DEVELOPING SUCCESSFUL LEARNING STRATEGIES IN STRUCTURAL GEOLOGY

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ABSTRACT

Geologic fieldwork requires much more than knowledge of the basic skills learned in the standard undergraduate curriculum. Synthesis of the skills into a mental construct called a schema must be done before one can address the kinds of problems that arise when doing field investigations. Schema-development cannot be taught explicitly, but a teaching strategy that includes gradational sets of exercises contributes to the kind of synthesis that is needed to develop a functional understanding of a subject. Appropriate use of descriptive geometry and trigonometry in Structural Geology courses does two fruitful things: it provides students with sets of tools they need to analyze three-dimensional structural patterns, and it stimulates the ability to visualize in three-dimensions. Both of these results are needed to develop a functional understanding of a complex project such a mapping exercise in a moderately complex area.

Keywords: Education – geoscience; education – mathematical applications; education - undergraduate.

INTRODUCTION

To do field work successfully, a geologist must have mastered the extensive set of skills associated with the identification of rocks and minerals, as well as those associated with the recognition and interpretation of sedimentary and structural features. In addition, based on the information provided by using such skills, she must have the ability to develop and revise a mental model of the area being studied. Basic skills are taught in the standard undergraduate curriculum, but model-building abilities develop much more slowly, which is one reason many students find field camp difficult. The problem is that development of a multi-dimensional mental image of an area and its history requires more than just mastery of the basic skills; an understanding of why and when the skills are to be used must also be learned before they can be applied appropriately. For example, it is easy to learn how to use a stereo-net to determine the orientation of an axial plane but it is not as easy to understand when that information should be used to focus future data collection efforts. Cognitive processes involved in creating and interpreting data are not equivalent. Just because I know how to drive a nail with a hammer does not automatically mean that I know how to frame a house. The analogy is a good one because fieldwork and construction of a house require more than skills; they both require a functional understanding of the project at multiple levels.

In what follows, I discuss some basic principles of synthesizing information that contribute to the development of mental models in general, and how the basic mathematics commonly used in Structural Geology courses contributes to the development of the functional understanding needed to do field mapping. Students often misunderstand the rationale for using mathematics in geology courses. At best, they consider it a tool and at worst, a burden. But when used properly, mathematics is as essential as the typical map exercises. This discussion begins with a description of some of the things geologists do in the field in order to illustrate the kind of learning processes involved. Then a mental model that each of us uses several times a week in our daily activities is introduced. This particular model is not in itself relevant to field work, but the description of its development will make clear why it provides a good example.

FIELD INVESTIGATIONS

A geologist doing fieldwork in an area usually begins with some knowledge of the region because most places have been studied in the past, so maps are available, on some scale, as are written descriptions of what prior investigators have determined. The reason for doing new work in the area is usually to obtain answers to new questions, ones that could not be asked in the past, either because new kinds of equipment are available now or because new ways to interpret data have been developed. So most of the time a geologist begins with some information about the area, information whose assimilation results in the development of a preliminary mental model of the area. This model might involve an image of the major structures and their orientations, the important lithologies, and the time sequence of events that have affected the area.

A number of things must be done at each outcrop examined during fieldwork. At the very least, information about the lithologies and the attitudes of beds must be recorded. Then details about things such as sedimentary structures (graded bedding and cross-bedding) and structural features (joints, faults, cleavage, lineations) must be noted. This information, as recorded in the geologist's field notes, is important for it will be the basis of the report that is eventually written. Revisions of the mental model that occur during field work are just as important because of the manner in which they affect the geologist's thinking. As the information is obtained and recorded in field notes, an experienced geologist culls and examines those parts of the data collected that clearly pertain to her mental model. For example, she might ask if the orientations of fold axes and axial planes in this outcrop are consistent with the model. If they are consistent, the information is "labeled" mentally by associating it with those parts of the model that pertain to orientation. The new information reinforces what was known before (so in a sense, the model is modified slightly), and in turn, the information is validated by what was known before. If the new information is not consistent with the model, the reason(s) for the discrepancy must be determined. Additional data from other outcrops may need to be collected and examined before the discrepancy can be explained. In fact, a discrepancy will often determine which outcrops will be examined next. If the discrepancy persists as more data are obtained, major adjustments will be made to the model, because it does not reflect what has been found in the area, and the adjusted model will be used to focus attention on further data collection efforts.

