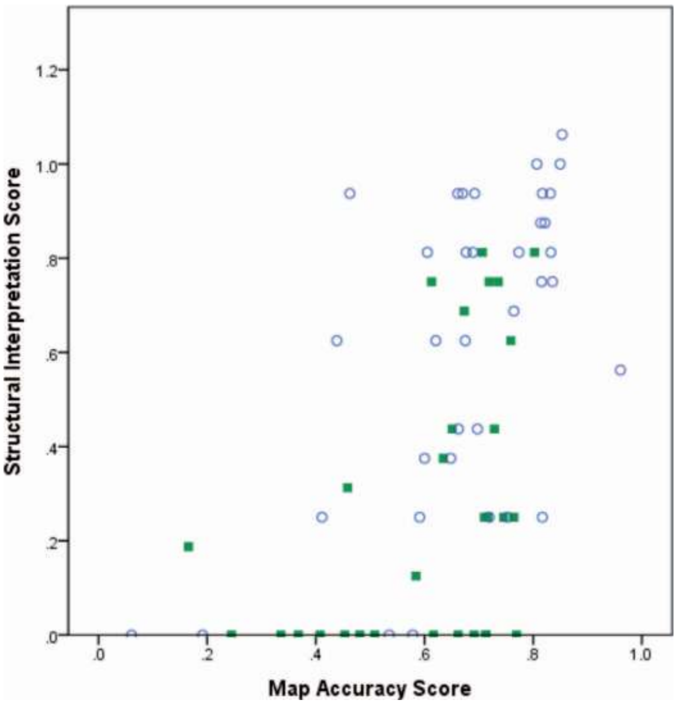

FIGURE 4: Map accuracy versus structural interpretation scores for participants experienced (open circle) and inexperienced (filled square) in mapping tasks. *Map accuracy* is a measure of the percentage of 1-m pixels that correctly match a consensus map of the surface distribution of rock types in the field area. *Structural interpretation* measures the extent to which participants correctly identified the two major geologic structures (a plunging syncline and the thrust fault). The structural interpretation score was a maximum of 1.20 because of a "bonus" feature (two small gabbroic intrusions), which participants were not expected to find in the map area but which two expert participants did identify and map. Color version can be found online.

that some participants were more sensitive to locations in the physical landscape in which they could most effectively collect data or form and test hypotheses to create the geologic map and to interpret underlying structures. Others may be sensitive to particular landscape features because of situational novelty but may miss opportunities that would be useful to achieving a meaningful interpretation of the landscape. To examine the frequency and distribution of locations in which mapping activity differed, vector grids at 100-m, 50-m, and 25-m scales were overlaid with participant tracks. A variety of scales were examined to look for consistent patterns while minimizing the effect of size and shape of the aggregation cell size on the results.

The number of experienced and inexperienced geologists that crossed each grid cell was counted, and the percentage of each participant type to cross each cell was calculated. Further attention was giving to the top 100 cells in which there was the greatest percentage of difference between the frequency of visits by experienced and inexperienced geologists. The closest whole-number cutoff to the top 100 cells was chosen to simplify the analysis, so cells that were traversed 18% more by geologists in one geologic-expertise category than the other were identified. Because each category of participants traversed a differing number of cells and experienced geologists were more concentrated in their paths than were inexperienced geologists, the 97 cells resulting from the 18% cutoff constituted approximately 5% of the cells navigated by experienced participants (6% approved of 1,161) and 2% of cells navigated by inexperienced participants (30 of 1,323) of the total 4,221 cells in the study region. Results are described more thoroughly below, but cells that were entered by 18% more of the experienced than inexperienced geologists were considered indicative of the importance of that location. The count of experience-dominated cells visited by each participant was then considered a surrogate for sensitivity to important locations on the landscape. Although geologic expertise was used to derive the sensitivity variable, it was not used directly in the statistical analysis. Statistical analysis was performed on participants with experience or inexperience in field mapping, so the use of the experienced designation with respect to geology as a discipline to identify the cells did not directly contribute to within-group statistical outcomes.

