Student questions: Heather Petcovic colloquium on "Thinking in the Field: How Experts and Novices Make a Geologic Map"

10/26/16

Responses by HP on 11/28/16

Question 1: Have there been repeat studies?
Not to my knowledge. One of my current PhD students is attempting a study modeled after this one looking at the role of knowledge, working memory, spatial thinking, and expertise in weather forecasting.
Question 2: Do you think the same results would occur in a study looking at a different subject?
We'll find out in about a year from now when my doc student finishes up! Forecasting is a little different from geologic mapping – not only is the "answer" (the weather) always changing, we think that different spatial skills are involved, especially disembedding (seeing patterns in "noise") and mental animation (envisioning movement), and we think that working memory plays a more sigificant role. So it will be interesting to see if we get the same results.

Question 1: Would you recommend spatial thinking exercises be implemented in introductory geology classes? Would you consider it that important to need exercises on it?
I would – there are a lot of highly spatial concepts even in basic geology classes, such as mineral structures, folds and faults, ocean circulation, and 3-D wind movement in the atmosphere. Spatial thinking is so fundamental to the geosciences that we ought to give students practice. What isn't clear from research yet is whether doing content-based exercises (like looking at geologic blocks) or content-independent exercises (like practice rotating different types of objects) is more effective.
Question 2: Do you think this research will help shape mapping and field classes in the future? Do you think the idea that process is greater than product will be emphasized or at least do you hope it will?
I'd like to hope that it will. I hope that field instructors can learn from this study that students are not adopting expert-like practices (like using the topo and air photo to form a geologic model and a navigation plan). Then they can emphasize these practices with students. We published a short paper in "In the Trenches" a few years ago to share the results of this study with instructors.

Question 1: What is a contact?
Where two different rock units (different rock types) meet.
Question 2: Did you get any input from experts about their teaching strategies?
No, we did not focus on teaching practices in this study. But we did ask all of the participants in the follow-up interview how they learned to map. We're still analyzing that data.

Question 1: You stated that some of the experts reported having received specific instruction in mapping strategies; did those respondents have any greater measured success during the mapping exercise?
Great question – I hadn't thought to look. I'm working on a paper about the interview data and specifically the mapping stratgies, and will have a look at this. Thanks for the suggestion!
Question 2: If you were to construct a second experiment to further distinguish the differences between levels of skill in mapping, would it be worthwhile to choose a somewhat more challenging site and test respondents who had all been through a more advanced level of field training? What other experimental strategies might one implement to better pin down the point at which a transition from novice to expert lies?
I would love to replicate this study at a more challenging site. It would be really interesting to see if experts fall back on novice-like strategies (nagivate to cover the area) or if they retain expert-like practices (develop a geologic model and test it) when confronted by a more challenging exercise. It would also be valuable to test for spatial skills more tightly alingned to mapping – for instance, we did not look at disembedding (how people see paterns in a lot of "clutter" or "noise") which I think would be a very important skill in mapping. The classic expertise literature puts the threshold for being considered an expert at 10,000 hours (roughly 10 years) of deliberate practice. I would be curious to see if this holds up in mapping (our most experienced participants had 25+ years of mapping experience).

Question 1: If the map of the field area was distorted when given to the participants how are they to accurately map the area is their topo map is incorrect?
Participants received an accurate topo and air photo. We distort the maps for talks and papers because the field station where we did the work does not want the correct "answer" to the field location shared publically.
Question 2: Would a person's physical ability be another variable in this experiment? Completion time was a major part of this experiment, could a person's physical attributes (in shape or not) be another variable causing time to either increase or decrease?
Absolutely. A lot of the participants told us during the interview that they were fatigued – it was a very long day for them. Certinaly people who were less in shape would take longer, plus those who were not used to the elevation needed more breaks. This would slow down their speed and increase their thoroughness score. We did not attempt to "correct" data for physical fitness but do recognize that there was a range of fitness among the participants.

Question 1: How might your expertise questionnaire be biased toward the knowledge of those who created the questionnaire?

Great question – to minimize our own bias, we looked at the requirements for professional licensure in California and a few other states (I forget which ones). We used the guidelines set up by ASBOG (Association of State Boards of Geologists), the organization that oversees state licensure as a professional geologist, to generate the experience questions. We also looked at the websites of several large geology programs (e.g., Jackson School, Penn State) to see what courses they required. And yes, the project team did make up the scoring - but we had a structural geologist and a mapping expert from outside of the project look over the rubric and give us feedback.

Question 2: How do you differentiate between novice, intermediate, and expert from questionnaire scores?

The highest score an undergraduate can possible get on our experience questionnaire is a 1.5 (out of 10). Most undergrads scored 0.5 to 1. The highest score that a grad student with no professional work experinece can get is a 6 (out of 10). Most grad students and young professionals scored in the range of 1.5 to 5. All of the people with 10+ years of professional experience (considered "expert" in the literature) scored a 7 or higher (out of 10). So we put the break between novice and intermediate at 1.5, and the break between intermediat and expert at 6.5.

