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Nora S. Newcombe
Temple University

Steven M. Weisberg
University of Pennsylvania

Kinnari Atit
Temple University

See next page for additional authors

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NORA NEWCOMBE
Temple University*

STEVEN M. WEISBERG
University of Pennsylvania*

KINNARI ATIT
Temple University

MATTHEW E. JACOVINA
Arizona State University

CAROL J. ORMAND
Carleton College

THOMAS F. SHIPLEY
Temple University

THE LAY OF THE LAND: SENSING AND REPRESENTING TOPOGRAPHY

ABSTRACT: Navigating, and studying spatial navigation, is difficult enough in two dimensions when maps and terrains are flat. Here we consider the capacity for human spatial navigation on sloped terrains, and how sloping terrain is depicted in 2D map representations, called topographic maps. First, we discuss research on how simple slopes are encoded and used for reorientation, and to learn spatial configurations. Next, we describe how slope is represented in topographic maps, and present an assessment (the Topographic Map Assessment), which can be administered to measure topographic map comprehension. Finally, we

describe several approaches our lab has taken with the aim of improving topographic map comprehension, including gesture and analogy. The current research reveals a rich and complex picture of topographic map understanding, which likely involves perceptual expertise, strong spatial skills, and inferential logic.

There are many ways to navigate the spatial world. In the past decade, we have come to rely on technology to find our destinations, using computers and smart phones to provide step-by-step instructions on the best route, display an overall map, or tell us which way is north (if we choose to ask that question). But humans did not evolve in the technological world, although they eventually created it. Our ancestors used many cues for wayfinding. Some of these systems were part of a common evolutionary heritage, shared with other mammals and also with birds, insects and even with reptiles and amphibians, as would be expected given the importance of successful navigation for survival. But humans' abilities for abstract and symbolic reasoning also supported our species in the invention of complex and culturally communicated systems (Gladwin 1970; Hutchins 1995; Huth 2013), and increasingly, technological tools. Thus, for humans, understanding navigation entails both understanding shared cross-species capacities for navigation, and the uniquely human symbolic additions that augment those capacities.

Modern cross-species research on navigation has generally concentrated on two navigation systems, often called the *egocentric* and *allocentric* systems (for reviews, see Jacobs & Menzel 2014; Wiener et al. 2011). These systems are distinct, but they can combine and supplement each other in various ways (e.g., Zhao & Warren 2015). Egocentric systems involve our bodily senses and body-centered encoding of spatial location, e.g., *the window is behind me*. Egocentric coding is useful for wayfinding only if it is updated by information about our movement through space, both in terms of direction (e.g., we know that the window that was behind us is now to our left, after we turn 90 degrees), and distance (e.g., we know that the window is now much further behind us after we walk 100 paces forward). When egocentric systems are updated in this way, they are often called *inertial navigation* systems, or *dead reckoning*. Allocentric coding does not depend on the body, but rather uses external landmarks, such as distinctive buildings or mountains in the distance. These landmarks are most helpful when they are large (and hence visible), distinctive (and hence recognizable), and, crucially, stable (or else they will be misleading). Landmarks may be related to each other to form a *frame of reference*. A particularly interesting kind of allocentric framework is provided by the geometric shape of enclosures (for review, see Cheng et al. 2013). This tradition of navigation research has led to many interesting discoveries and a rapidly growing body of knowledge.

Productive as this research agenda has been, however, the dichotomy between egocentric and allocentric systems over-simplifies the problem of navigation. For instance, research on these two systems generally ignores things such as the positions of the sun and the stars, the direction of the prevailing winds, and the ocean currents, information that can be used not only by human navigators lacking access to GPS but also by many non-human species, such as migrating birds and foraging bees. The traditional dichotomy also neglects the usefulness of *gradient cues* (Jacobs & Schenk 2003). Gradient cues include scent (Wallraff 2004), sound (King & Parsons 1999), and luminance (Petie et al. 2011). For these cues, the intensity of the stimulus is greatest at the source, and decreases logarithmically as the source becomes more distal (e.g., the smell of doughnuts gets less intense as you move away from the bakery). Such cues tell us about direction (we can follow our nose to the bakery, or away from it). These cues also tell us about distance, through processing of the intensity's rate of change over time (the bakery must be very close when the smell of sugar is becoming rapidly more intense).

The topic of this article is terrain slope, another important, yet relatively under-studied, gradient cue that can be perceived and used for spatial orientation by birds and by other mammals. In addition, humans have invented ways to measure slope precisely, to measure the associated but distinct concept of elevation, and to organize, integrate and transmit these measurements using symbolic means, notably topographic maps. However, interpreting such maps is not straightforward, and we consider how learning to interpret them can best be supported and how the user's level of expertise can be assessed.

1. ENCODING SLOPE AND TERRAIN

Slope is a gradient cue that differs from light, smell or sound. One point of contrast is that it is multi-modal rather than unimodal, perceivable by the kinesthetic sense (angle of the joints/muscular exertion), by the vestibular sense (sense of balance), and by the visual system (angles formed when a sloped terrain intersects a vertical plane). Multi-modal input might be surmised to make slope a particularly accessible navigational cue. However, slope information turns out to be equally accessible for spatial search when presented unimodally, so the fact of multimodality does not seem to provide a significant advantage (Weisberg et al. 2014). A second point of contrast is that slope does not consistently vary as a function of distance in the natural environment as do gradient cues such as smell (e.g., a mountain can be steepest at its base, midpoint, and/or apex). This fact may make slope more challenging to use for navigation, because sensing slope does not provide information about distance or precise location. Furthermore, use of slope in wayfinding is also complicated by the fact that most terrain involves multiple topographical features (e.g., undulating and intersecting river valleys wandering among hills of varying heights). Nevertheless, experienced navigators report that they seek to use the "lay of the land" along with other cues to maintain their spatial orientation in natural environments.

How accessible is slope as a spatial cue? Most research to date has focused on experimental settings where there is a simple unidirectional tilt. Slope is a potent cue in studies using pigeons, the most extensively studied species[1], who learn a spatial search task about three times faster on a floor sloped at 20 degrees than on a flat surface (Nardi & Bingman 2009) and who rely heavily on slope information, even when other sources of information have more predictive power (Nardi et al. 2010). Rats also appear to use a unidirectional slope, specifically a slope of 10 degrees, in spatial search tasks (Miniaci et al. 1999). In human experiments, slope has been limited to 5 degrees for safety reasons, and, perhaps as a consequence, it has seemed less accessible than in the studies with pigeons and rats. But slope is still useful, supporting above-chance spatial search, although there is a male advantage in using it (Nardi et al. 2011), which appears in 8- to 10-year-old children as well as adults (Holmes et al. in press). Unfortunately, we have very little information for any species about more complex environments, in which slope varies unpredictably to define complex systems of valleys and hills. But tellingly for the surmise that slope may be a difficult navigational cue to use, only people who self-rated as better navigators were able to use slope information to learn about complex terrain in a virtual reality study (Weisberg & Newcombe 2014).

Overall, we can conclude that, although slope is potentially a helpful spatial cue, it may only be variably encoded by humans even in fairly simple situations, and that extracting the "lay of the land" for navigating more complex terrain is likely to be yet more challenging. Perhaps for that reason, humans have created tools to measure slope and elevation, and have also devised symbolic representations such as topographic maps that store and integrate those measurements. But these tools are themselves not easy to learn to use, a topic to which we now turn.

2. SYMBOLIC REPRESENTATION OF TOPOGRAPHY

Slope and elevation are both relational concepts. Elevation is related to slope but is not at all the same thing. Consider alpine plateaus or mesas, flat structures that occur at high elevations. Elevation is seemingly simply defined as distance above sea level, but it is actually a complex measurement to make, partly because sea level is not as constant as one might imagine – see http://www.youtube.com/watch?v=q65O3qA0-n4. Topographic maps represent earth's surfaces using contour lines, which join locations with equal values of elevation. Slope is defined by relations among the lines, i.e., contour lines need to be related and integrated in order to visualize the terrain. Learning to read topographic maps is difficult (e.g. Clark et al. 2008; Rapp et al. 2007), yet skill with them is essential to geoscience, architecture, urban design, and landscape planning (Petcovic et al. 2009), and for emergency responders, e.g., when asked to find landing sites for rescue helicopters (Wilkening & Fabrikant 2011).

Efforts to devise ways to facilitate acquisition of skills with topographic maps have often focused on providing additional visual information, such as various kinds of shaded relief (e.g. Phillips et al. 1975; Pingel & Clarke 2014; Potash et al. 1978), stereo effects (Rapp et al. 2007), color-enhanced contour lines (e.g., Taylor et al. 2004) or direct

color coding of slope (Wilkening & Fabrikant 2011). Such efforts have typically achieved significant effects, but limited ones in terms of the size of the performance boost and/or generalization (e. g., when the cues are removed, contour map reading returns to baseline).

One source of guidance for how best to boost performance is descriptions of expert performance. Experienced topographic map users report that they look for meaningful patterns rather than focusing on individual contour lines (e.g. Chang et al. 1985; Gilhooly et al. 1988). For example, Pick and colleagues (1995) found that when asked to locate their position in the world on a topographic map, experienced topographic map users try to match structures in the terrain (e.g. valleys and ridges) to structures on the map and vice versa. McGuigan (1957) found that novice topographic map users who saw terrain images paired with topographic maps showed better performance than six other groups that received alternative types of instruction on both contour interpretation (e.g. absolute and relative height judgments) and contour visualization (e.g. determine the direction of slope). Furthermore, participants' skill in pattern recognition was strongly correlated with their proficiency in contour interpretation.

Guided by these descriptions, we have made several efforts to improve students' ability to read topographic maps, all based on the idea of using cognitive tools to support learning, rather than modifying the materials or changing the mapping conventions. In this article, we will briefly report on three interventions. The first two were conducted in parallel and used gesture or analogy to support learning. Building on the lessons learned from the first two, the third aimed to use instructional language to focus attention on one of two concepts, either forming a concept of elevation and the meaning of contour lines, or using the contour lines to visualize the shape of the terrain. Overall, these interventions can be seen as efforts to scaffold a transition from action-to-abstraction, along a continuum of progressive abstraction. These studies led us to a deeper understanding of the components of topographic map understanding, which will require future research to evaluate fully.

