Using Concept Maps to Plan an Introductory Structural Geology Course

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ABSTRACT

A concept map is a visual representation of concepts and their relationship to each other in a body of knowledge. They show the hierarchy of these concepts and emphasize the links between them. Concept maps are valuable pedagogical tools used to design the syllabus for an undergraduate structural geology course. Their value as an aid to student learning has been widely documented (Novak, 1990), and we have found them particularly suitable in the initial planning of courses such as structural geology where many new concepts are introduced.

Concept maps used in the design stage of our structural geology course has resulted in a significant re-ordering of the topics. A more logical sequence begins with descriptive topics (joints and faults) and progresses to more abstract topics (stress and strain and continuum mechanics). The resultant sequence of topics is not that used in most traditional structural geology textbooks. Although it is not necessary for a course to be taught in the same sequence as material is presented in a textbook it is more convenient for students if it does.

INTRODUCTION

For the past several years our methods of teaching undergraduate structural geology courses have evolved in response to an effort to achieve more meaningful learning in our students (Ausubel, Novak and Hanesian, 1978). Two principal modifications to the way we deliver material to students have resulted from our work: firstly the direct delivery of computer developed material during lectures (James and Clark, 1992), and secondly the use of concept maps, both to aid syllabus design and to aid student learning. A concept map is a representation of the inter- relationships among concepts and has the advantage over lists in that it is not linear and can help students visualize these inter-relationships in concept rich subjects. The use of concept maps to aid student learning is described elsewhere (Clark and James, 1997).

Statement of the Problem - Structural geology is a subject that many students find difficult to learn. Many new concepts are introduced, some being rather abstract. Moreover, inter-relationships do not become apparent until all concepts have been introduced. It is our experience that the teaching and learning of structural geology is not as effective as it could be. Assessment results taken prior to the innovations described here indicate that only a small group of students has been successful in understanding the higher order concepts and their inter-relationships. The majority of students completed the course by rote learning, but did not carry the knowledge into subsequent courses.

To address these problems, we modified our approach to teaching the subject matter by incorporating constructivist methods including the use of concept maps. The overall goal of this project was to encourage students to adopt a deep/holistic approach to learning in order to better understand the concepts of structural geology. In addition we wanted students to develop a sound understanding of what they had learned, so that they could relate it to previously learned geologic concepts they already held and then relate these concepts to new concepts as they are introduced. To achieve our goal we modified our approach to teaching. We encouraged the students to use concept maps and other techniques (James, Peterson, Hillis and Clark, 1995) to monitor their metacognition. Secondly, we as teachers used concept maps to help plan the curriculum. In this second part of the study we were testing whether the use of concept maps would indicate a more logical sequence of topics for presentation.

To determine the extent to which we achieved these goals we investigated whether:

1. the teaching methods became more overtly constructivist;
2. there was a change in the order of presentation of topics;
3. the order of presentation normally followed by textbooks was the same as the order determined using concept maps.

Learning Theory and Constructivism - The central concept of the learning theory of Ausubel et al. (1978) is the idea that meaningful learning takes place when new knowledge is consciously incorporated into the concepts and ideas previously acquired by the learner (the knowledge structure of the learner). This is facilitated when new material presented by the instructor can be linked into the existing knowledge (cognitive) structure of the students. During the teaching process, as the students mull over a new idea, for example by doing exercises, the new idea may be categorized under a broader overall concept, or may itself be broad enough to organize several related concepts under it. It may be linked under a broad concept and interlinked with several other equal concepts or it may be ranked under a concept and be somewhat independent of other equal concepts. The idea is massaged until it fits into the progressively differentiated knowledge structure in a logical place, linked to a broader overarching concept or perhaps with several narrower concepts linked below it.