Measure of Quality of Outcome—Map Accuracy and Interpretation

The geologic bedrock maps produced in the field by each participant were scanned at 600 dots/in. (236 dots/cm) and stored as TIFF (tagged image file format) files. Geologic rock units were digitized as vector polygons. Two geologists, external to the project but with extensive experience in the region, constructed a consensus map of the correct rock distribution and structure for the study area. Quality of outcome was quantified in two ways: accuracy of the placement and surface distribution of the different rock types, and accuracy of each participant's interpretation of the overall geologic structures (Fig. 4). These two measures reflected the consensus view among geologists that a geologic map must accurately show the locations, distributions, types, and orientations of the rock units and contacts among units and simultaneously represent the overall geologic structure.

A percentage measure of rock-distribution accuracy was calculated by comparing the number of 1-m pixels on the participant's map that contained the same rock as the consensus map. To quantify the participant's structural interpretation of the underlying geology, we used a scoring rubric that awarded points for correctly identifying the two main structural features (the plunging syncline and the thrust fault) as shown on the participant's map and key. Two researchers independently scored the maps and achieved a 95.5% interrater agreement (for additional details, see Baker et al., 2012). Geographic information system (GIS) analysis of participant tracks and resultant maps took place in ArcGIS 10.0 software (ESRI, Redlands, CA). Participant characteristics and quality of outcome were compared by expertise level using Pearson's and Spearman's ρ-correlation coefficients to determine the significance of relationships. Statistical tests were performed in SPSS 19.0 software (IBM, Armonk, NY).

RESULTS

Participants were considered sensitive to the importance of a particular location in the landscape if they visited that location during the mapping task. When the percentage of

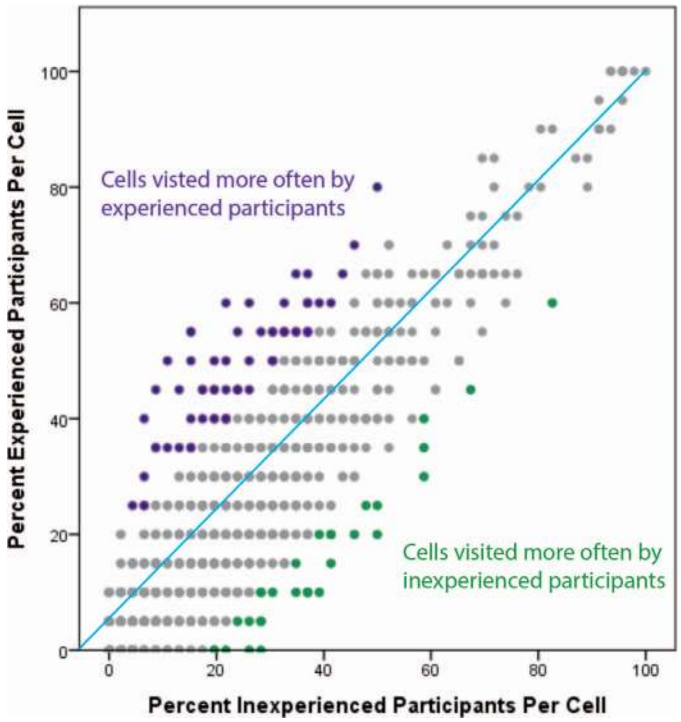

FIGURE 5: Percentage of experienced and inexperienced geologists who visited each 25-m cell during the field mapping task.

participants visiting each 25-m cell in the field area was examined by geologic-expertise level (Fig. 5), noticeable patterns appeared. Nearly all participants visited locations near the entrance to the field site (locations of obvious outcrop) and along the exit road leading from the field area (the easiest exit path). Both groups also visited sites near the center of the map area, a location critically important to interpreting the geologic structure (i.e., the axis of the syncline) because of visibility of key contacts and evidence of the valley-forming shale unit at the surface. Both groups also showed a clear tendency to follow the same general routes through the field area and spend time at the same critical locations. This tendency was influenced by accessibility limitations from topographic and vegetation in some portions of the field area.