Question 1: Race was one of the criteria gathered during the study. Did a participant's race have any correlation with their mapping success?

We had too few non-white participants to do any stastical analysis.

Question 2: How were the number of pixels accurately scanned from a participant's map? It seems like there might be a significant error in determining the pixels of a correct color from a hand-drawn map.

Great question! We had a student digitize the maps after they were scanned. She watched each particpant's interview as she digitizied that person's map to ensure that she was interpreting the colors, symbols, and contacts correctly. We met with her to help out if she got stuck with any of the interpretations.

Question 1: Why does the high knowledge group seem to actually decrease in accuracy if spatial thinking is high, or is it within errors?
You are correct – in the high knowledge group, the accuracy of the final map decreases as spatial thinking skill increases. The line on the graph shows the correlation, but there's actually quite a lot of scatter in the data and the correlation was not statistically significant. It might suggest that people who knew the "answer" to the geology were less careful with drawing the distribution of rock types because they didn't visit the map area thoroughly.
Question 2: How much more did the experts depend on previous specific, similar structures that they've mapped before to connect and help elucidate this structure?
Interesting question – we did not ask in the interview whether participants had mapped a structure like this one before. That would have been a great question. The literature on chess experts suggests that they can recall a large number of game board configurations because they have built up a "database" of ones they previously encountered. I suppose the same could be true in mapping – that experts can draw from a "database" of structures they previously mapped. There is a saying that "the best geologist has seen the most rocks"!

Question 1: What are some ways to train non geologists (say like a physicist or a chemist) to be a good field scientist?
Get out and do it – there is some research emerging on vitural field trips that suggests they may have similar learning gains to actual field trips, but based on some survey research I've done the geology community believes that there is no subsitute for the authentic experience of being in the field.
Question 2: How would you expect someone with no geologic background, yet a high spatial awareness skill to do on an activity like mapping?
Our findings suggest that they would be very accurate in drawing the locations of different rock types. But they would struggle to interpret how the rocks fit together under the surface. If they do know understand what folds and faults are, I predict they would struggle to see the "big picture" of what the rocks are doing underground. Realistically, without knowing how to navigate with a topo and aerial photo, the task probably can't be done at all!

Question 1: Do you think these results will translate to other demographics?
Not sure I understand, what other demographics? This is a really small sample (67 people) so even though we chose people carefully it cannot be representative of all geologists in the US (let alone all geologist everywhere). But it is a start.
Question 2: Are there really people who are seriously that scared of cows?
Apparently so! But to be fair these are "cattle" not "cows" – the really big ones with horns. We were warned by the site owners to stay away from the herd because they might be aggressive about protecting their calves. In fact two of our participants were chased by a bull, but ran into the woods and it didn't follow them.

Question 1: Did you see any similarities with quality of the map or methods between those who had not taken any field courses and those who did not have mapping as a primary component of their field camps?
Having a basic field methods course was a prerequisite for participating in the study (that being said, I think two or three folks slipped in without having had a formal course). We did not look specifically at the type of field course each person had, but this information was embedded in the mapping expertise score. So a participant with a higher mapping expertise score had more direct mapping experience in their field camp (or on a research project or internship) directly related to mapping. Mapping expertise strongly correlated with map quality – so the more training a person had in mapping, the better they did at mapping (not a very surprising result!).
Question 2: What is the plan for using these results? Will you be trying to speak to different universities who run a field camp/mapping course to help instructors understand and promote better mapping techniques?
We wrote a short paper in a journal of the National Association of Geoscience Teachers with some advice related to fieldwork. I don't know that this work is at the point where we can make specific recommendations, but I'd like to see a study of actual teaching practices at field camps (there hasn't been one).

Question 1: The data that was collected, was it done over two years of field work and the next three years analyzing the data?
The data were collected over two summer field sessions (2 weeks in Auguest in each year). And yes, it did take several years to analyze that much data!
Question 2: Was this study done for an actual field course or was it specifically done for for this research?
It was done specifically for this research project, although we used a location that is owned by a field camp and used as an exam site for students.

Question 1: How does spatial thinking help geologists to best navigate unfamiliar terrain?
A key spatial thinking skill is relating objects and their locations (including the location of the observer) in space to locations on a map. This is how people learn to navigate using topo maps or photos. The better people are with this skill, the more effectively they can navigate through unfamiliar places. Some of our participants commenting in the interviews that they had a hard time figuring out where they were in the map area – which might be why a lot of novices went to the high point for an overview and worked around the marked boundaries of the area – there were easy places to figure out their location.
Question 2: What are some of the ways to adopt spatial thinking when in the field?
Our study results suggest that for students, knowledge of geology is even more important than spatial thinking. So, I'd recommend additional work with maps and photos even before going into the field to enhance skills in navigation. If you don't know where you are, you can't make a good map.