2.1. Topographic Map Assessment (TMA)

As a vital methodological prerequisite, we also developed a common yardstick, a way to evaluate students' ability to read and reason about topography that could be used across studies and hence allow for comparison among different labs and classrooms. The TMA was constructed collaboratively by cognitive psychologists, educators, and geoscientists. Items were created by gathering samples of topographic maps tests online and emulating the types of questions using maps gathered from the United States Geological Survey web page http://www.usgs.gov/. A geoscience educator checked the items for accuracy and for appropriateness for the ability levels of novices. The test consists of 23 items with 28 possible points. (See Appendix A for the complete set of items, and Appendix B for the scoring rubric.) It requires students to engage with topographic maps in a variety of ways, potentially tapping multiple dimensions or levels of understanding. For example, some items require participants to draw the direction a stream would flow between two points, and the path it would take (e.g., items 2, 10, 11, and 12). Other items require matching an image of a terrain to a location on a topographic map (items 8, 15 and 16) or require knowledge about a contour interval (the change in elevation between two contour lines; items 5, 6, and 9). This variety taps much of the knowledge a student would need to interact with topographic maps outside of a field setting.

We evaluated psychometric characteristics of the TMA in a large sample of female psychology majors (N = 261), restricting ourselves to women because they were much more common in psychology classes, and because they showed wide variability in their ability to solve the items, in part because they perform less well than men. In a sample that included both sexes, we found a large gender difference on the TMA, with men ($M = 18.0$, SD = 4.0) significantly outperforming women ($M = 15.2$, $SD = 4.1$), $t\ (78) = 3.00$, $p = .004$, $d = 0.68$).

Reliability for the TMA was very high ($\alpha = .76$). Furthermore, the TMA exhibits a wide range of performance (Min = 4, Max = 27, $M = 16.9$, $SD = 4.3$) and item response theory analyses (Rasch model and a 1-factor latent trait model) reveal that the assessment covers a broad range of ability (see Figure 1). These are good indications that the TMA is useful for assessing topographic map reading ability in novice students.

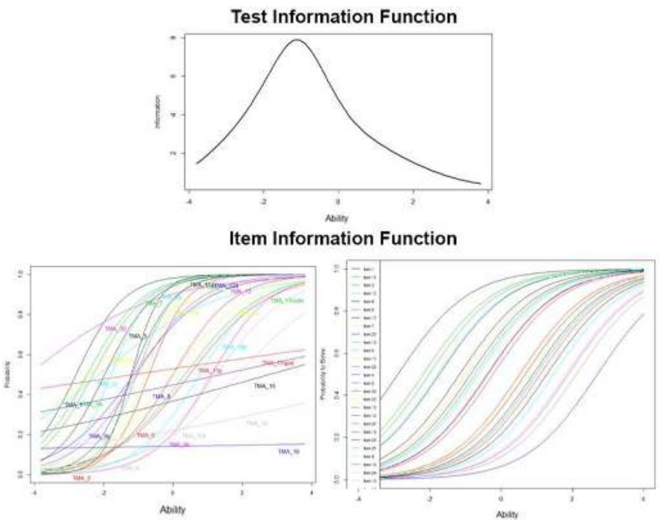

Figure 1. IRT analyses and plots for the LTM model (top and lower left) and Rasch model (lower right) show the test covers a broad range of ability levels, and most items have high information (steep slopes of items on the lower right graph). The test information function (top) shows the test is calibrated mainly for novices, since the peak of the curve is centered below zero.

2.2. *Can Gesture Improve Topographic Map Reading?*

Gestures help novices solve complex 3D spatial problems such as understanding block diagrams in the geosciences (Atit et al. 2015), and translating between different 2D diagrams of organic molecules in chemistry (Stull et al. 2012). The effect of gesture may be based on several factors. First, gesture helps learners to focus attention on critical information (Alibali & Kita 2010; Sauter et al. 2012) and to reduce cognitive load (e.g. Goldin-Meadow et al. 2001). Second, in so far as gestures are actions, they provide an embodied grounding to learning, but they are not just actions—they are also symbolic and hence are on the continuum lying between action and abstraction (Goldin-Meadow & Beilock 2010). They can directly represent some complex spatial relations, such as relative orientation and shape (Atit et al. 2014). Furthermore, they represent in a way that allows for symbolizing continuous and analogue, not categorically (like language). Perhaps because of their abstraction away from action, gestures are known to promote generalization and retention (Novack et al. 2014).

Building on video analyses of expert geoscientists describing topography (Atit et al. 2013), we used two kinds of gestures to attempt to highlight relevant information on topographic maps, using the map shown in Figure 2. We presented gestures paired with the maps as well as with physical models of the maps' 3D structure, as shown in Figure 3, because of observations that models may support spatial learning (Alles & Riggs 2011; Stieff 2011). That is, both interventions used the models as part of the instructional package. One kind of gesture was the pointing and tracing gestures often used to focus a listener's attention to spatial information (e.g. Atit et al. 2014; Heiser et al. 2004; Lozano & Tversky 2006), used here to highlight relevant patterns. The pointing and tracing gestures were used to highlight relevant contour patterns on topographic maps. The other kind of gesture was the hand shapes shown below in Figure 4. The hand shapes were used to represent the 3D structure (also represented by a 3D model) of relevant terrain features. There were two comparison groups, one that received basic text-based instruction on topographic maps, and one that received no instructions.

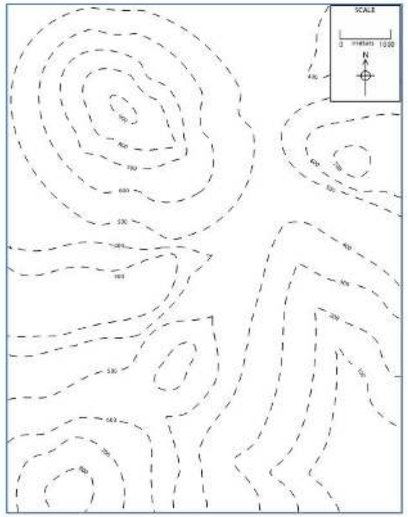

Figure 2. An image of the Sample Map used during instruction, a topographic map adapted from Bennison & Moseley (2003) that contains contour patterns representing a hill, a valley, and steep and gentle slopes.

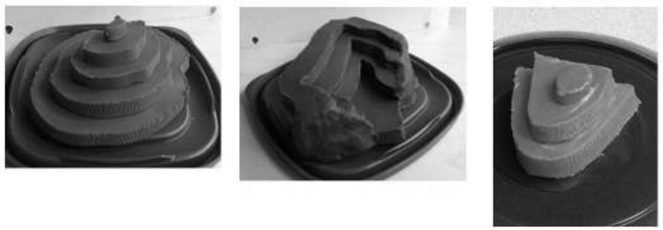

Figure 3. Images of the three aligned models of the structures represented on the Sample Map: from left to right, hill, valley, and steep and gentle slopes.

Figure 4. Images of the gestures used by the experimenter during instruction for the 3D Visualization group: from left to right, the gesture of a hill, the gesture of a valley, and the gesture representing slope (the angle of the hand varied depending on whether a steep or gentle slope was represented).

We found that the basic textual instruction was helpful: students who read the passage did better on the TMA than students who dived into the TMA without preparation. But the Point-and-Trace group, where gestures were used to draw attention to contour patterns, performed better than either control group. The 3D Visualization group, where gestures represented the 3D shapes directly, performed better than the No Instruction group, but its performance did not significantly exceed the Text-based Instruction group. On the other hand, its performance was also not significantly lower than the Point-and-Trace group, suggesting some modest level of effect not large enough to detect even with a substantial sample.

One possible reason why Point-and-Trace was most clearly helpful is that these gestures draw attention to the contour lines that define elevation categories, in the same way that color highlighting or shading does. Because they are active delineations of the lines and their shapes, these gestures may both solidify the notion of elevation and encourage the abstraction of the visual patterns collectively defined by the lines and how they map onto terrain shape. Speculatively, discriminating the terrain features that are captured by the shape gestures could be a skill that emerges later in the acquisition of fluency in reading topographic maps.

2.3. Can Analogy Improve Topographic Map Reading?

Our other initial intervention study aimed to capitalize on the role of analogy and comparison in spatial learning (e.g., Markman & Gentner 2001). Participants were randomly assigned to one of two groups. In a Topomap group, participants were shown sets of images of virtual environment 3D terrains and their corresponding topographic maps (i.e., numbers 1-4 in Figure 5 were shown at one time; then a second set of four images was shown depicting a different type of terrain). They were then asked to write down similarities and differences between the 3D terrains and between the topographic maps for each set of four images. In a Verbal group, participants were given a verbal analogy quiz as a filler task, and asked to complete as many analogies as they could. Timing was yoked to the amount of time a participant in the Topomap group took on the comparison task. Both groups then completed the TMA. But unfortunately, the two experimental groups did not significantly differ on the TMA. Why did the analogy intervention not work? One possibility is that it was insufficiently strong. Participants did not receive many problems, and never explicitly compared the topographic maps with the corresponding 3D visualizations.

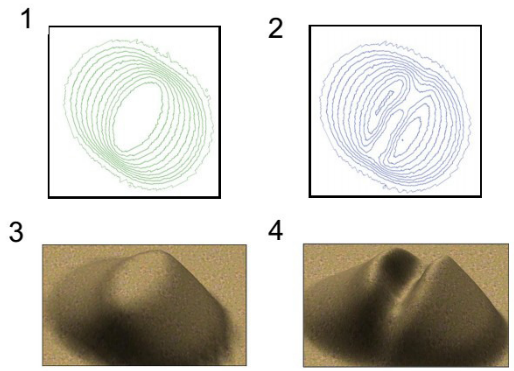

Figure 5. Sample stimulus for Analogy Study

However, there was one intriguing result of this study. We analyzed the language used to describe the similarities and differences in the Topomap group during the comparison task, with particular attention to the words ’elevation’, ’shape’, ’color’, ’slope’, ’height’, and ’line’. We then tested whether participants in the Topomap group who used a specific spatial word (e.g., ’elevation’) performed better (or worse) than participants who did not use that word. Using a Bonferroni correction for multiple comparisons, the only word that showed a significant difference was ’elevation.’ That is, participants who used the word elevation in describing the similarities or differences between the two maps performed significantly better than participants who did not use that word, and significantly better than the Verbal group. These findings were intriguing, but only correlational. We could not determine whether participants who used the word elevation already understood topographic maps, and were using appropriate language to describe the knowledge they had, or if the comparison drew some participants’ attention to a relevant feature (’elevation’), but not other participants.