No one can expect to "see" everything in an outcrop that is needed to understand an area that has a moderately complex history, so the geologist must have some ideas about what she expects to find at each outcrop and must expect to change her ideas as data are collected.

If revisions to the mental model are not made, the fieldwork will consist of merely recording what is observed - the equivalent to doing an experiment in the hope that something interesting will occur. That is not a satisfactory way to do science. Facts are not useful unless they are collected for a purpose. No one can expect to "see" everything in an outcrop that is needed to understand an area that has a moderately complex history, so the geologist must have some ideas about what she expects to find at each outcrop and must expect to change her ideas as data are collected.

The iterative process described in the previous paragraphs is much easier to describe than to do or to teach. It is not enough to tell students that one must construct a three-dimensional model of an area in one's mind, because the words do not convey what is involved in comparing spatial relationships between units at scattered, sometimes distant, outcrops. Likewise, the words do not convey how to know when to ask questions of the form: "What was the orientation of the fold axes I saw yesterday? Are these units stratigraphically above or below the others, or at the same level? These kinds of questions are important because they pertain to the number of deformation events and their time sequence. Answers to such questions should also have some effect on the outcrops one examines next. Therefore, the field worker needs more than a picture in her mind; she also needs to have consequences of the various components of the picture oncall. Synthesis of the data modifies one's mental image of the area, but like the information entered into a relational database, to be useful, the mental model must also contain labels that associate causal relations to the different parts of the image. It is not possible to describe explicitly how the labeling is accomplished, but consideration of the manner in which other mental models are constructed and modified may be helpful in designing exercises that facilitate labeling.

NATURAL LEARNING PROCESSES

Most of the learning we do is done subliminally. We do not think explicitly about how to survive in our culture: we learn how by living in it. An example of one kind of learning we all do but do not think about involves commuting to work. My drive to work takes about an hour. Each day I use the same route, more or less, which involves about 25 miles on a state road through rural areas and about 10 miles in an urban setting. The density of traffic can vary considerably, depending on the time at which I leave, so the driving experience is slightly different each day. But unless something extraordinary occurs on the trip (perhaps a bad accident slows traffic), I hardly ever remember much about the drive; each day's experiences blend into previous ones, resulting in a mental construct called a schema that I will call the "commute" schema (cf. Rumelhart, 1980).

Schemata are models of how the world works that are based on our past experiences. That they are personalized is clear, because my drive to work each day differs from those of my colleagues, most of whom live in urban and suburban settings, so my impressions of my trip to work usually differ from theirs. There will be some similarities between my commute schema and theirs, but the overlap is not usually large. Schemata are important because they allow us to deal with daily occurrences smoothly. They can perform this function because they present a blurred image of the past. The blurring is fortunate, because the last thing I want is to remember every instance of every trip I take. With that much information I would never be able to get to work, because decisions such as which route to use as an alternate when traffic backs up, or the best way to deviate from the normal route when I have to stop at the Post Office would be impossible to make. If I had to use every bit of information that is potentially in my memory every time a decision had to be made, I would never accomplish anything.

Of course, when a completely new situation occurs, a response based on an existing schema may not be sufficient, in which case that fact is overlaid onto existing information and a slightly new schema becomes available for use in the future, one with more detail. In effect, when we learn something new we attach a label to the information and store it in a way that it can be used effectively in the future. Storing the new information with a model that we routinely call upon ensures that it will be available when needed in the future. In addition, the overlay process causes my responses to the world to slowly evolve. As an adult, my responses to situations differ from those I chose to use as an adolescent because my schemata have been modified over the years. I demonstrate that I have learned new things by changing my responses to situations. If my judgments are sounder now than those I made 40 years ago (and I certainly hope they are), it is because the things that have happened to me in those years have changed the mental models I use to interpret the world. As experiences accumulate, new options are presented to me by my schemata, so my response to events change. So the way we deal with the world changes with time as we experience new situations. Responses are (usually) rational and practical because they are based on empirically based models of how things have happened to us in the past - models created by abstracting salient features of the past, not based on the totality of our experiences (Schank, 1990).

The process described above represents how people learn and change over time. It is a long-term, largely self-paced and unconscious process that provides people with what is needed to fit into our culture. Gatewood (1985) described the cognitive processes involved in this kind of learning. Much of it is accomplished by mimicking what we see others do and then actually doing the tasks. Initially, we flounder and require directions. Eventually we develop a "big picture" of the tasks, one that gives us the confidence that we need to succeed at them.