Question 1: Is there any specific reason why the research chose the land studied?
We scouted out several potential sites and chose this one because (1) one member of the project team knew the director of this field station and they were willing to host our project, (2) the site was small enough to map in 1 day, (3) the "answer" was known – the field station staff could provide us with a consensus interpretation of the geologic structure and rock distribution, and (4) it was easy enough that an undergraduate student could do it. So it was a good choice for the goals of the project and for logistical reasons.
Question 2: How would the results of this study improve the curriculum of teaching field trip in geology in a long term?
My hope is that field course instructors focus more on process than on product – that they discuss with students how to make choices of moving through an area to maximize potential for collecting high quality data and making good interpretations.

Question 1: Why was "obvious geology" listed as a strategy to avoid? Wouldn't simple/basic geology help the field worker gain a quicker understanding of the whole area?
I think that point was poorly explained, sorry – what I meant was that participants didn't want to bother going into an area of the field when they already knew what the rock types would be. So for example, there was a steep cliff of dolostone in one part of the area. Most of the participants didn't both to climb down to the base of the cliff because it was pretty obvious from looking that it was the same rock type all the way down.
Question 2: Is it possible that the students being studied felt pressured or rushed knowing that they were being monitored? Is there a way to observe field practices with less influence (if relevant) on the participants?
Yes, that is certinly possible. Some of the participants joked that "big brother" was watching them all day, so they were certainly aware that they were being monitored. We tried to be as unobtrusive as possible – we let participants know where the researchers were stationed purely for safety reasons. We tried to balance being as unobtrusive as possible with ensuring safety of the participants. Overall there was minimal interaction between the researchers and participants while they were out mapping.

Question 1: Besides looking at aerial photos and topographic maps, what is the #1 suggestion you would give to a new field student?
I'd advise them to make interpretations as you go. Too many students gathered their data in the field and then went back to the station and drew their maps. At that point it is too late to go back and re-check things. I'd push them to try and connect the rock types and think about the "big picutre" each time they stop to take an observation or a measurement.
Question 2: If you re-did this study, what would you do differently?
Great question – the biggest thing I'd do differently is choose different (or additional) spatial tests. I really wish we had measured the skills of disembedding (finding patterns in messy data), perspective taking (imagining a view from a different perspective), and direction finding. We didn't go into this study expecting to find results about expert-novice differences in spatial thinking, so we perhaps didn't choose the most optimal tests. I also wish I had budgeted for two gradaute assistants (instead of one) so that data anaysis had gone faster!

Question 1: In order to bring novices up to speed more quickly, are there any indications from your research about whether more field experience (early introduction) or more focus on building core geologic knowledge prior to field work is more effective?
I can't say based on our data whether one or the other of these would be more effective. I can say that I think both are important – expertise comes from deliberate practice, so the more field experiences you have the better you will be at something. Clearly from our study, students could benefit from practice with air photos and maps to help to build that core knowledge.
Question 2: Is there a correlation between the perceived success on the mapping project and experience level (i.e. novice/expert)?
Interesting question! We did ask people how confident they were in their map, but I haven't analyzed the results in a systematic way. Overall I'd say that experts were more confident in their maps, but not always. Likewise, experts were more successful in the task, but not always. It would be interesting to see if we could notice the Dunning-Kruger effect – this is a well-known phenomenon in psychology where poor performers typically overestimate their ability to complete a task and high performers typically underestimate their ability.

Question 1: Did you find that ability in all types of spatial thinking that you tested correlated (that is, if a subject was good at mentally rotating shapes, did they also tend to be good at locating on topomaps)?
Yes, we did find an overall statistical correlation between the various spatial tasks. People who were better at one specific task tended to be better at all of them, but not aways. The broader research literature suggests that people can be good at one task (like mentally rotating an object) but poor at another (like finding hidden objects). Also keep in mind that we tested general special thinking skill, and not geology-specific skills. So it is very possible for somebody with lower spatial thinking skill to still be good at reading topo maps because they have acquired knowledge and experience that bypasses the need for spatial thinking.
Question 2: Can you teach expert thinking explicitly, or must it be taught by example and long practice?
That is the million dollar question of expertise research! Much of being an expert is the result of deliberate practice over long years. But I do think that instructors can model expert thinking for students. I think we can be explicit in sharing HOW we come to an answer and WHY we make certain choices in mapping. This can then help students to think more like an expert, we still have to recognize that they won't become experts without a lot of pratice.