The effectiveness of this approach to teaching, known as constructivism, has been extensively documented (Carpenter, Zenger, Tolhurst, Day, Barron and Dozier, 1999; Chang and Barufaldi, 1999; Chang,

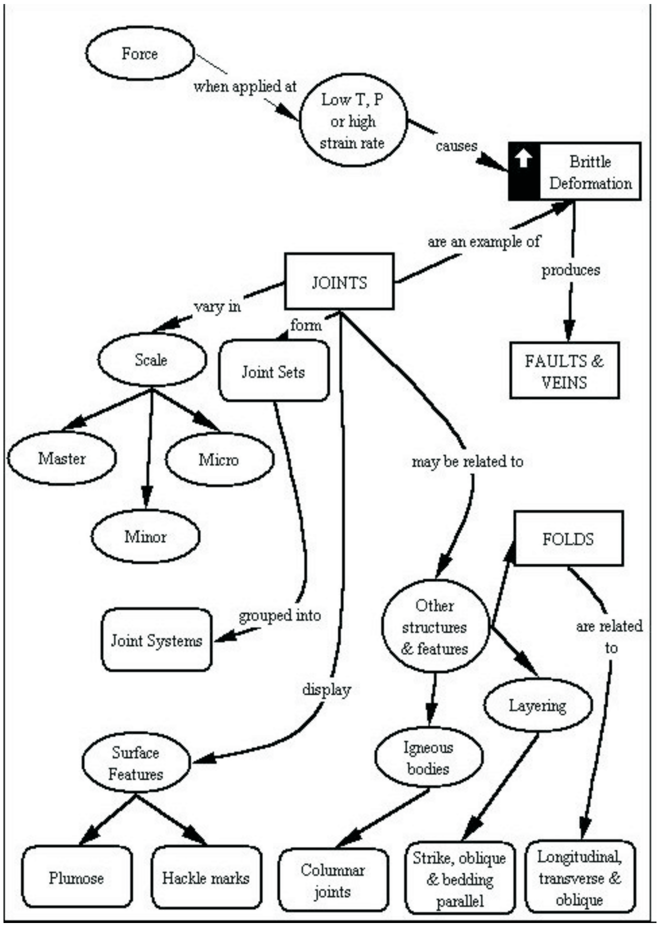

Figure 1 Example of a concept map constructed to illustrate the relationships between concepts introduced in a lecture about Joints.

Hua and Barufaldi, 1999; Confrey, 1984; Crebbin, 1995; Duckworth, 1987; Lochhead, 1983; Lord, 1997; Shepardson and Pizzini, 1993; Slater, 1993; Slater, Carpenter and Safko, 1996; Starr, 1995; Starr and Krajcic, 1990; von Glasersfeld, 1989). This style of teaching has been practised intuitively by good teachers since the days of Socrates (von Glasersfeld, 1989). Constructivism merely supplies a theoretical foundation that is compatible with what has worked in the past and one which may help less intuitive educators improve their methods of instruction.

Concept Mapping - We introduced concept mapping into our teaching for students to develop a better understanding of the topic, enabling them to recognize major concepts and their links. We wanted to promote the development of a hierarchical knowledge structure that in turn would promote better application of concepts and skills. Cuevas, Fiore and Oser (2001) have shown that training systems that enable learners to build an appropriate mental model of the relationships among concepts encourage the acquisition of knowledge structures more similar to an expert model (Tynjala, 1999). Accurate and well-integrated mental models may reduce the cognitive load on working memory and attention associated with complex tasks by making structural relations clearer. In this way the efficiency of the learner's information processing is increased (Marcus, Cooper and Sweller, 1996).

Concept mapping had its origins in the research of Novak and others at Cornell University (Novak, 1990). The research was based on Ausubel's (1968) assimilation theory of cognitive learning that proposed that new concept meanings are most effectively acquired through assimilation into existing frameworks. In an attempt to represent the frameworks and the changes to the frameworks as learning proceeds, Novak and colleagues developed the idea of concept/propositional frameworks that they described as "cognitive maps" or "concept maps" (Novak, 1990). Following the additional ideas of Ausubel that cognitive structure is organized hierarchically, and that most new learning occurs through derivative or correlative subsumption of new concept meanings under existing concept/propositional ideas, a hierarchical representation was incorporated into the concept maps.

Previous studies (Carey, 1985; Donaldson, 1978; Driver, 1983; Symington and Novak, 1982) suggest that concept maps help students "learn how to learn" and that concept maps are a useful way to represent knowledge and therefore an aid for students in organizing and understanding new subject matter. A review by Horton, McConney, Gallo, Woods, Senn and Hamelin (1993) of many of these previously published investigations of the effectiveness of concept maps in improving student achievement and attitudes revealed that concept mapping has generally positive effects.