The main difference between an expert and a novice is that the expert makes decisions that are appropriate because the decisions are based on empirically developed schemata. When we say that something is "second nature" to a person, we are saying that the person's past experiences have created a schema that provides knowledge of what to do next. Just as I develop an alternative strategy to get to work when I sense traffic congestion ahead, the experienced field geologist works efficiently by utilizing schemata that provide her with appropriate questions and actions. The novice may determine the orientation of an axial plane because she knows how to do it. The experienced geologist makes the calculation because she knows the result will answer a question about the structural pattern in the area. To the novice, the skill is a tool; to the experienced geologist it is part of a strategy. The difference between being a tool and being part of a strategy is that with experience, the geologist uses the tools in a variety of slightly different circumstances. With experience, the relationships between tools and the reasons for using them become clear. Knowing why a tool is used involves a deeper understanding than knowing what a tool can do.

ACADEMIC LEARNING PROCESSES

Learning by modifying schemata differs markedly from the learning that is involved in our formal educational system, in which students are not allowed the luxury of adapting slowly over time. In school, students are expected to assimilate over relatively short time spans abstract information that is usually presented to them orally, by means of a specialized vocabulary. The setting is artificial, the material is presented in a formal manner, and the students are expected to understand what is presented to them quickly, because the schedule requires that new topics be introduced fairly regularly. The academic model of learning differs markedly from that by which students have learned everything else in their lives, so it should not be surprising that students usually develop a functional understanding of an assigned project slowly. We may sometimes forget that students will not automatically be able to "see" the big picture just because we have described it to them in class. They tend to use rule-following strategies for assignments because it takes time and experience to develop the schemata needed to successfully invoke a strategy to complete a complex project. For this reason, the cognitive processes used by experienced geologists will not develop completely in most students during field camp. But some things can be done in the classroom to facilitate this development. I contend that a teaching strategy that involves extensive use of geometry and trigonometry in the undergraduate curriculum can do more than help students solve academic problems; the proper use of mathematics can also help them develop the functional understanding they need to "see" what we, after many years of experience have learned to see. The approach described here will not be sufficient, but I think it is necessary.

DEVELOPING A MATHEMATICS SCHEMA

In a discussion of how a beginner integrates individual tasks into a functional understanding of a complex operation, Gatewood (1985) discusses the difference between two kinds of commands. Using the analogy of a house once more, they would be: "build a stud-wall here" and "frame the house." Someone with basic skills can do the first task, but doing the second requires an understanding of the entire project. How does each task fit into the entire project? How does each task relate to what others on the team are doing? These are questions that a beginner does not usually know to ask, much less attempt to answer.

A novice working on a project has two kinds of things to learn: the skills associated with each of the tasks and the sequence of the tasks. At first, there will seem to be little difference between learning the skills and learning the sequence. Eventually, repetition provides mastery of the skills. At that point, the tasks and their sequence will appear separate. Once the sequence is learned the novice has the luxury of watching what others are doing and recognizing how the tasks done by each person are related to each other and to the overall project. This kind of overview is required to develop a functional understanding of the project.

The process sounds simple, but different people develop a functional understanding at different rates. For example, some of the exercises done in a Structural Geology course involve orthographic projections that allow us to project a three-dimensional situation onto two dimensions. This technique allows us to do things such as determine the orientation of the line of intersection of two planes (the axis of a plunging fold) or the net slip on a fault. When I took the course, in the 1960s, the text we used was the second edition of Billings (1954), and the exercises were provided in a set of appendices. The appendices contained detailed step-by-step descriptions of what had to be done, accompanied by very detailed, labeled diagrams. At first, I could not visualize what was involved in the projections because the distinction between lines drawn on the ground surface and those projected to the surface from depth made little visual sense to me. I knew what the words meant, but could not visualize what the diagrams represented. The words consisted of the kind of jargon that Gatewood (1985) says is used by experts to convey information efficiently but which baffles novices.

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So to do the problems, I had to memorize the sequence of steps involved in each of them. About the middle of the semester, while doing one of the problems, I drew a line in the proper manner, and for the first time, "saw" what it represented. That was an interesting experience because I realized that I no longer had to slavishly follow the memorized instructions; I could see what had to be done to find the net slip on a fault. I do not know what caused the epiphany, so I cannot tell students how to experience it, but I know what led up to it, so I can try to provide a somewhat similar experience.