Inexperienced geologists tended to visit a greater percentage of the field area (see Fig. 6 below) during the mapping exercise and, although the boundaries of the area were clearly marked, spent more time outside the field area. We speculated that the inexperienced participants felt something could be gained through an outside perspective or to ensure that conjectures about geologic structures were consistent with what could be seen beyond the task's boundary lines. The routes of inexperienced participants through the landscape were more dispersed, especially in the upper and central portions of the field area. In contrast, experienced participants were much more likely to follow the same paths as other members of their group, although the cohorts completed the task during different weeks over two summers.

The percentages of experienced and inexperienced participants who visited each cell were highly correlated with one another ($r = 0.93$). The scatterplot of this relationship (Fig. 6) shows more experienced participant–dominated cells than inexperienced participant–dominated cells because the movements of the less-experienced group tended to be more scattered throughout the landscape.

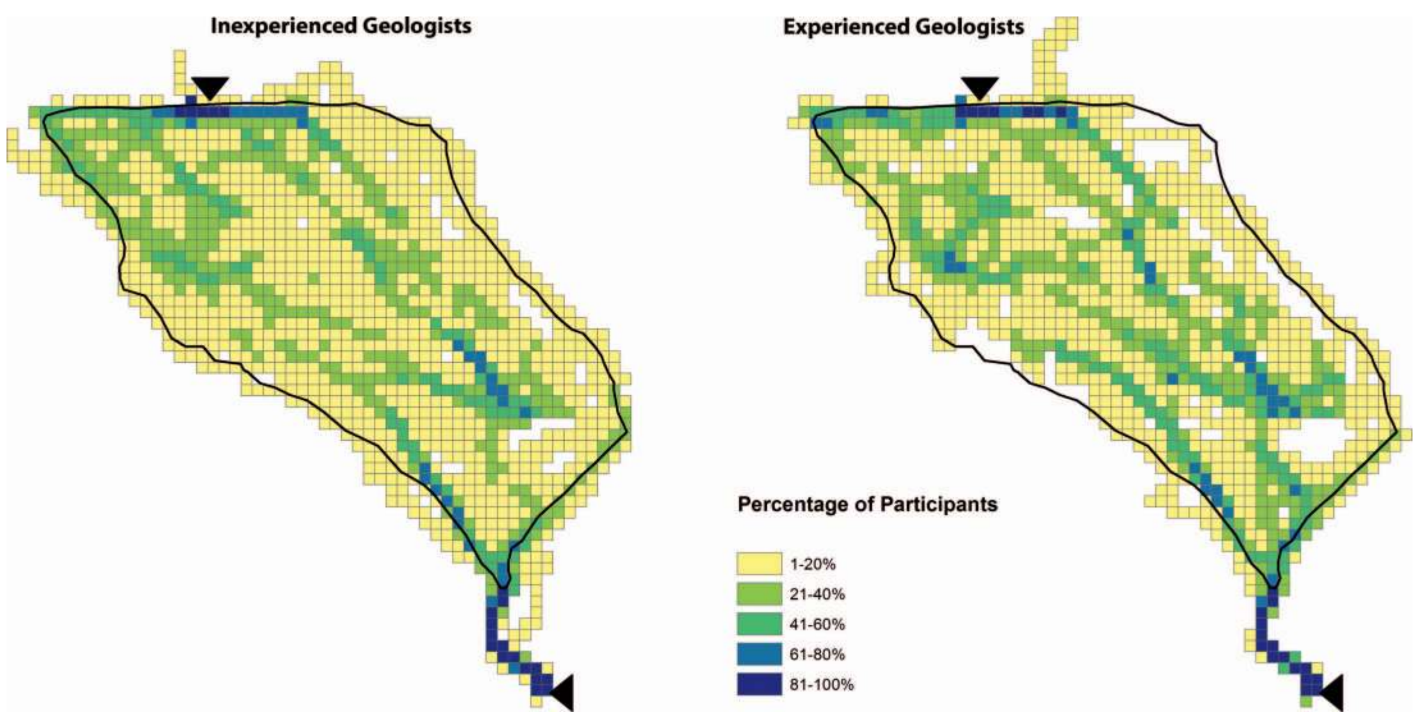

FIGURE 6: Scatterplot of the percentage of experienced and inexperienced geologists who visited each 25-m cell during the field-mapping task. Each point represents a single cell of the field area. Colored points indicate cells with at least 18% more experts (purple) or novices (green) than the opposite group of participants. Color version can be found online.