Representing concepts and the organization of subject matter using concept mapping helps students to visualize relationships among the parts of the subject matter, in order to build mental models (Figure 1). Concept maps present a two-dimensional view of a discipline or a part of a discipline (Stewart, Van Kirk and Rowell, 1979) that allows for the representation of the propositional relations between concepts. This method gives students a much different perspective to the traditional note-taking method that is one-dimensional and often does not illustrate relationships between concepts. The concept map not only identifies the major ideas (concepts), but also shows the relationships among them. In contrast, rote learning is characterized as learning in which the information, in a sense, is arbitrarily stored; the learner does not have the relevant concepts required to incorporate new knowledge.

Two aspects of structural geology make the constructivist method and the use of concept maps particularly suitable in the initial planning and teaching of detailed courses. Firstly, many new concepts are introduced and their mutual inter-relationships are not immediately apparent. The sheer volume of new concepts overwhelms many students. They respond by resorting to rote learning methods and no attempt is made to relate the concepts to each other. Secondly, what appears to be a logical sequence for the presentation of new ideas in fact may not take into account what the students already know. Therefore it is important to consider the prior knowledge and experiences of students when determining the order of presentation. The initial stages of a course should consist of concrete-empirical experiences that are carefully selected to lead the learner to the abstract ideas that the teacher wants the student to grasp at a later stage.

Concept maps and the constructivist approach also help identify the most appropriate sequence of topics (Cliburn, 1986; Starr and Krajcic, 1990). Fairly abstract ideas or inclusive generalizations are placed above subordinate ideas. Concepts are listed vertically

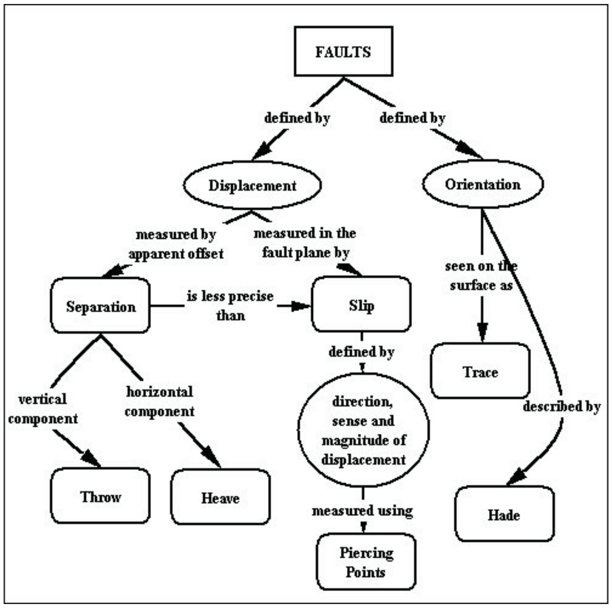

Figure 2. A concept map summary of a lecture on faults.

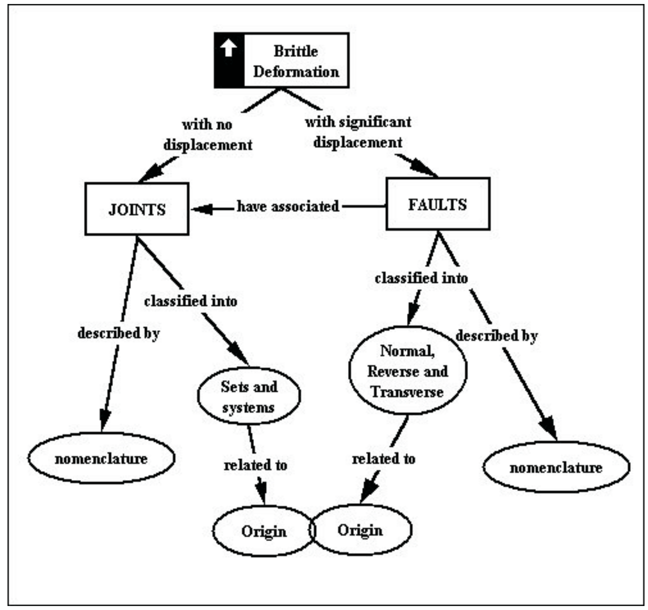

Figure 3 Concept map showing the relationship between a lecture on joints and a lecture on faults

according to their level of generality within the particular conceptual system. This arrangement provides a visual representation of the relationship between the different parts of the course and helps determine the best sequence for its presentation. These diagrams are also helpful for students who can use them to develop their own concept organization (Moreira, 1979). Students who have been taught by this method report that the technique is very helpful (Cliburn, 1990).