Question 1: Given your findings, do you believe using a class of students to survey large areas would be an effective and efficient way to map regions?
I think it is doable if the students are well trained and have demonstrated their skill in mapping. One thing we did not look at in this study is the effect of having people work in teams. Most mapping is done in pairs or teams, and we cannot say from this study how that would effect the success of mapping.
Question 2: Do students become more intelligent over time or is their accumulation of knowledge in geology contributing to their potential?
This is another million dollar question in cognitive science. There is a big debate going on as to the role of "talent" versus "training" – in other words, researchers are trying to understand how much of a person's overall intelligence is genetically interited and how much is gained through experience and education. The consensus seems to be that both knowledge and spatial thinking can be gained through practice. So people may not become more "intelligent" but they cerainly can become more "smart" though accumulating and effectively using knowledge and skills.

Question 1: What do you think is the best approach to teaching young people about spatial thinking?
The research literature suggests that we should spend more time on spatial skills when people are young. Interestingly, some research suggests that first-person and map-based video games improve some types of spatial thinking (in particular navigation and remembering the location of objects). There is also some research suggesting that playing with spatially oriented puzzles and toys (like Legos) can help improve spatial thinking. In school, we could do more with developing students' sense of scale, helping to build their understanding of very large and very small distances and sizes.
Question 2: You had mentioned that there is no correlation between experts and spatial thinking and quality of the maps, yet there seems to be a slight slope to that line on your graph. Were you just implying that the correlation is marginal, or was the graph skewed?
This sounds like a similar question to one previously answered – so I'll repeat my answer here: You are correct – in the high knowledge group, the accuracy of the final map decreases as spatial thinking skill increases. The line on the graph shows the correlation, but there's actually quite a lot of scatter in the data and the correlation was not statistically significant. It might suggest that people who knew the "answer" to the geology were less careful with drawing the distribution of rock types because they didn't visit the map area thoroughly.

Question 1: Do you think that other scientific fields would benefit from “field camps” in the same way?
A big part of teaching is helping students to understand the culture and practices in the discipline. Many geoscienstists do fieldwork, so it makes sense that we teach in the field. I’ve heard that ecology and archeology both use field camps in teaching students about fieldwork in those disciplines. But “bench” sciences probably wouldn’t benefit from a field-oriented teaching approah; they are better of using research lab techniques appropriate to their disciplines.
Question 2: Experts have spent much more time in the field than most students. Does the gap in thinking come from experience over the years, or a lack of understanding of the bigger picture?
Both. Because they have years of experience and have seen many types of structures in the field, experts are quicker to grasp the big picture. Our point is that making this kind of thinking more obvious to students might help students work more efficiently and effectively in the field.

Question 1: The importance of spatial thinking in developing a novices knowledge and an experts approach is a little more “work smarter not harder,” is it a point of concern that an expert may miss key elements of an area simply because they did not go thoroughly travel the area?
One of our key findings from Study 2 was that for all participants, the more thorough they covered the area, the more accurate their maps were in depicting the distribution of rock types. So it pays to be thorough (even for experts) to get the right rocks in the right places. But experts who moved quickly through the area had a better understanding of the underlying structure (the syncline and fault). Two of our experts found mafic intrusions in the area which we didn’t even tell the participants were there, and both had among the fastest completion times. It seems that getting the “big picture” and then strategically planning a route to hit the key geologic features means that it is very unlikely that an expert will miss any key features.
Question 2: While I understand that field study and lab study are two sides of the same coin so-to-speak, which do you think is more important or more beneficial for the researcher and why?
I did some follow-up survey work on this and can say that the consensus among the geologic community that we sampled (at a GSA meeting) is that fieldwork should be a basic component of all undergraduate programs, even for students planning a lab-based career. The feeling is that students need to see where their data are coming from and appreciate the nuances of sampling and interpretation, even if they plan to stay in the lab.

Question 1: When determining the subject's backgrounds did you consider other sources where they might have learned how to make maps such as boy/girl scouts or the military?
No, we did not ask for experiences outside of school on the survey. We did ask "Where did you learn geologic mapping?" during the interview (data are still being analyzed). A few participants volunteered during the interview that they had learned in the military, with scouting organizations or orienteering clubs, and in one-on-one mentoring situations (for example, summer internship mapping with an expert).
Question 2: With this greater understanding of the psychology and behavior of experts and novices, what changes would you implement in undergraduate level education?
One thing I would recommend is "debriefing" after mapping exercises in field courses. Talking over not just what the geologic "answer" is in the field area, but where students went, what they saw, and why they made certain choices. I also recommend modeling expert behavior, for example, the instructor might have students map an area themselves, then take the group back the next day and walk through where the instructor would go and why, thinking aloud as s/he explains what s/he is thinking. This is something often done in math & physics classes where the instructor solves a problem on the board in front of the class – I don't see why we couldn't try this approach in a field setting.