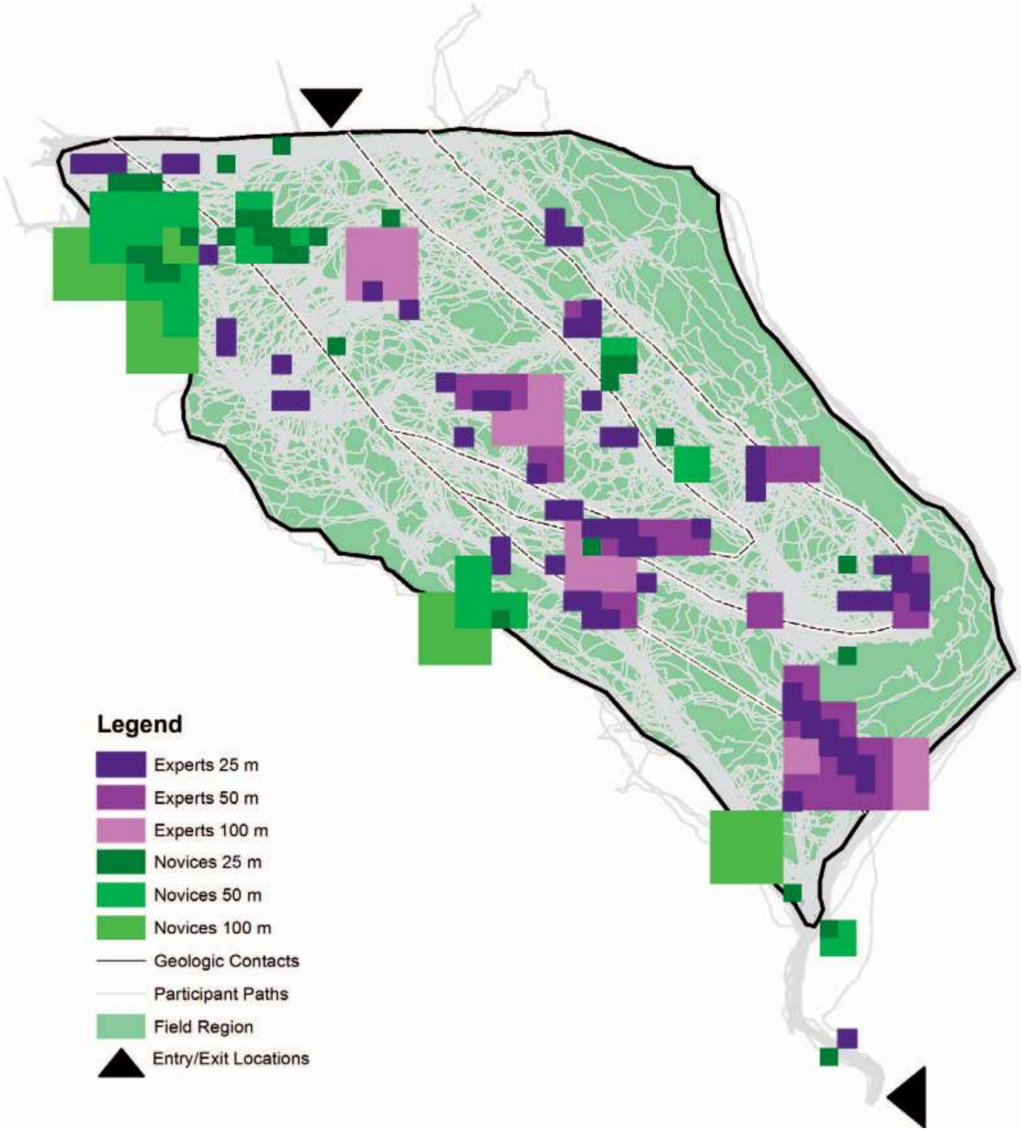

FIGURE 7: Cells of varying scales (25, 50, and 100 m) in which experienced or inexperienced geologists dominated visits to the cell area by at least 18%.