In addition, participants who used the term ’elevation’ performed better on a particular subset of items from the TMA. Particular items from the TMA differentially focus on analyzing the concept of elevation or on visualizing the terrain in 3D. Two cognitive psychologists and two expert geoscientists coded each item for whether it was more likely to require knowledge about Elevation or knowledge about the Shape of the terrain. There was consensus for the four coders on 16 out of 28 items, 9 of which were coded as Shape, 7 of which were coded as Elevation. Participants who did use the term elevation outperformed control participants on Elevation items, but not Shape items. Participants who did not use the term elevation performed worse than control participants specifically on items requiring knowledge about elevation, but equally on items requiring visualization.

2.4. Analyzing Elevation or Visualizing Terrain?

The results of the gesture study suggested that point-and-trace gestures are especially well-suited to supporting topographic map reading. One possible reason is that they focus attention on the contour lines and encourage the formation of a concept of elevation. The importance of such a concept is also potentially at the source of the correlation found in the analogy study between use of the word elevation and better TMA performance. In addition, however, the point-and-trace gestures may have actually done a better job than the shape gestures of highlighting the shape of the terrain. Following the contours with a finger may demonstrate their 2D shape and allow extraction of the 3D shape. Given this reasoning, we decided to do a study in which we held gesture constant and varied language in order to focus learners’ attention either on elevation or on shape.

We devised three conditions in a between-subject design. In the Visualizing condition, participants were encouraged to focus on the shape of the contour lines, and imagine how they might look in 3D. In the Analyzing condition, participants were told that each contour line represents one value of elevation, and to consider that the concept of elevation implies that as contour lines are closer together, elevation changes more quickly. In both conditions, participants imitated pointing and tracing gestures (the same gestures as those used by the Point-and-Trace group in the experiment described earlier) made by the experimenter, and then answered questions about a sample map using their own gestures. Participants in the control condition received no instruction, but saw the same stimuli, were asked open-ended questions about each map, and were allowed to gesture if they chose (although doing so was not specifically encouraged). Condition assignment was pseudo-randomized and counter-balanced for map experience based on reports of experience with topographic maps (on a scale of 1-7).

The Visualizing and Analyzing conditions both outperformed the Open-ended condition on the overall TMA. However, the two groups turned out not to have learned the same things. Using the same Shape and Elevation item coding as before, participants in the Visualizing condition performed well on Shape items relative to other conditions, but poorly on Elevation items, and conversely participants in the Analyzing condition performed poorly on Shape items but well on Elevation items (see Figure 6). Data from the Open-ended condition showed that participants in the Visualizing condition were at baseline for Elevation items, whereas participants in the Analyzing condition were at baseline for Shape items.

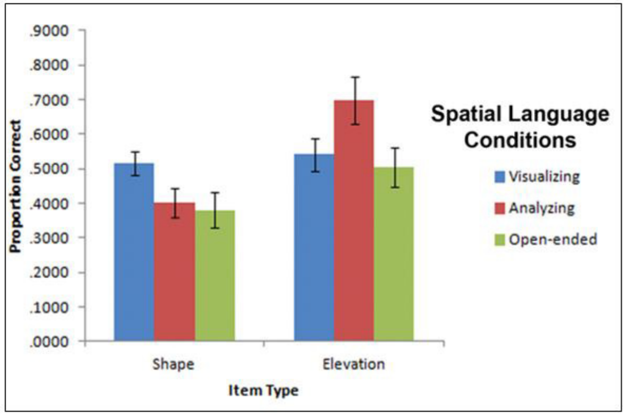

Figure 6. Differential advantages for the Visualizing and Analyzing groups on Shape versus Elevation items from the TMA.

3. CONCLUSIONS AND FUTURE DIRECTIONS

There are two broad types of future directions suggested by this research. There are many possible ways to help learners new to topographic maps. For example, we could begin the action-to-abstraction sequence by embodied grounding in action, providing active slope experience on a tilted treadmill to instantiate what certain degrees of slope feel like. Those degrees could be communicated perceptually with visual images of those slopes in an actual landscape or videos of mountain paths, schematically using tilted lines, or symbolically using number of degrees or how close together contour lines would be for that degree of slope. As another example, people might benefit from using both point-and-trace and shape gestures while solving problems on the TMA. As a third example, people working with TMA-type items could be asked to predict observer view, or predict stream flow and so forth, but then see the correct answer immediately, perhaps with an explanation. Prediction with feedback and explanation helps learning, as does viewing worked examples.

Another, and complementary, avenue is to follow up these findings

by clarifying the nature of the developmental or learning progression. Is there in fact a sequence from perception (side views, aerial views, action) to 3D models to 3D ziggurat-like models (as we used) to schematic depictions to gestures to symbolic representations (i.e., the conventions of contour lines, or words such as elevation)? Does the order in which gestures, models, and perspective views are offered affect the development of skills in topographic map understanding? For example, perhaps first using pointing and tracing gestures to learn how to find contour patterns followed by using 3D gestures and models to help visualize the structures would be an effective progression, or perhaps shape and elevation can be learned independently. We are only at the start of the journey to understand how to understand the lay of the land.

ACKNOWLEDGEMENTS

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Notes

[1] This choice of species may seem odd: given that birds can fly, why would they make extensive use of a ground-based cue? However, pigeons forage for food on the ground, and spend a considerable amount of time on their feet rather than on wing. Furthermore, their claws allow them to grip tightly even on steep inclines, allowing for the effect of slope to be studied with a wide degree of variation.

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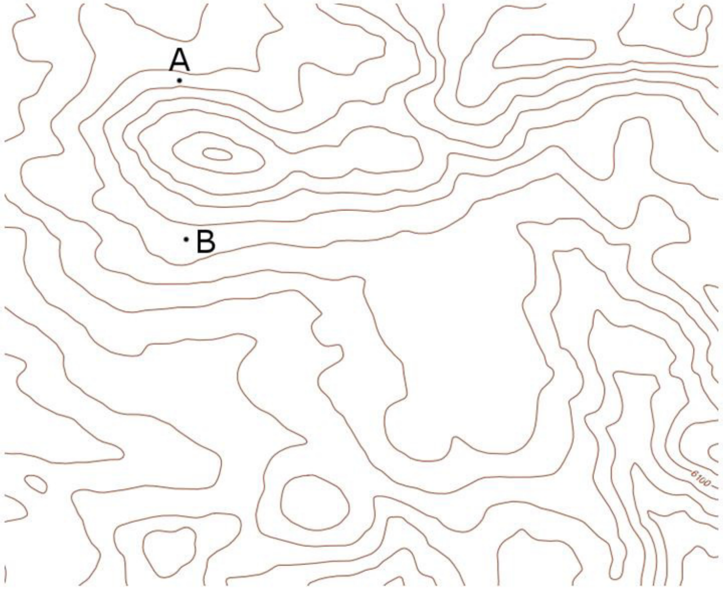
APPENDIX A

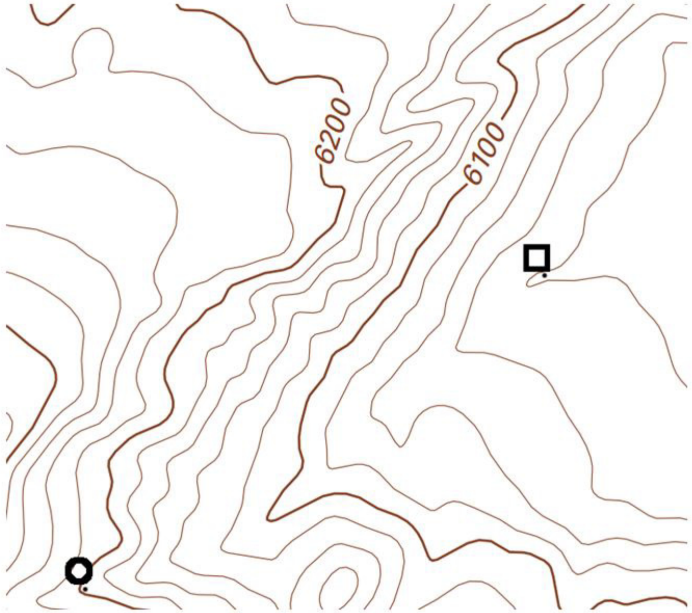
Topographic Map Assessment

Developed by Matt Jacovina, Carol Ormand, Thomas F. Shipley, & Steven Weisberg

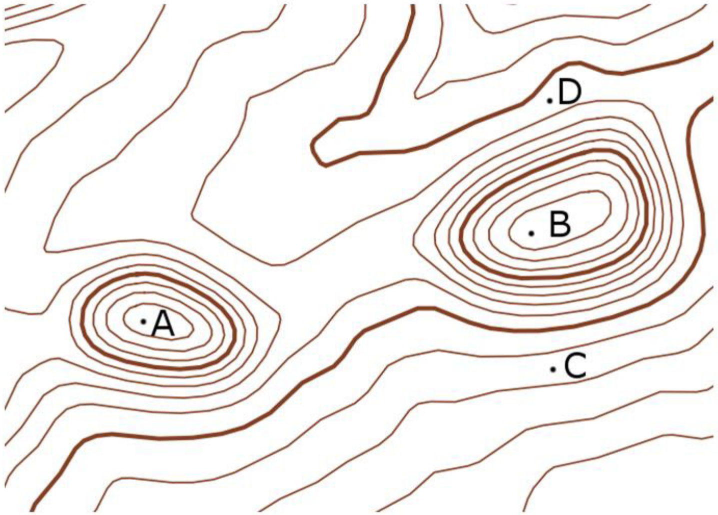
Please complete this 18-item assessment. The assessment is not timed. Try to answer each item to the best of your ability.



1. The contour interval for this map is 100 ft. Imagine you had to walk to get from point A to point B, and wanted to do so as easily as possible. Sketch the route you would build, and explain why you chose that particular path.

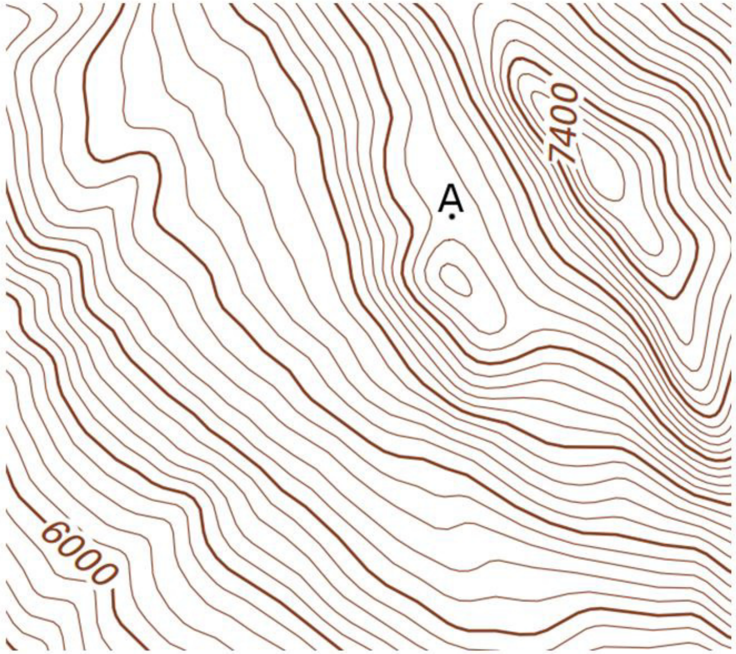


2. Imagine there is a stream that connects the circle and the square. In which direction would the water flow? Why? Please draw the path the stream would take.