Question 1: Do you think this same method of identifying key differences between novices and experts could be applied in the case of virtual field trips?
I would love to see somebody do a study like this one on virtual field trips. Virtual environments might be optimal for doing an eye tracking study – to see what features experts attend to visually and why. Call me up if you want to do a PhD project ;)
Question 2: What are your thoughts on the effective domain and how it influences learning, specifically during field trips?
Great question! Alison Stokes and Allen Boyle have done a lot of work in this area. They've got a couple of papers on the affective domain in fieldwork, and have found that it is hugely important. Interstingly they have found that students value the social environment of residential fieldwork more so than instructors do. Nir Orion has also done some (now "classic") work about novelty space and how being in an unfamiliar setting can impact feelings and learning. Much more research needs to be done in this area to get at how affect and cognition impact one another.

Question 1: You spoke of the critical thinking skill geologists possess. Do you think it would be beneficial for non-geologists to do field geology work as an exercise to help build critical thinking? Or, would a one or two time deal not be beneficial? Did your "non-experts" feel they benefited from the field work?

Our non-experts in this study were geology undergraduate majors, so even though they had less experience, they were still geoscientists. I think it is very important to have at least a little bit of fieldwork in an introductory course for non-majors, if only to introduce them to how geoscientists collect and interpret data. I would like to see introductory courses for non-majors focus more on the actual practices of scientists (how they work) than on learning a bunch of facts. That's my opinion as a teacher of intro courses for the last 14 years, not a result of this study.

Question 2: I like the idea of asking students/experts what route they would take through their field work, given only a topographic map to choose that route. This teaches them how topography is largely governed by how easily weathered a rock unit is, and can give them a good clue as to where friable units and secondary geology may be. Would this be worthwhile to integrate into basic geology classes, even those without a large field component?

Intro classes tend to be packed with a lot of stuff already, so I don't know if that is the best place to teach these kind of skills. I could see doing something like this in a geomorphology class, or in a structural geology class where mapping is introduced. Personally, I didn't really learn this until gradaute school when I took on a Masters project that invovled mapping of weathered rock units and learned quickly to map based on changes in soil color, changes in vegetation, and differences in topography. This is a pretty subtle skill so might be better in later courses.

Question 1: I have done previous mapping as an undergraduate for different professors. I did consider myself a novice as this was my first field mapping experience. Different geologists/professors have different techniques/viewpoints of different outcrops and does this create bias in the data?

Absolutely! One of the really interesting things about geologic mapping is that you never can know if you are "right." You cannot scrape away all of the rocks and see what's underneath (at least most of the time you can't). So there are only more plausible and less plausible answers. One of the reasons why we chose the site we used in the study is that the geology was very well known – the field course has used this location for decades and had a consensus map that they all agreed was "correct." So we didn't have to rely on just one expert's opinion in this case, which greatly reduced the potential for bias.

Question 2: I have found older Brunton compasses (metal ones) to be much more reliable than the plastic ones to obtain strike and dip of features such as lineations and fractures. In the study, was the same equipment used?

Participants were responsible for bringing their own field gear (Brunton, hammer, colored pencils, clipboard, etc.). We supplied the base maps and a GPS (which was only used to track movement, not for finding locations). We did check that everyone had declination set right, but didn't otherwise check equipment. So there is likely variation in the quality of the equipment, as well as variation in how accurately it was used (some participants hadn't mapped in quite a while, and told us in the interview it took them a while to remember how to do strike and dip).

Question 1: What do you mean by a model in the context of your work, and what differences did you see between the models novices and experts created?
We are using "model" to refer to a mental model – what each person sees in their head as they explain the 3D geologic structure. Nearly all of the participants used words coupled with hand gestures to describe their models (which is why the interviews were video recorded). Expert models were generally more accurate (most of the experts did correctly recognize the plunging syncline and the thrust fault) and included subtle secondary features (small secondary faults, some parasitic folding, and other minor features). Many novices were able to identify a fault but were unable to determine the type, or simlarly recognized a fold but didn't determine what type. The most common incorrect model was a "layer cake" of steeply dipping beds, in other words many participants missed the fold entirely and just mapped a sequence of dipping units. A few participants had no discernable model at all – they could describe what rocks were where, but when asked they couldn't say what the rocks were doing underground.
Question 2: How can this work and your results be possibly extended to education in other science fields?
It would be interesting to see how this might apply to other disciplines within the geosciences. For example, how do experts decide where to collect water samples in a lake? In a groundwater system? Do they have 3D models of the subsurface? What about doing seismic interpretation? I could also see a similar study done in ecology where biologists are collecting data in the field. One of my PhD students is replicating this study in meteorology; we are looking at what spatial skills are used in weather forecasting and what expert/novice differences occur in the forecasting process.