We continued the sensitivity analysis by examining cells at different scales where visits by participants of different expertise levels differed by >18%. Fig. 6 shows, for each cell traversed by at least one participant, the percentage of experienced and inexperienced participants who traveled through that cell. Cells to the top and left of the 1:1 ratio line were visited by a greater percentage of experienced than inexperienced geologists. Highlighted points represent those cells farthest from the 1:1 ratio of experienced to inexperienced visitors. Experienced geologists had a greater number of locations at all scales in which they dominated the inexperienced visitors by >18%. The 100-m cells were located along the central portion of the study area, nearly linearly, whereas the 25-m cell locations were scattered throughout the landscape, and the 50-m cell locations were always associated with 100 m or groupings of 25-m cells in the landscape.

As expected, cells in which experienced geologists concentrated their efforts were linked specifically to geologic features in the field (Fig. 7). For example, the areas dominated by visits from those participants in the center of the map area corresponded to good outcrops showing bedding-orientation changes in the axis of the syncline. The nose of the syncline (Fig. 7) was also dominated by visits from those with experience in the discipline and has particularly good exposure. Experienced geologists also visited an area in the lower-left corner of the map (Fig. 7), where the fault can be mapped by changes in the soil type. In contrast, locations dominated by inexperienced participant visits were concentrated along the outer edge and upper portion of the study region. Inexperienced geologist–dominated cells were rarely associated with geologic contacts among rock units. One of the most visited areas by inexperienced geologists, in the upper-left corner of the map area, offered a high-elevation view of nearly the entire field site; presumably, the less-experienced mappers visited that area in an attempt to gain a visual overview of the site.

Finally, the correlations among dispositional factors and success at the task were examined for those participants with differing expertise in mapping. Although our measures for

TABLE III: Pearson's correlation coefficients among participant ability (as measured by geologic knowledge), inclination (as measured by track thoroughness), and sensitivity (as measured by visits to expert geologist–dominated locations).

	Inclination	Sensitivity
Participants inexperienced in mapping		
Ability	0.168	0.087
Inclination		0.772**
Participant with mapping experience		
Ability	0.528**	0.528**
Inclination		0.377*

*$p < 0.05$, **$p < 0.01$.

knowledge, inclination, and sensitivity were each significantly correlated with one another for experienced mappers, only sensitivity and inclination were significantly correlated for inexperienced mappers (Table III). This difference clearly affects the quality of the mapping outcome. For the experienced mappers, the three components of dispositional thinking were each significantly correlated with the accuracy of the rock distribution (Table IV), but only knowledge and sensitivity were significantly correlated with accuracy for the structural geologic interpretation. For the inexperienced participants, however, knowledge and inclination were significantly correlated with accuracy of rock distribution, but only sensitivity was correlated with accuracy of the structural interpretation (Table IV).

DISCUSSION

In this study, the three logically distinct components necessary for dispositional behavior (knowledge, inclination, and sensitivity) were examined for their relationship to one another and to success in a bedrock geologic mapping task. First, we found differences by prior mapping-experience level in the relationship of these components to each other. Knowledge, inclination, and sensitivity were strongly correlated for experienced mappers, suggesting that the greater a participant's knowledge of geology, the greater their inclination to investigate the field area and the greater their sensitivity to geologically significant field locations at which to make observations. It is perhaps unusual to use collective expert-route strategies to define an individual level variable of the similar group, but, in this case, we found it useful to examine the frequency with which each experienced geologist located himself or herself with respect to other experienced geologists and, ultimately, assessed success through comparison of participants by experience in mapping. Among inexperienced mappers, we found a correlation only between inclination and sensitivity, suggesting that the more motivated a person was to thoroughly investigate the field area, the more sensitive he or she was to opportune locations, but this was not directly associated with knowledge.