CONCEPT MAPS IN COURSE PLANNING – A CASE STUDY

We have incorporated concept maps into our instructional materials to aid student learning (Clark and James, 1997). Moreover, we have used them to plan and order the syllabus, especially the sequence of topic presentations. The use of concept maps for syllabus planning initially was not intended; rather it evolved during the course development process to help choose the best sequence for the presentation of the topics.

Once we decided to incorporate concept maps into lecture presentations, it became necessary to develop a set of concept maps that represented the topics to be covered. Lecture summaries that had been given to students in previous years were used to guide the content of the concept maps that were to be incorporated into the lectures. These concept maps were modified prior to incorporation into lecture slides both in the overall layout and content. Changes to the specific content involved inclusion and deletion of concepts and changes to the linking phrases. Changes to the layout involved re-ordering and re-arranging the hierarchy and addition of extra links and in some cases deletion of links. Although the modifications were mostly minor, the need for modification indicated that it was not always possible to interpret the desired meaning and emphasis from the lecture summaries alone. This implies that if students were to use only these materials without interaction with

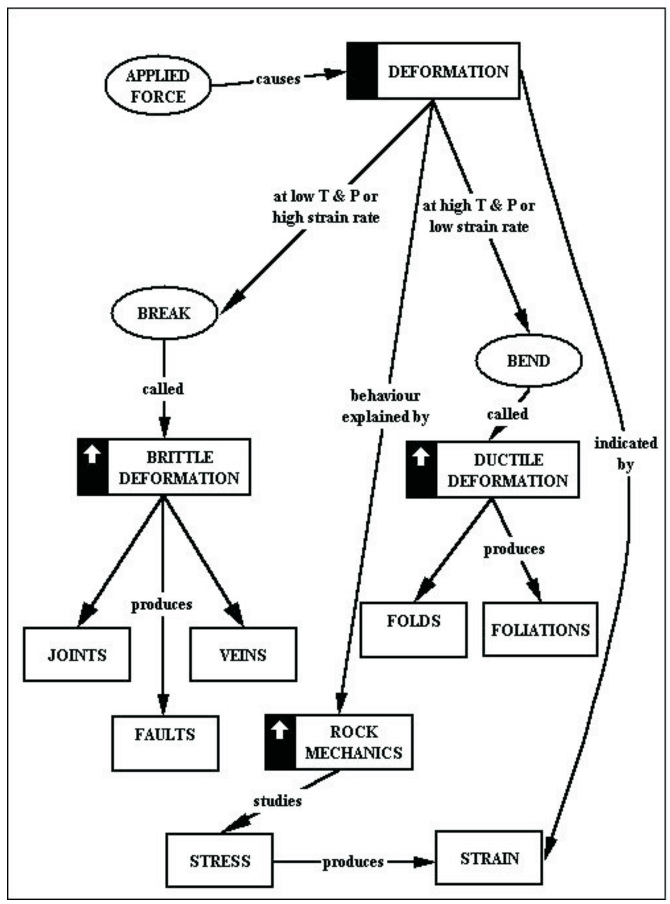

Figure 4. A concept map that shows the links between the major topics in the course.

Prior To Change	New Order	Typical Text Order (from Hatcher, 1995)
Part A - Continuum Mechanics	**Part A – Descriptive Structural Geology**	**Continuum Mechanics**
Introduction to rock mechanics	Joints	Stress
Introduction to continuum mechanics	Faults	Stress
Stress	Faults	Strain measurement
Stress	Veins and tension gashes	Mechanical behavior of rock materials
Strain	Folds	Microstructures and deformation mechanisms
Strain	Folds	**Descriptive Structural Geology**
Experimental deformation	Fabrics	Joints and shear fractures
Ductile behavior	Lineations	Fault classification and terminology
Brittle behavior	**Part B - Continuum Mechanics**	Fault mechanics
Part B – Descriptive Structural Geology	Rock mechanics	Thrust faults
Joint	Continuum mechanics	Strike-Slip faults
Faults	Stress	Normal faults
Faults	Stress	Fold geometry and classifications
Veins and tension gashes	Strain	Fold mechanics
Folds	Experimental deformation	Complex folds
Folds	Brittle structures	Cleavage and foliations
Foliations	Ductile behavior/structures	Linear structures
Lineations	**Part C - Tectonics**	**Tectonics**
Part C - Tectonics	Tectonics	Tectonic structures in plutons
Tectonics	Tectonics	Structural analysis
Tectonics	Tectonics	

Table 1 Comparison of the sequence of structural geology course topics before and after the application of the concept map strategy. The third column shows the sequence of topics in a frequently used structural geology textbook

the instructor, they might misinterpret emphasis and relationships.