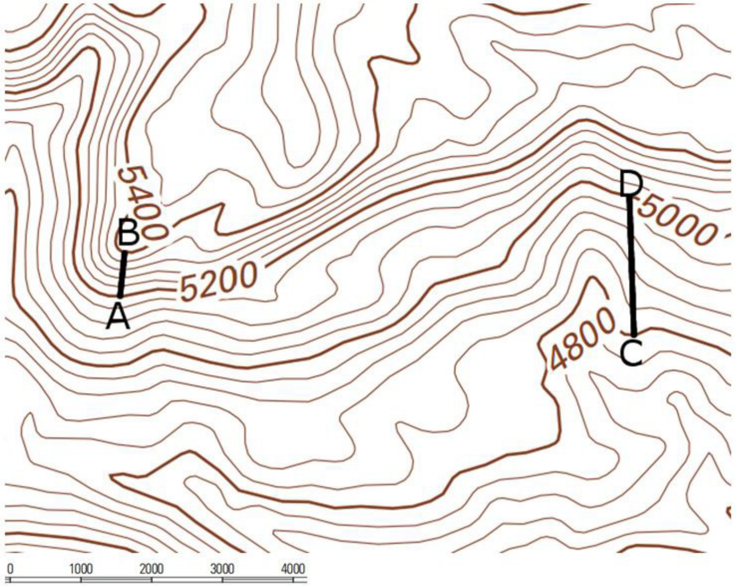


3. The contour interval on this map is 20 feet. One person is standing at each point on the map. Please answer (Y/N) the following questions about whether the people standing at two points can see each other. Assume they are able to use binoculars. Also assume there is no vegetation.

- A and B.
- A and D.
- B and C.
- C and D.
- B and D.



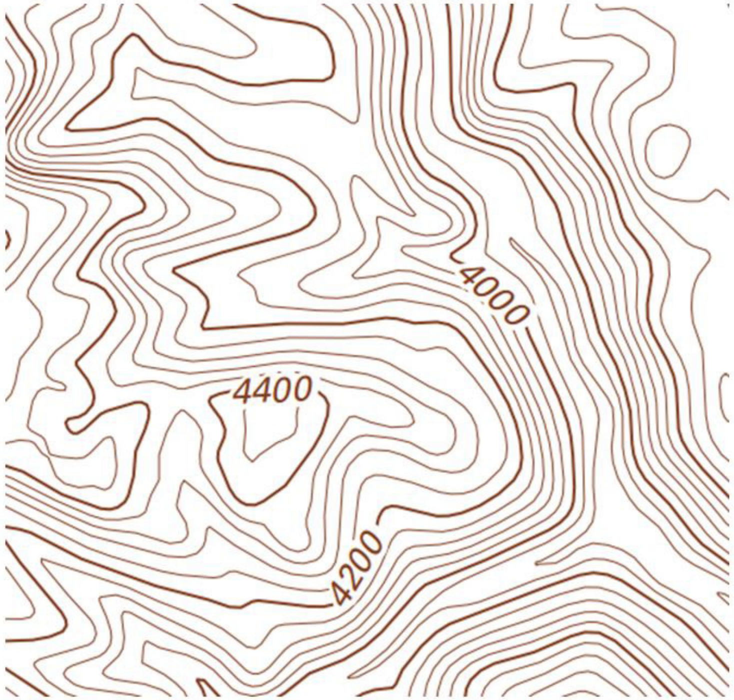
4. The contour interval for this map is 40 feet. What is the elevation at point A?



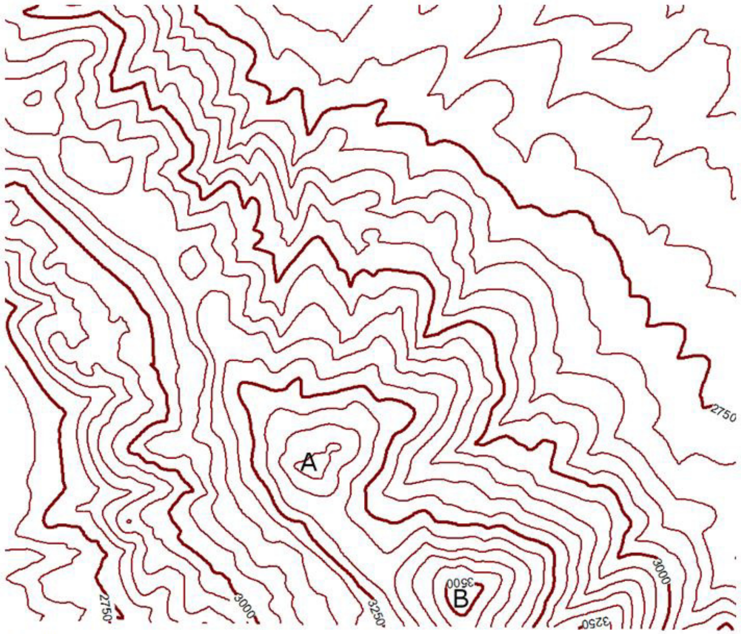
5. Imagine Josh traveled on foot from point A to point B, and Amy traveled on foot from point C to point D.

Who walked up a steeper slope?

Why did you choose the answer you did?

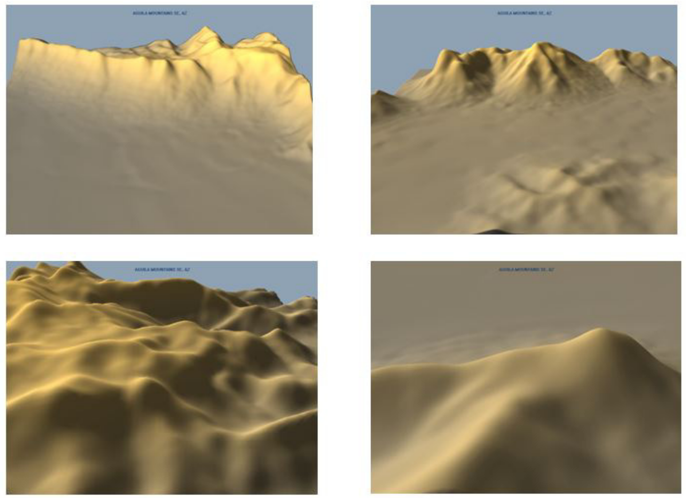


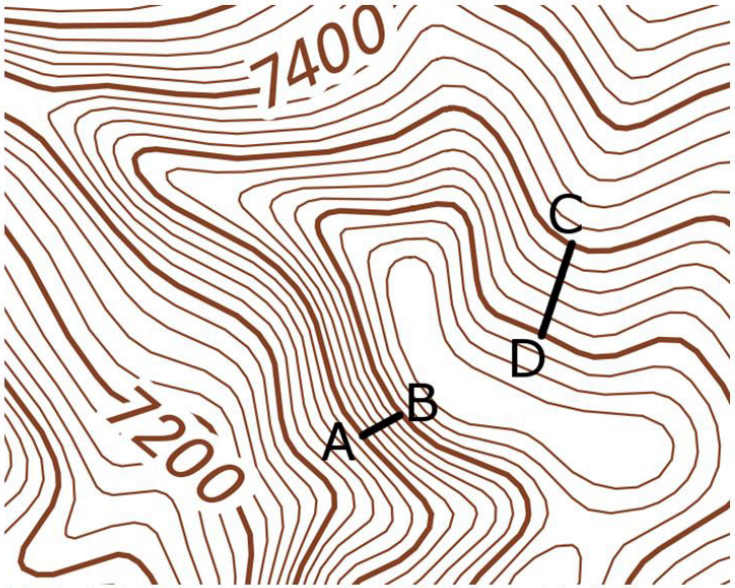
6. What is the contour interval on this map? That is, how much does elevation change moving from one line to another?



7. Which hill is higher: A or B?

8. Which of the following views best represents what someone would see standing at the start of the arrow and facing in that direction?

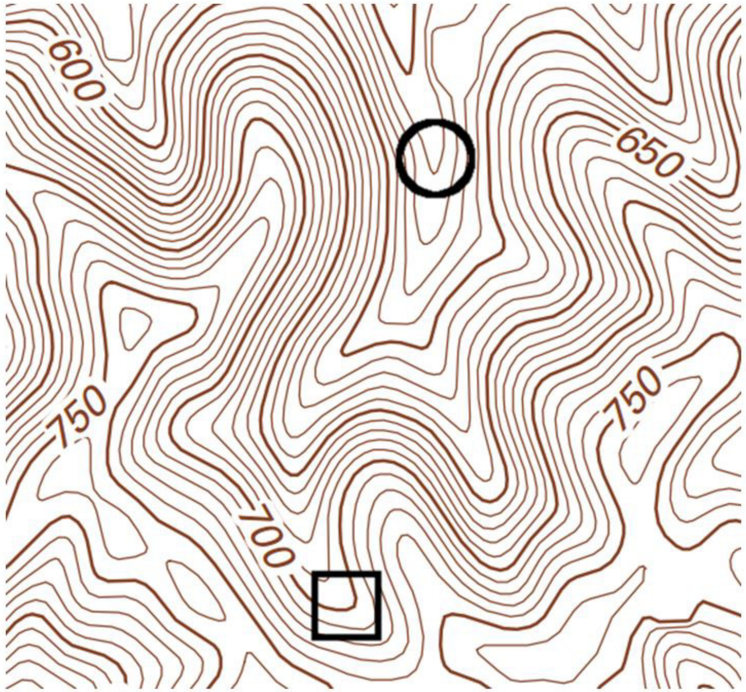




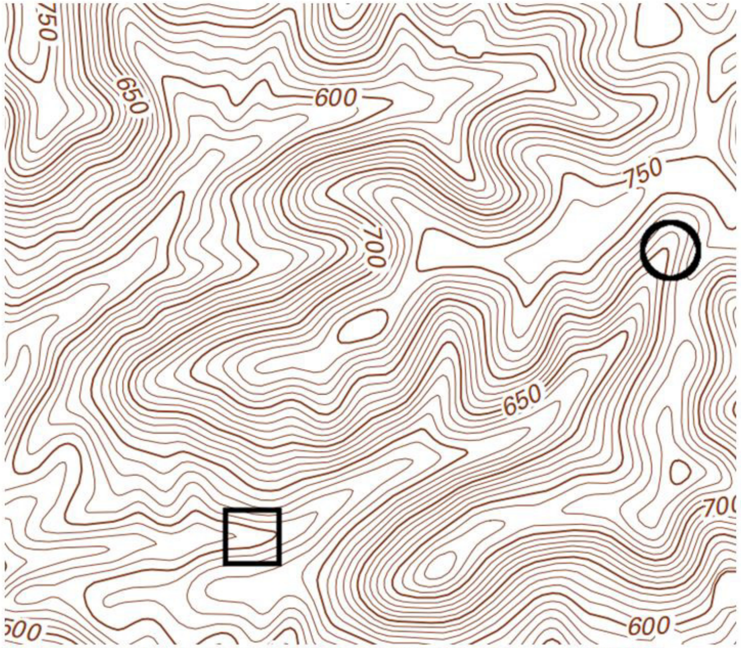
9. Imagine Josh traveled on foot from point A to point B, and Amy traveled on foot from point C to point D.