Question 1: Which group did you find to have better spatial reasoning, the novices or the experts?
Interstingly, neither. There was no statistical correlation between level of expertise and spatial thinking as measured by the cognitive tests. The whole population in our study had higher spatial thinking skills than "average" Americans (as measured by other studies and reported in the cognitive science literature). I've done some additional work that has supported this finding; we just published a study of expert structural geologists that shows they have very high spatial thinking skills, comparable to those of architects and dentists!
Question 2: To which geologic areas did the novices seem to be drawn?
Novices in general didn't plan their routes relative to the geology. They spent more time in the highest elevation area, and along the boundaries of the field area (presumably to avoid getting lost). They did spend a lot of time along one limb of the fold where there were good outcrops.

Question 1: You showed a graph that had a negative correlation between the percentage of the map correct and the visiospatial ability for experts. Why?
See previous reponse, repeated here - in the high knowledge group (experts), the accuracy of the final map decreases as spatial thinking skill increases. The line on the graph shows the correlation, but there's actually quite a lot of scatter in the data and the correlation was not statistically significant. It might suggest that people who knew the "answer" to the geology were less careful with drawing the distribution of rock types because they didn't visit the map area thoroughly.
Question 2: How could you increase spatial ability to help novices geologically map?
I wouldn't. I would work on spatial thinking in introductory classes so that more people can be successful in the geosciences. Our findings suggest that knowledge of geology is more important than spatial thinking in mapping, so I would focus my energy on making sure that students learned about how different types of geologic structures look and maps and air photos, and how to plan effective field routes to those structures. Knoweldge is easier to attain than spatial thinknking skills, so I'd focus more on knowledge building.

Question 1: Are there instances where novice's may do better than experts?
Absolutely! One novice map was in the top 10 scoring overall, and there were a few experts who didn't get the correct geolgic interpretation. Novices tended to be more thorough during mapping and therefore see more of the field area. Some of their maps had more accurate rock distribution than expert maps. Sometimes experts can be sloppy because they know the "answer" and are trying to get done quickly.
Question 2: How do you account for precious knowledge of the field map site. It would seem reasonable to infer from the geologic history of the US that folding would be expected in that area.
Great question! We asked on the application form if people had been a student at the field course that we were using. We elimiated participants who had been students at the field course within the past 5 years from the applicant pool. We ended up with 2 participants who had been students at the field course (1 more than 20 years ago, 1 about 7 or 8 years ago). To reduce the bias of famliarity, we took everyone to a location about 5 miles away from the mapping site where all of the rock types outcropped. We read scripted information about each rock type (its general lithology, age, and stratigraphic position) and then allowed all participants about 10 min at each rock type to take additional notes. We did not allow them to ask additional questions and did not use the actual stratigraphic names of the units. Some of the participants told us during the interview that they expected to find faults and folds simply because we were in the Rockies, and a few knew the regional geology. So we couldn't completely eliminate a "familiarity bias" that worked in some participants' favor, but we did try to reduce it.

Question 1: Did the fact that the participants were aware of objective of the project have any effect on the outcome of the research? As in, would you expect different results had the motive of the project not been revealed to the participants? For instance, a novice would probably have a pre-conceived notion that an expert would fare well than him/her and and hence, under-perform anyway.

Good question! Any type of social science research runs the risk of changing participant behavior simply from participants knowing they are in a research study. The study was carried out under approval from a human subjects research board, which meant we had to consider both the goals of the research and the rights of our participants to moral and ethical treatment. We felt there were no compelling reasons to withhold the study objectives from the participants, and obtained written consent to volunteer from everyone who participated. We did run cohorts of mixed experts and novices, and of course participants noticed that there were people of all ages and backgrounds in each cohort. Some of the novices did say during interviews that they were intimidated by having experts around, but for the most part we tried to make it clear that we were more interested in the process than in whether people got the answer "right" (and everyone got paid regardless if they mapped correctly or not!).

Question 2: During the course of this project, was a novice allowed to discuss the possibilities of his/her data/observation with an expert?

No, to keep things comparable between cohorts we did not allow any discussion of the cognitivie tests, the mapping exercise, or the final map during the study. We discovered during the first group that participants REALLY wanted to talk about things, so we held a "debriefing" session after the study was over. We told everyone just to hold their questions and that we'd answer anything at the end. So once everyone was done mapping and done their final interview, we gathered the group together with the researchers, shared the "answer key" and talked about the study. I would love to do a follow-on study with pairs of people mapping to see whether two brains really are better than one!

Question 1: When it comes to field geology, what have been some of the most difficult aspects for you when training beginners?

Beginners tend to get caught up in the details and forget to make "big picture" interpretations. I recall as a novice myself being asked to interpret a stratigraphic secion and being at a total loss – I could tell you what sediments were where, but not what it all meant. I think this is one of the hardest things for novices to do, integrate their observations with their interpretations.

Question 2: What are some key importances when developing spatial thinking from people who are just starting out to more advanced field geologists?