In looking at the results for correlations among dispositional components and success at the mapping task, it appears that each component may influence success in different ways. Experienced mappers overall had stronger correlations than inexperienced mappers among all three dispositional components and success metrics. For both

TABLE IV: Correlation coefficients among participant ability (as measured by geologic knowledge), inclination (as measured by thoroughness), and sensitivity (as measured by visits to experienced geologist–dominated locations) and metrics of success at the mapping task. Rock-distribution accuracy is parametric, and correlations are Pearson's *R* values, whereas structural interpretation accuracy is nonparametric, and correlations are Spearman's ρ-values.

	Ability	Inclination	Sensitivity
Participants inexperienced in mapping			
Rock-distribution accuracy	0.529**	0.451*	0.292
Structural interpretation accuracy	0.201	0.302	0.425*
Participants with mapping experience			
Rock-distribution accuracy	0.765**	0.458**	0.348*
Structural interpretation accuracy	0.442**	0.320	0.401*

*$p < 0.05$, **$p < 0.01$.

experienced and inexperienced mappers, however, understanding the surface distribution of rock types correlated with knowledge and inclination (as well as with sensitivity, for experts only). Here, we might infer that a high level of geologic knowledge and skills, coupled with a desire to carefully traverse the area, leads to an accurate map of surface rock distribution for all participants. On the other hand, sensitivity was the only component to correlate with an accurate representation of the structural geology in the field area for all participants (as well as with ability for experienced mappers only). We can infer that participants who were more sensitive to geologically critical locations in the landscape were more successful in understanding the underlying geologic structure. Conversely, participants who understood the structure were more likely to choose to visit geologically critical areas.

Our results indicate that during a task-driven, in situ landscape encounter, sensitivity to opportunities in the landscape for quality geologic problem solving is one of the most pronounced differences between inexperienced and experienced mappers. Success for experienced mappers (in terms of both map accuracy and interpretation of geologic structures) significantly correlated with the number of experience-dominated locations visited, such that more locations visited led to higher map quality, but this relationship was not true for inexperienced mappers. The fairly restricted paths through the landscape made by experienced geologists (Fig. 6), the sheer number of 25-m cells dominated by visits from both groups of participants (Fig. 7), and the clear spatial differences in patterns between inexperienced and experienced geologist–dominated cells (Fig. 7), each support the notion that geology-centric sensitivity to landscape is critical to success in this geologic mapping task and cannot be compensated for by sheer mapping experience. Among experienced mappers, sensitivity to the landscape was significantly correlated with the other aspects of dispositional thinking as well as with spatial and structural accuracy of the outcome. Locations dominated by experienced geologists tended to cluster directly over geologic contacts among rock units, along the syncline axis in the middle of the field area where there was quality outcrop exposure, along the only exposure of the fault, or at other locations that may have been directly related to small rock outcrops. Locations dominated by inexperienced geologists, in contrast, were nearly all located within single rock units and along the exterior boundary of the study area, dominantly in a topographic high that afforded an overview of the field site. Among inexperienced mappers, sensitivity to landscape was significantly correlated with inclination, but not with ability or accuracy in assessing the rock distribution.

This relationship between understanding the underlying structural geology of the region and visits to specific, critical field locations identified by experienced geologists is interesting. Participants who were able to place themselves in those locations had a better understanding of the underlying structure, but, as yet, we are unable to clarify the causal relationship. Does a fundamental understanding of the landscape influence novice participants to visit similar locations as experts, or does being present in those expert locations enhance an understanding of the structure? Experienced geologists were clearly testing hypotheses that they developed both from the initial aerial photograph of the area and from direct observations of the rocks (Baker et al., 2013; Callahan, 2013), so sensitivity to landscape, understanding of structure, and rock-distribution accuracy support one another.