- Who walked up a steeper slope? How can you tell?

- Who traveled a greater vertical distance? How can you tell?

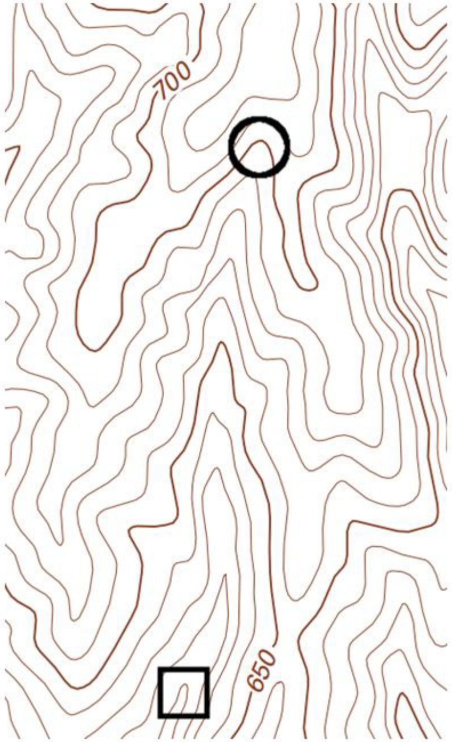


10. Imagine there is a stream that connects the circle and the square. Please draw the path you believe the stream would follow. In addition, clearly mark the direction you believe the water would flow, and why.

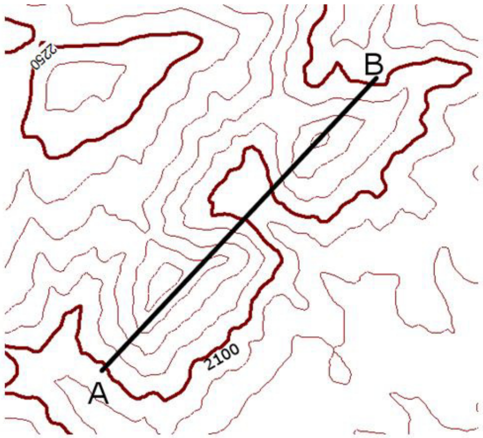


11. Imagine there is a stream that connects the circle and the square. Please draw the path you believe the stream would follow. In addition, clearly mark the direction you believe the water would flow, and why.

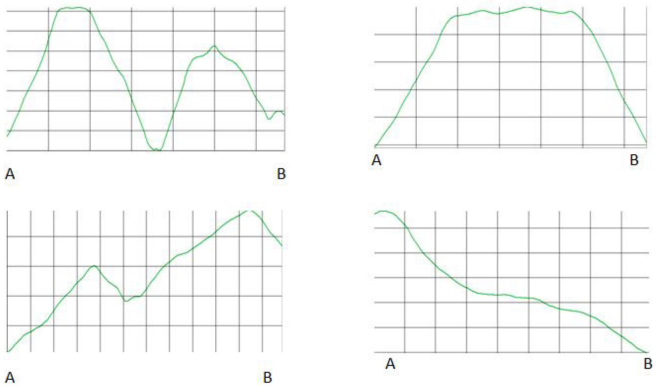
Finally, do you think the water would flow faster near the circle, or near the square? Why?

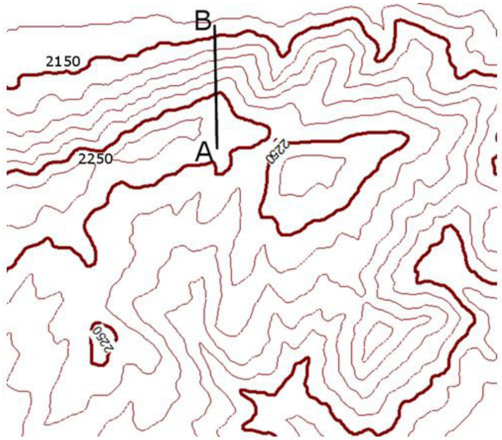


12. Imagine there is a stream that connects the circle and the square. Please draw the path you believe the stream would follow. In addition, clearly mark the direction you believe the water would flow, and why.

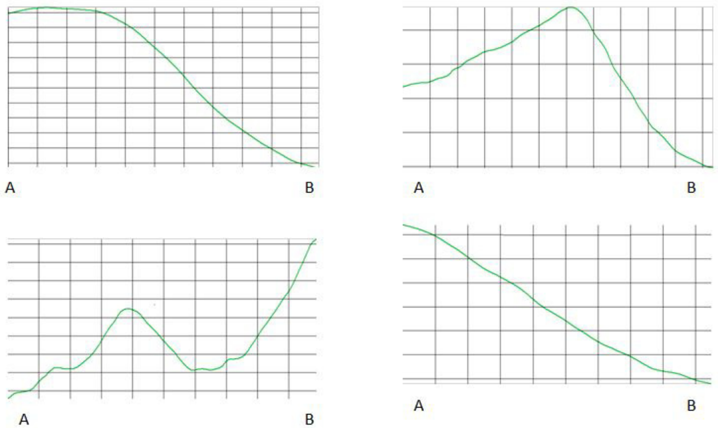


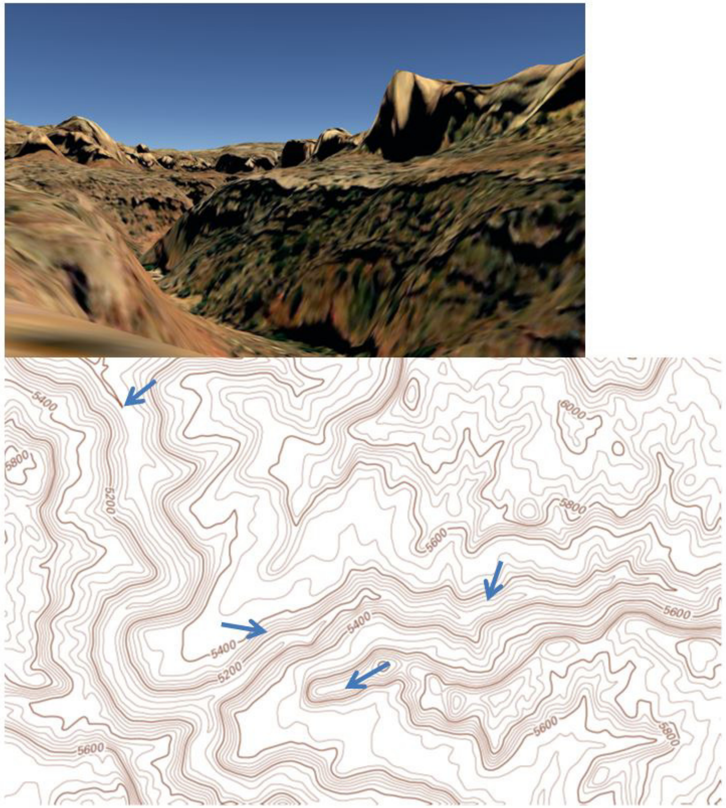
13. Which elevation profile (below) matches the cross-section of the line AB (above)?