I don't think we know yet what the key spatial skills are in geology, or how to develop these. The most work has been done in structural geology – Carol Ormand and her research colleagues from SILC (Spatial Intelligence Learning Center) have created a "spatial thinking toolkit" for the geosciences with spatial exercises in structural geology and mineralogy. But so far nobody has tacked intro students. I've got a Masters student working on a thesis project having to do with sense of scale – how intro students grasp very large and very small sizes and distances. Our ultimate goal is to develop some teaching exercises for intro classes to improve scale.

Question 1: How can we use this data to implement spatial thinking learning in classrooms today?
Our study doesn't speak to spatial thinking directly, but I think that exercises focused on spatial thinking in intro classes as well as work with maps in structural geology and geomorphology classes would be beneficial (see previous responses).
Question 2: Did you see any differences between the spatial thinking of male novices and female novices?
We didn't look specifically for gender differences. We used one spatial test that has a known gender bias (males do better on average than females). But we did not see any statistically significant difference by gender on this or any other test.

Question 1: What are some of the most unfamiliar areas to date?
I'm not sure I follow the intent of this question, but to me the big questions that remain are whether the results of our work would hold up if the study were replicated with a different field area, and whether we would find the same results if we used different spatial thinking tests (for example, if we tested for disembedding and perspective taking).
Question 2: What are some of the main reasons for the differences between novices and experts when developing models of a field?
I think it has to do with differences in knowledge and how that knowledge is structed. The research literature suggests that experts know more because they have had a wider range of experiences, and that their knowledge is more inter-related. So an expert can recall a lot of information at once because of how that information is networked. Experts can call on a wide range of potential geologic models because they've seen more models. Novices have to map the "hard way" by figuring out the answer from scratch.

Question 1: You mentioned in your talk the existence of a test group with an intermediate level of geological knowledge. Did they tend to perform closer to the Experts' patterns and speeds of movement in the field, or closer to the Novices' patterns?
We treating the group of participants differently depending on what we were looking for. In some of the published work, we treated the group as a continuum so there we no breaks between novice and expert. In other work, we broke the participants into either two or three subgroups – so in one study we had novice, intermediate, and expert and in another we had experienced and inexperienced. Which actually makes it challenging to talk about this project as a whole. In general the middle group was quite mixed – some folks had among the best maps in the study and used expert strategies, while others had very poor maps and used novice strategies. Most of the work we published looked at the novice and expert ends of the spectrum, but it might be interesting to take a closer look at how the middle group worked.
Question 2: You reported that Novices exhibited high traffic patterns at borders of the region to be mapped and at higher altitudes. In the analysis of these results, was there an explanation proposed for why Novices frequented edges of the terrain which were not at higher altitudes?
A number of the novices said they worked around the borders of the map area to avoid getting lost. So it seems to be a navigation strategy to keep oneself oriented.

Question 1: Would it be possible to repeat this study with participants who have absolutely no geologic knowledge, but still rank highly in spatial reasoning? It would be interesting to compare their results with those of novice geologists.
Oh yes, that would be interesting. My worry would be that if they didn't know what folds and faults were, they couldn't form a 3D interpretation of the geologic structure. But I bet they would be very accurate in determing the rock distribution.
Question 2: Could we possibly conduct this study without informing the participants about their participation, akin to a field course such as the one offered at ASU, where the participants could still have the interview at the end? Their prior knowledge of the study might have skewed the results.
Yes, see prior response - Any type of social science research runs the risk of changing participant behavior simply from participants knowing they are in a research study. The study was carried out under approval from a human subjects research board, which meant we had to consider both the goals of the research and the rights of our participants to moral and ethical treatment. We felt there were no compelling reasons to withhold the study objectives from the participants, and obtained written consent to volunteer from everyone who participated.

You would have to make a very compelling case to the human subjects oversight board about why witholding information or informed consent would be beneficial – in short you would have to demonstrate that the benefit from the findings would outweigh your ethical and moral obligation to obtain a person's willing and freely given permission to be in a research study. I am not convinced that we could have won that argument, nor do I feel that it would be ethical to conduct a study without giving people the opportunity to decline to participate if they wish.

Question 1: Have you thought about developing a continuing education course for instructors to further disseminate your research?
I had not, thank you for the suggestion!
Question 2: You state that there is a vast difference in movement patterns, and more field judgments, you also suggest that you could teach novices how to perform better and more quickly in the field, but is there really a substitute for experience?
That's the big question in expertise research – and I think there really is no substitute for experience. Part of become an expert is deliberate practice. But I do think we can make a case for improving the education experience so that students can become more expert-like in their thinking more efficiently.

Question 1: I first wanted to say that I'm thoroughly impressed with the research you've put forth and I think the implications of this understanding of the habits of all sorts of geologists can better help us shape how to more effectively deliver geological curriculum to both children and adults. Did this serve as a motivation for your work or is it merely a happy side effect of your research's potential?