Limitations, Conclusions, and Educational Implications

We did not deliberately set out to research dispositional thinking in the field; rather, we fitted existing data to the Perkins et al. (1993, 2000) model in an attempt to open up the study of field mapping (and, hopefully, geoscience education more broadly) to the possibility for exploring the role of dispositions. As such, limitations of this study need to be recognized. First, our use of *dispositions* is different from what is typically studied in the literature. We focus on performance of a specific task and comprehensive understanding of a natural setting, but other researchers typically define *dispositions* as stable behaviors, such as curiosity, open-mindedness, mindfulness, creativity, and the like (e.g., Costa, 1991; Perkins et al., 2000). The closest formally recognized definition of *disposition* to our study is *critical thinking* (Facione et al., 1995; Ennis, 1996). Further work is needed to deconstruct mapping and, more broadly, field geology, into specific tasks (e.g., planning a field route, recognizing rock types, developing a mental model of the geologic structure) and to identify dispositions that affect performance on each of these tasks.

Next, we recognize that because we are working with existing data sets, our proxy measures are imperfect. The GCI, for example, measures general knowledge of geology rather than fieldwork ability (although knowledge is a critical element of ability). A future study could use direct measures of fieldwork ability, such as skill in reading topographic maps and interpreting aerial photographs, identification of rock types, use of a compass to measure strike and dip, etc. Inclination could be directly ascertained by measures of motivation, self-regulated learning, or engagement (e.g., the Motivated Strategies for Learning Questionnaire of Pintrich et al., 1993). Sensitivity could be further explored by having students identify locations for optimal data collection from a variety of field photographs, maps, and physical locations.

Although these existing data are not perfect proxies for ability, inclination, and sensitivity, we have found evidence that dispositional thinking, in addition to cognitive ability and learned behavior, contributes to success in a problem-solving task in the "wild." Knowledge, as measured by a geologic-content knowledge instrument (or what Perkins would term *ability*), and inclination, as measured by the thoroughness of the route taken through the field area, both correlated strongly with participants' understanding of the surface distribution of rock types in this mapping task. Sensitivity, as measured by paths that visited expert geologist–dominated locations, correlated with participants' understanding of the underlying geologic structure. Furthermore, we found that sensitivity was the most-pronounced component distinguishing inexperienced from experienced mappers. Among more-experienced mappers, sensitivity to the landscape was significantly correlated with both knowledge and inclination, as well as with the accuracy of rock distribution and an understanding of the geologic structure. Among inexperienced mappers, sensitivity was only correlated with inclination and an understanding of the geologic structure. It appears that novices who were sensitive to key locations in the landscape were more successful at the mapping task.

These results are significant for education of field researchers because cultivation of cognitive sensitivity to landscape presents a different sort of instructional challenge than that of directly teaching discipline-specific content or traditional mapping skills. Novices may possess the knowledge and skills to create a high-quality geologic map, but without the inclination and the sensitivity to opportunities to best use those skills, they may struggle with this task. In the case of geologic mapping, explicit instruction in landscape interpretation, to identify optimal locations, and in route planning to reach these locations may be needed. Some recommendations in this regard include the following:

- Explicit training in the use and interpretation of topographic maps, including identification of likely areas for outcrops, bedrock change, optimal locations for viewing the overall landscape, key locations for strike/dip measurements, etc. Students may also need training in relating maps to actual field locations.
- Explicit training in the use and interpretation of aerial photographs, including identification of key outcrops, bedrock change, key locations for measurements, vegetation change, etc. Similarly, students may benefit from learning to relate photos to actual field locations.
- Explicit training in viewing a landscape (still photos, virtual environments, photo panoramas, etc.) and using that view to justify decisions that relate to later, in-field actions, such as planning and carrying out fieldwork routes, optimal sampling sites, or locations for making inferences about geologic structures.

Unfortunately, there has been little research done on how field problem-solving skills are optimally taught, but moving beyond the mechanics of mapping to encourage students thinking about how, when, and where to employ their fieldwork skills may be warranted.

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