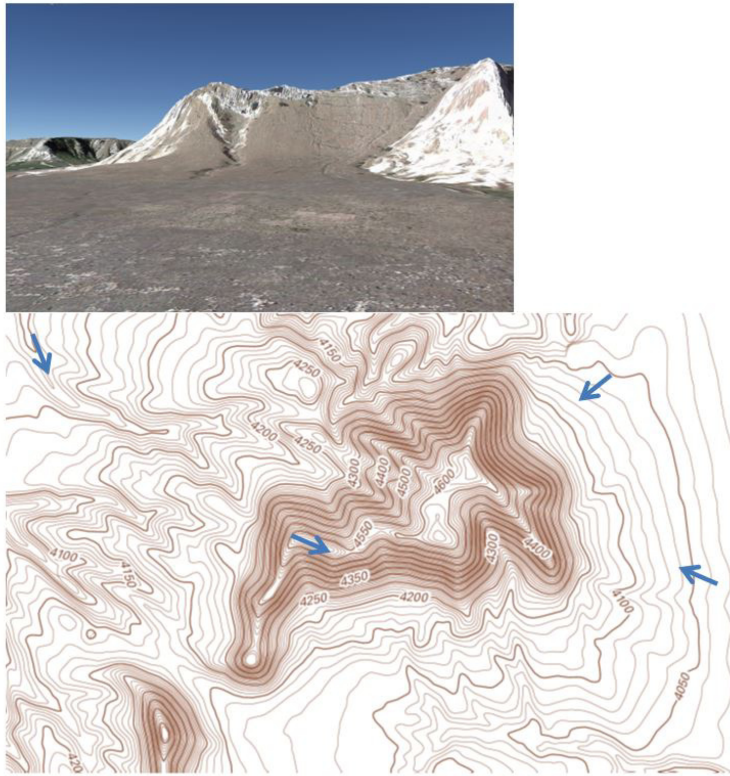


14. Which elevation profile (below) matches the cross-section of the line AB (above)?

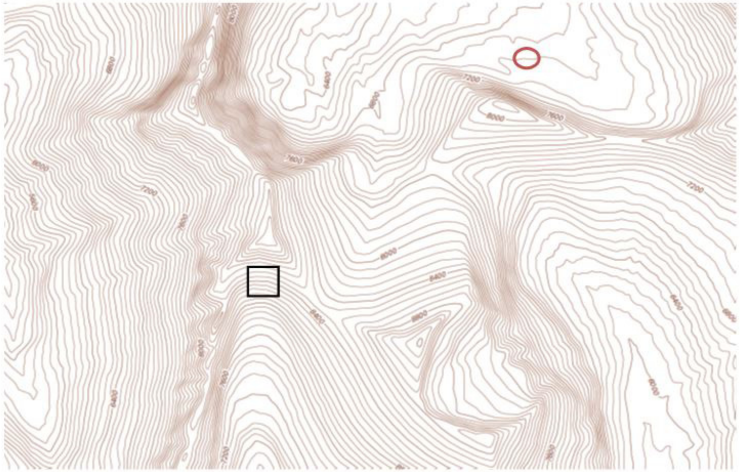




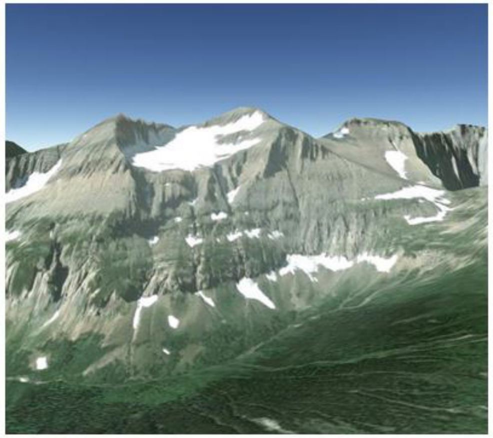
15. Imagine you see the view of the picture above. Circle the arrow on the map that indicates where and which direction you think you are facing.

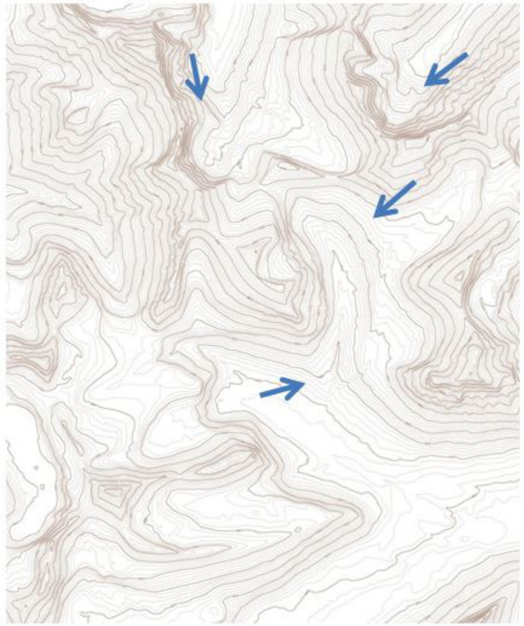


16. Imagine you see the view of the picture above. Circle the arrow on the map that indicates where and which direction you think you are facing.



17. You are standing at the square, but you want to get to a place (on the map) where you would be able to see a small lake at the circle. Assume there is no vegetation. Please draw a line from the square to another place on the map that indicates the route you would take to a spot where you can see the circle. Explain below, why you chose the spot as well as the route to get there:





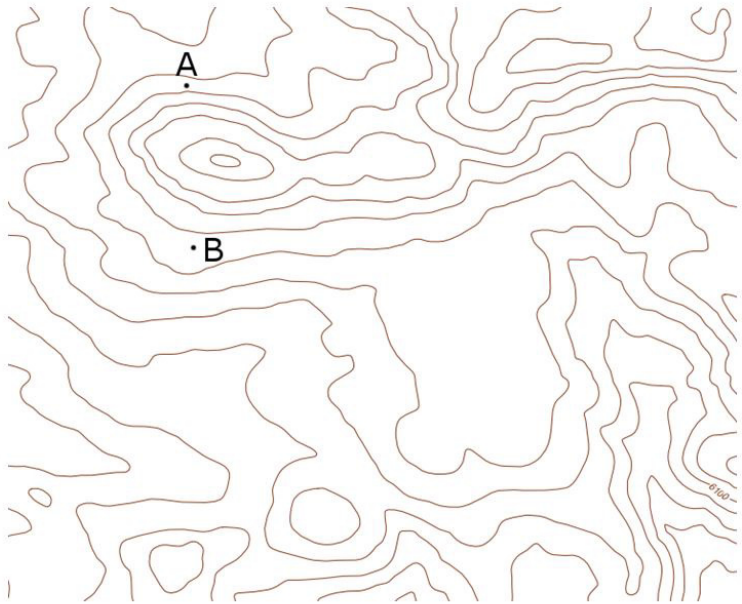
18. Imagine you see the view of the picture at top. Circle the arrow on the map that indicates where and which direction you think you are facing.

APPENDIX B

Topographic Map Assessment

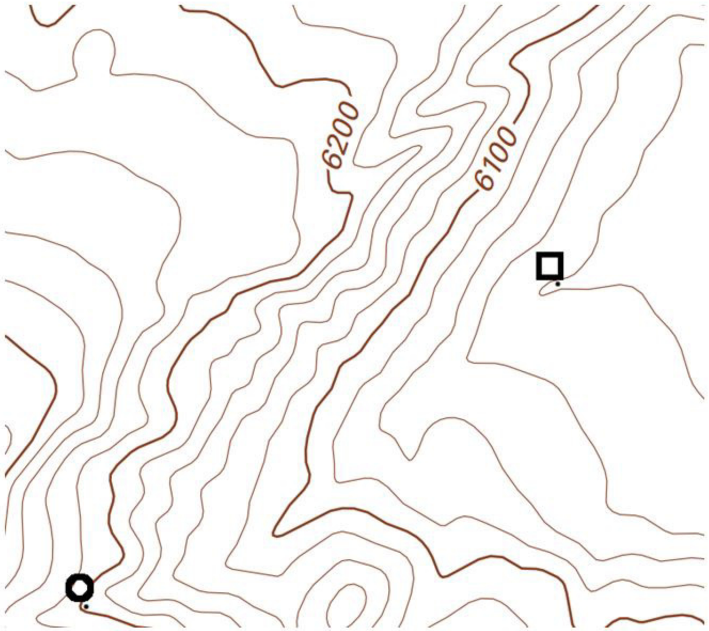
Developed by Matt Jacovina, Carol Ormand,
Thomas F. Shipley, & Steven Weisberg

Please complete this 18-item assessment. The assessment is not timed. Try to answer each item to the best of your ability.



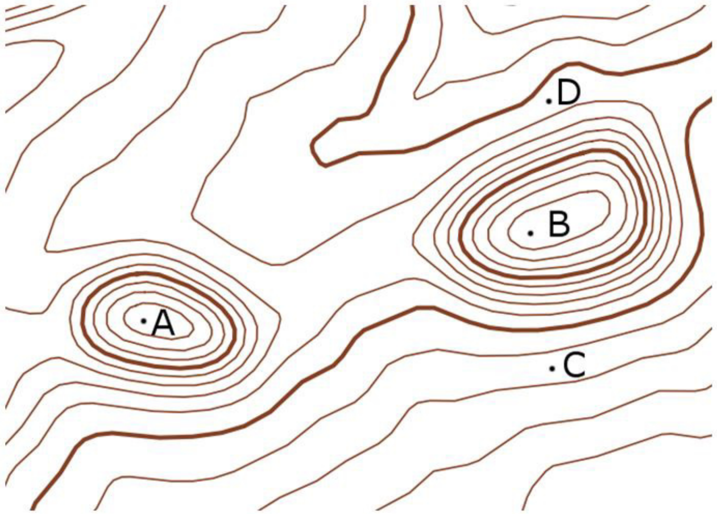
1. The contour interval for this map is 100 ft. Imagine you had to walk to get from point A to point B, and wanted to do so as easily as possible. Sketch the route you would build, and explain why you chose that particular path.

(1 point) Answer: Explanation should match the route drawn.



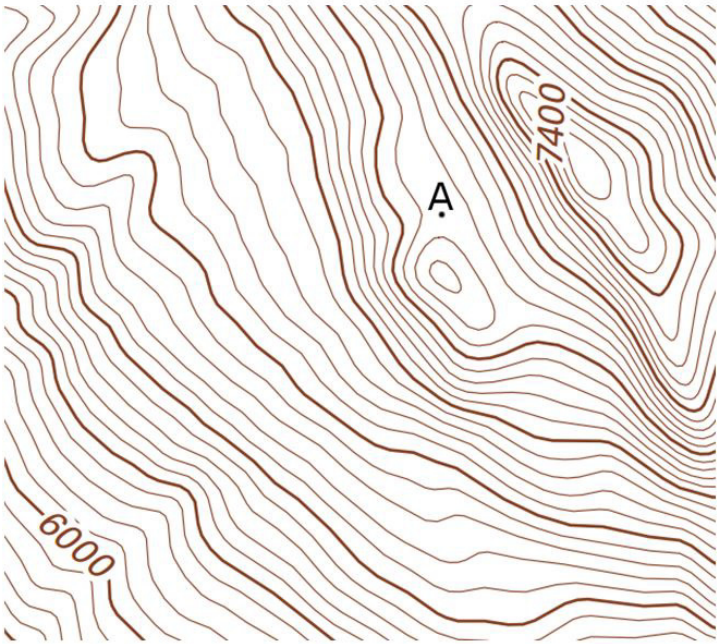
2. Imagine there is a stream that connects the circle and the square. In which direction would the water flow? Why? Please draw the path the stream would take.