All of my research is motivated by the potential to improve the education of geoscientists – that's what I love about what I do. Some research has more immediate application than others. For example, I think this project has some great implications for teaching, but it will take follow up work to further explore and refine these ideas.

Question 2: Do you believe that geology is a strong suited field of science which greatly needs more bodies to keep its research fresh and in the public eye? Do you feel this way about any other field of science? And what sort of implications would research like this have on other fields of study such as astronomy or chemistry?

Interesting questions! The projections that I have seen identify geosciences as a growth field, with a higher than average demand for employment. There is a lot of concern that the current supply of geoscientists will be unable to meet these demands as older employees start to retire. So yes, geosciences definitely needs more bodies. Basically all of the science fields can anticipate growth, but I especially see opportunities in the environmentally focused geosciences as the demand for clean water increases and we have to deal with consequences of a changing climate. A study like this one could be replicated in another field, but with a "problem" that is within the discipine as opposed to geologic mapping.

Question 1: Were any of the members of your study already familiar with the local geologic and structural conditions prior to the mapping? If so, how much do of that knowledge played a role in the results?

See previous response (repeated here) - We asked on the application form if people had been a student at the field course that we were using. We elimiated participants who had been students at the field course within the past 5 years from the applicant pool. We ended up with 2 participants who had been students at the field course (1 more than 20 years ago, 1 about 7 or 8 years ago). To reduce the bias of famliarity, we took everyone to a location about 5 miles away from the mapping site where all of the rock types outcropped. We read scripted information about each rock type (its general lithology, age, and stratigraphic position) and then allowed all participants about 10 min at each rock type to take additional notes. We did not allow them to ask additional questions and did not use the actual stratigraphic names of the units. Some of the participants told us during the interview that they expected to find faults and folds simply because we were in the Rockies, and a few knew the regional geology. So we couldn't completely eliminate a "familiarity bias" that worked in some participants' favor, but we did try to reduce it.

Question 2: Do your results show any correlation between spatial thinking and age, particularly for novice mappers?

Spatial working memory is known from other research to decline with age. Interestingly, we saw a slight but not statstistically significant decline in the spatial tests with age (although we only looked at the study population as a whole and not specfiically at novices or experts). This might be an example of "use it or lose it" where older geoscientists are still using their spatial skills on a regular basis and thus keeping these skills sharp.

Question 1: Have you examined the geological mapping behavior/performance of novices/experts in another field with similar requisite skill sets (e.g. engineering, other physical science)?

No, but see previous responses about our new work with a doctoral student looking at replicating this study with novice and expert weather forecasters. It will be interesting to see if our results play out in another discipline.

Question 2: What do you think are the most essential elements of a field trip/camp experience for an intermediate/expert in a different field with similar requisite skill sets (e.g. engineering, other physical science) to have as part of a lateral transition into geoscience?

Based on our study, I'd say that developing knowledge of geologic structures would be key. Also working with topo maps and aerial photos to understand how structures look as surface landforms and planning out routes to take while mapping that allow a person to test hypotheses as efficiently as possible.

Question 1: Would you ever considered making a graphical design computer class to teach about making geologic maps?

Personally no, as I don't have the right kind of background to teach a graphical design course! But I think it would be a good idea for someone to offer one.

Question 2: Do you use programs like ArcGIS?

We did use ArcGIS extensively for the analysis of the tracks and to overlay tracks on participant maps.

Question 1: Can the pedagogical results regarding visualization be replaced within an astronomy context regarding performing observations on-site?

That is is really interesting question. I think there could be some transfer from this study to the context of planetary geology. Certainly these folks have to interpret geology from surface landforms. It would be intersting to do a "virtual" version of this research looking at how geologists "move" though an area that they cannot physically visit.

Question 2: Are there plans to verify this study with a larger sample size?

Not at present, we are headed in the direction of starting a project looking at how to infuse technology into field courses that would better support students in making hypotheses and interpretations as they are collecting data. Then we want to compare the technology-enhanced course with a "regular" course to see if there are differences in mapping performance.

Question 1: Did you see a correlation between mapping trek and age? I'm thinking that older folks may be more inclined to take a perpetually-downhill approach to conserve energy.
We didn't specifically try to correlate these variables, but I'd agree. Many particpants told us that they wanted to conserve energy by heading mainly downhill and avoiding backtracking. This likely has to do with both age and physical fitness level.
Question 2: Do you think the experts would have just an easy of a time recognizing the syncline without the aerial map, which seemed to show some folded texture outright near the nose of the syncline.
In our follow-on study, more experts used the air photo to identify a fold than used the topo map. Whenever I have given this talk, the structural geologists in the room always can immediately spot the fold from the air photo (I've also had some correctly spot the fault as well). It would be interesting to see what happens with just a topo versus just a photo, and to replicate this study where the geology is less obvious.

Thank you for these questions! It was quite thought-provoking to answer them.