The exercises in Billings are gradational, in that the basic skills learned early in the semester are used over and over, in problems ranging from simple to complex. So, for example, finding the bearing and plunge of a line might be required a dozen times during the semester, in several different contexts. The repetition contributes to understanding, as does the application in several different kinds of problems. In addition, both orthographic and stereographic projections are used for some of the applications. For example, a student would be asked to find the bearing and plunge of the:

- line of intersection between a fault and a set of sedimentary beds.
- ore shoot that formed along the line of intersection of two faults.
- axis of a plunging fold.
- net slip of a fault.

Eventually the steps become automatic and a "bearing and plunge" schema develops. Likewise, application of the bearing and plunge schema creates a visual image of the structure studied in the problem. This may be what I experienced. One hopes that even later, when given a geologic map, students will develop a strategy for analyzing the area that includes the bearing and plunge schema, as well as other schemata developed in their course work.

Note the progression described here. First the student learns how to do a task. Then she applies it in many different contexts. Eventually, an understanding of the task develops (in the form of a schema) and after that, she recognizes that she has a tool to use when faced with a new situation.

Another approach to developing physical insight by using schemata based on mathematics utilizes trigonometry. Data are usually collected at scattered outcrops, whose locations have as much to do with topographic relief as with the nature of the major structure in the area. If we want to determine the thickness of a unit, given only its attitude and existence at more than one location, we can construct map and cross-sectional views of the area that will provide a picture of the unit suitable for the appropriate calculations. We can do this because attitude information orients a structure in three-dimensions, regardless of the orientations and locations of the local exposures, and knowledge of trigonometry allows you to create a set of contiguous right triangles to determine distances, depths, and thickness using the properties of the triangles.

These calculations are possible because the Pythagorean theorem, which is the basis for trigonometry, is basically the metric for Euclidean space. No matter how one chooses to decompose a line into perpendicular components, the length of the line remains constant. Going further, no matter how one chooses to examine a structure (in whichever direction a cross-section is made from a map view), lengths, and therefore areas and volumes are not affected by the decomposition.

So, in principle, the more practice one gets in using trigonometry to analyze the shapes of structures, the depth to a layer, or the thickness of a unit, the more insight one develops with respect to three-dimensional geometry. In practice, the insight may develop slowly, as it did with me when doing the descriptive geometry problems. But if students are asked to do similar kinds of things often enough in new contexts, the same schema development process should provide both understanding and a tool that will facilitate creating strategies for solving new problems. It would also be useful to ask students to explain in writing (or verbally, in class) what part each triangle plays in the overall task. Why did they determine the value of one particular length or angle? Of what use is that particular calculation? When students get in the habit of asking themselves those questions, we should expect to see a marked improvement in their problem-solving skills, and their ability to imagine what it is they are analyzing. At that point, they may be ready to do field work.

CONCLUDING STATEMENTS

The kind of understanding discussed here does not develop if we work a problem once and do not encounter it again until a test several weeks later. When we are given entirely new kinds of tasks to do each week, we memorize the steps needed to do them, but rarely are we able to internalize them because we do not have a functional understanding of the project. If the schema concept is to be fruitful, it is necessary to expose students to a topic many times, from slightly different perspectives before they will be able to master the material in the sense of applying it effortlessly.

Properly designed instructional strategies involve more than mere repetition. Using the properties of right triangles to analyze slightly different situations is probably necessary but it is not sufficient. The ability to solve new problems is the sign that the skills have been assimilated. That ability does not come from repetition alone. Assimilation requires reflection. One must think about the task at hand and recognize how it differs from previous ones. In addition, when feasible, one should address each problem using more than one technique (trigonometry, orthographic projection, stereographic projections). Students who use a mix of techniques eventually "see" the problem in different ways and separate the core of the problem from the details of the problem-solving technique. When that separation occurs without effort, the student does not have to think about it explicitly; instead she has the luxury of thinking about what comes next. In other words, she starts to develop a functional understanding of tasks and how they relate to the overall project.

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"I realized then how valuable to me had been the close attention I had given to minute details of structure in my youthful studies in the mountains of Corsica, for this had led me to infer that the structure in a specimen might repeat in miniature that of the great rock masses from which the small piece had come."

Raphael Pumpelly