(1 point) Answer: Circle to Square



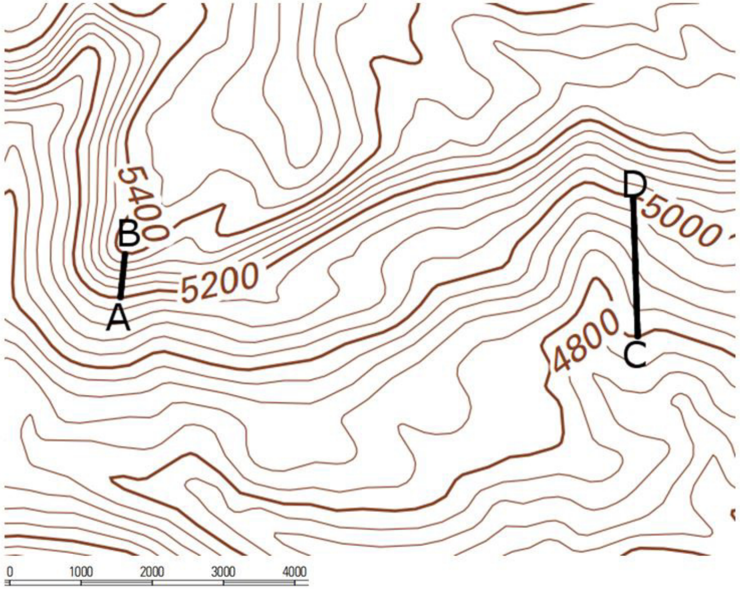
3. The contour interval on this map is 20 feet. One person is standing at each point on the map. Please answer (Y/N) the following questions about whether the people standing at two points can see each other. Assume they are able to use binoculars. Also assume there is no vegetation.

- A and B. (1 point) Answer: Yes
- A and D. (1 point) Answer: Yes
- B and C. (1point) Answer: Yes
- C and D. (1 point) Answer: Yes
- B and D. (1 point) Answer: Yes



4. The contour interval for this map is 40 feet. What is the elevation at point A?

(1 point) Answer: 7040-7080 feet



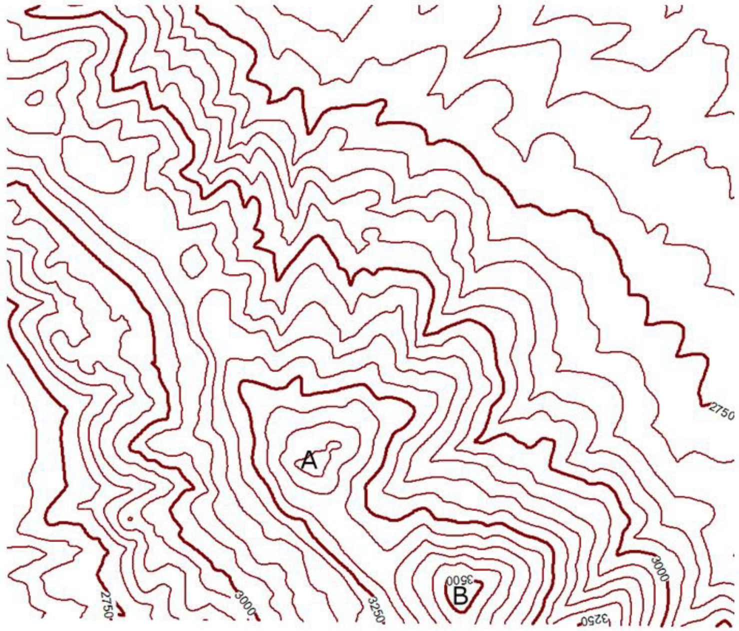
5. Imagine Josh traveled on foot from point A to point B, and Amy traveled on foot from point C to point D.

Who walked up a steeper slope?
(1 point) Answer: Josh

Why did you choose the answer you did?
Explanation is not worth any points.

6. What is the contour interval on this map? That is, how much does elevation change moving from one line to another?

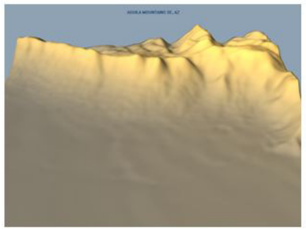
(1 point) Answer: 40 feet

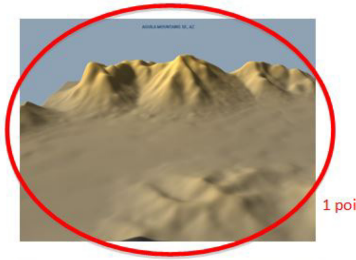


7. Which hill is higher: A or B?

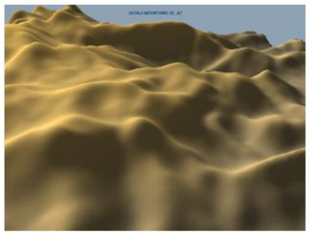
(1 point) Answer: B

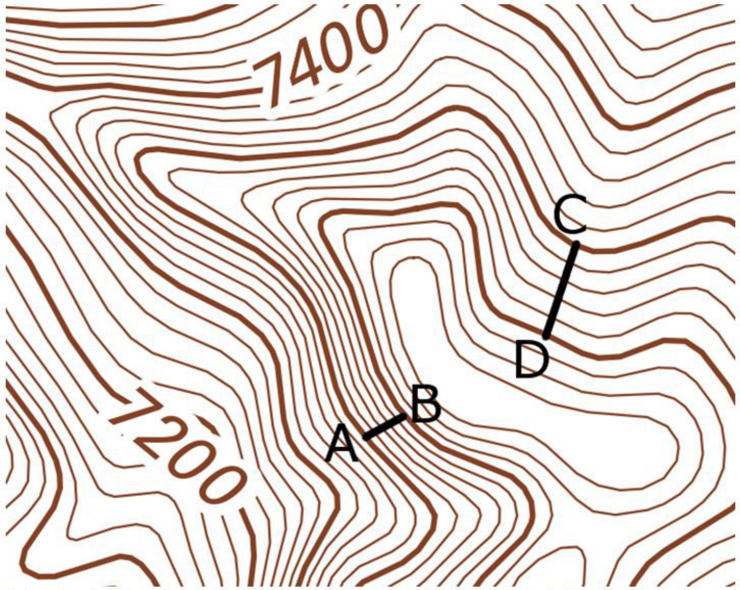
8. Which of the following views best represents what someone would see standing at the start of the arrow and facing in that direction?





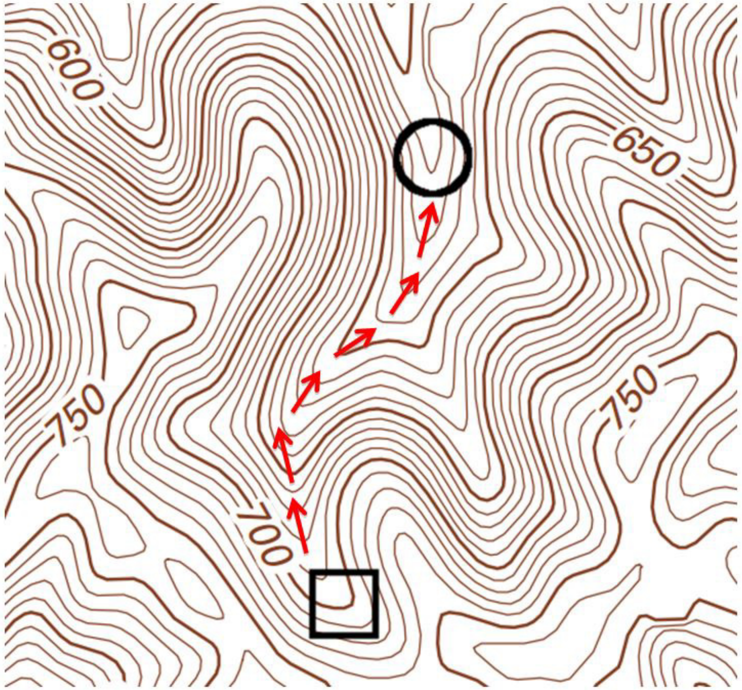
1 point





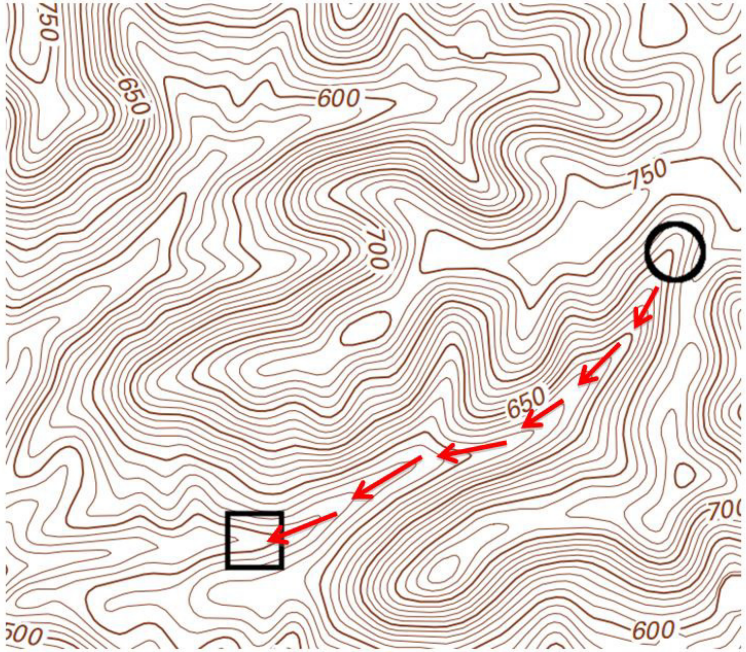
9. Imagine Josh traveled on foot from point A to point B, and Amy traveled on foot from point C to point D.

- Who walked up a steeper slope? How can you tell?
  (1 point) Answer: Josh
- Who traveled a greater vertical distance? How can you tell?
  (1 point) Answer: Same



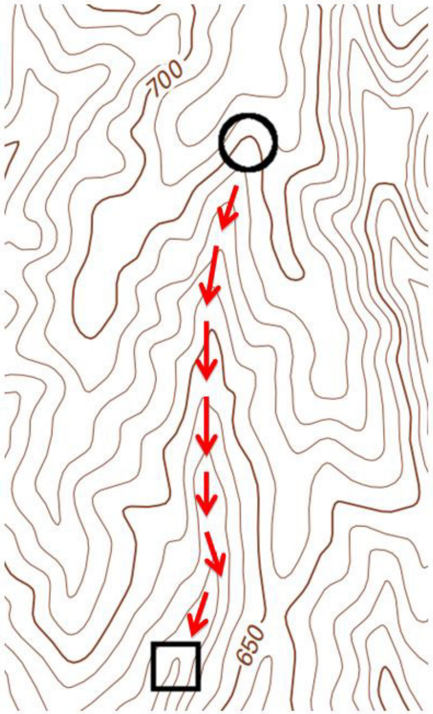
10. Imagine there is a stream that connects the circle and the square. Please draw the path you believe the stream would follow. In addition, clearly mark the direction you believe the water would flow, and why.

(1 point) Directional answer: Square to Circle
(1 point) Path Answer: correct answer is drawn in the image



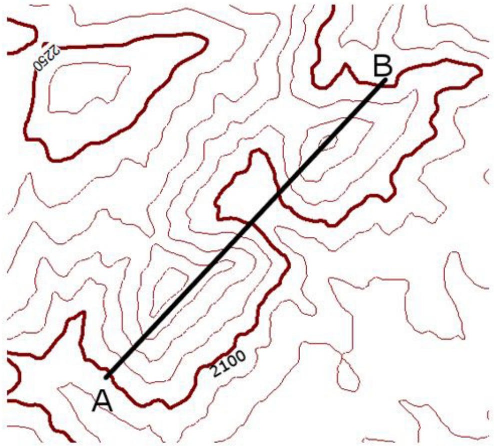
11. Imagine there is a stream that connects the circle and the square. Please draw the path you believe the stream would follow. In addition, clearly mark the direction you believe the water would flow, and why.
(1 point) Directional Answer: Circle to Square
(1 point) Path Answer: Correct answer drawn in the image.

Finally, do you think the water would flow faster near the circle, or near the square? Why?
(1 point) Answer: Circle



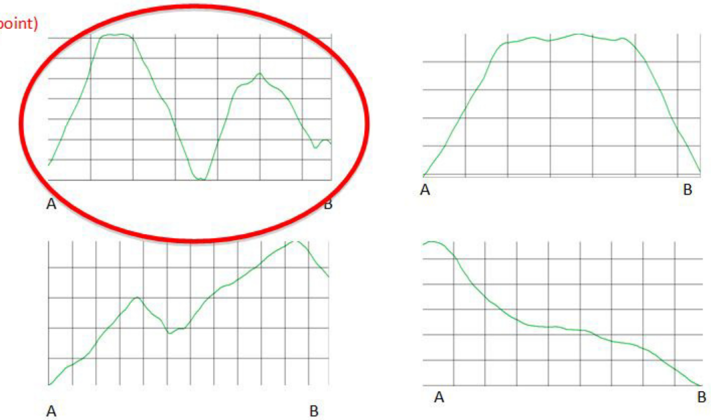
12. Imagine there is a stream that connects the circle and the square. Please draw the path you believe the stream would follow. In addition, clearly mark the direction you believe the water would flow, and why.

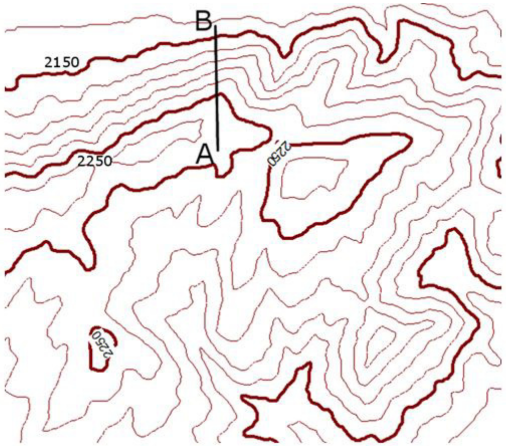
(1 point) Directional Answer: Circle to Square
(1 point) Path Answer: Correct answer drawn in image



13. Which elevation profile (below) matches the cross-section of the line AB (above)?

(1 point)





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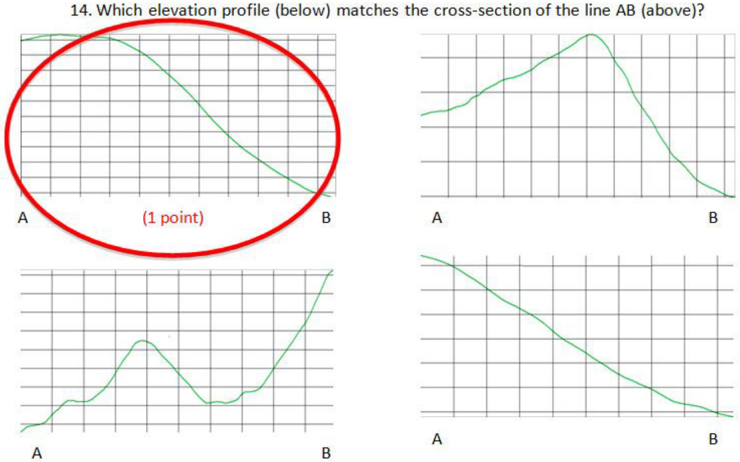
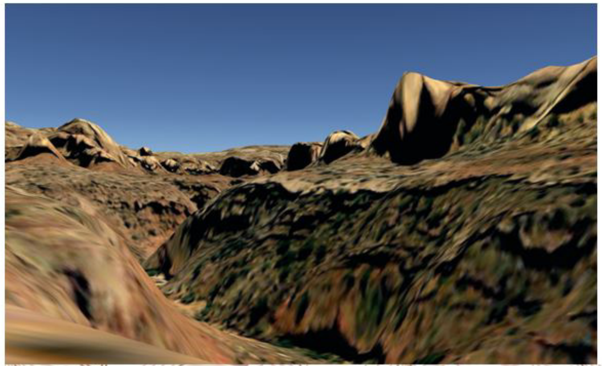
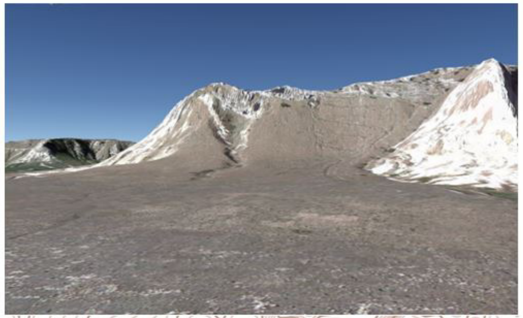
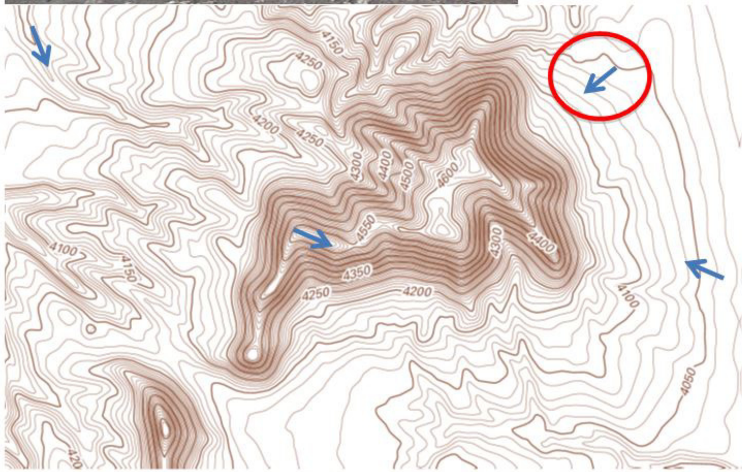




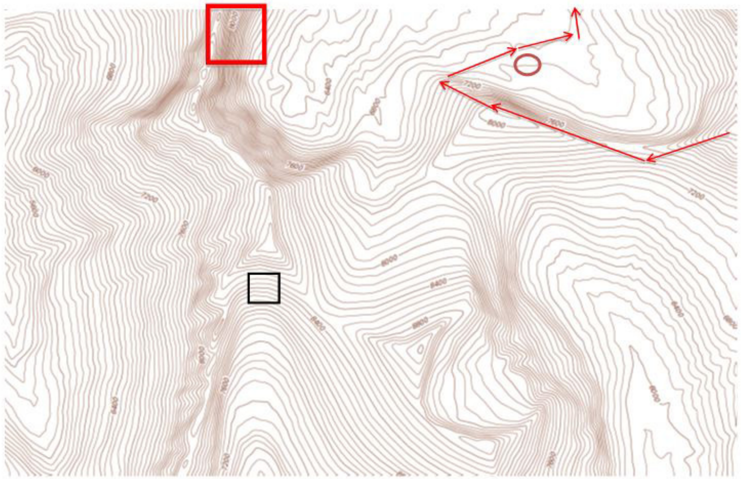
15. Imagine you see the view of the picture above. Circle the arrow on the map that indicates where and which direction you think you are facing.
(1 point)





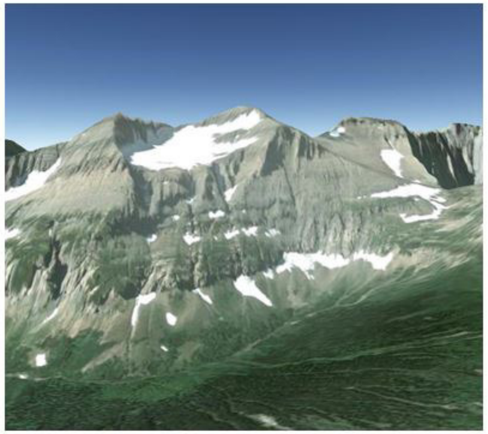
16. Imagine you see the view of the picture above. Circle the arrow on the map that indicates where and which direction you think you are facing.

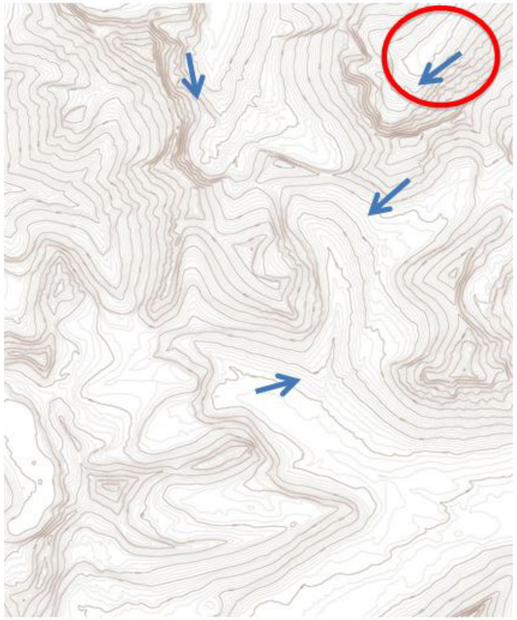
(1 point)



17. You are standing at the square, but you want to get to a place (on the map) where you would be able to see a small lake at the circle. Assume there is no vegetation. Please draw a line from the square to another place on the map that indicates the route you would take to a spot where you can see the circle. Explain below, why you chose the spot as well as the route to get there:

Location Answer: Correct location can be anywhere within the bounds of the red square or red arrows drawn in the diagram (1 point)
Route Answer: Participant needs to draw a relative low energy route (1 point)





18. Imagine you see the view of the picture at top. Circle the arrow on the map that indicates where and which direction you think you are facing. (1 point)