Using this two-step process it was possible to prepare a relatively simple concept map for each lecture. These were incorporated into the PowerPoint presentations and used with students in teaching (Figures 1 and 2). It was also possible to develop concept maps that showed the links between consecutive lectures (Figure 3) and others that provided a summary of the major topics (Figure 4). It was this latter type of map that was developed to give students an overview of the course.

Still another modification to the concept maps came as a result of incorporating them into the lecture presentations. During these lectures an instructor who was not delivering the lecture prepared another set of concept maps. This set of concept maps represented an interpretation of the desired relationships between the concepts presented and the relative importance of concepts. Presence or absence in a concept map and position in the hierarchical structure of the map determined relative importance of concepts.

When these maps were compared to those prepared for students it was found that there were differences that reflected the emphasis given by the instructor during the presentation. The concept maps prepared during the lecture were the ones that were most acceptable to the instructor. They were the ones incorporated into subsequent teaching, and the ones that guided the planning in subsequent years.

As stated above the two-dimensional nature of concept maps makes them especially useful in curriculum planning as a visual representation of the hierarchy and links among concepts. This aids the curriculum planner to introduce concepts in an order that allows the learners to incorporate them into their existing knowledge structure (the constructivist method).

As a result of this evolutionary process of constructing and re-organising concept maps, an apparently logical sequence for the presentation of topics in this course was changed. The course as we teach it in the second year of the undergraduate program consists of two major parts: the theory and application of continuum mechanics to the behavior of materials; and classical descriptive or morphological structural geology. Continuum mechanics describes the way in which rocks respond to applied forces and explains the variation in deformation features that result from differences in rock properties and the environment in which the processes occur. Descriptive structural geology describes the outcomes of the deformation processes.

It seemed logical, therefore, to start the course by teaching continuum mechanics and to conclude by describing the outcomes. Indeed this is the sequence in which the topics are presented in many introductory structural geology texts (Smith, 1992). However, when concept maps were developed for the individual parts of the course, it became apparent that the students did not have the existing conceptual framework into which they could incorporate the new continuum mechanics knowledge. Most students studying structural geology at this level do not have the background in mathematics and mechanics to handle a detailed continuum mechanics treatment of the course. When this situation occurs the new knowledge is more likely to be forgotten after a short time. Cognitive research clearly shows that students can learn most readily about things that are tangible and readily accessible to their senses. With experience, they develop the skills to understand abstract concepts. These skills develop slowly, however, and the dependence of learners on concrete examples of new ideas persists throughout life (Project 2061 American Association for the Advancement of Science, 1989).

As a result of these observations the sequence of topics was changed (Table 1) so that the first section to be treated was the descriptive structural geology section and the more abstract rock mechanics section was treated last. Twiss and Moores (1992) in the preface to their text support this approach:

> As a result of many years of teaching this material (structural geology at an introductory level) we have adopted a somewhat novel organization for the book. Our aim is to introduce observations about the Earth first, followed by the relevant mechanics and experimental results that are needed to understand the observations. Thus we introduce the concepts of stress and fracture mechanics only after we have described fractures and faults as they are observed in the Earth....the relevance of... [the theory] is then clear, and its application to understanding structures rests on an established foundation of knowledge about the Earth.

Smith (1992), in a review of introductory structural geology texts, showed that there is no consistent starting position but the majority of commonly used texts treat the abstract theoretical basis for rock deformation before describing the resulting structures. Of the texts that Smith examined, only Park (1989) completes the concrete ideas before visiting the abstract theory. Although the sequence that should be used for teaching a course does not necessarily follow the order of topics in a text, it is more convenient for students if it does.

In the new sequence that resulted from this study the first topic we start with is *joints*. As well as being familiar with this topic from the introductory geology course, students recognize that joints are a common structure in most rocks. Joints are part of the larger topic, brittle deformation. The phenomenon of materials breaking when they are subjected to large forces is familiar. To reinforce this, a demonstration of brittle behavior is part of the first session (breaking a plastic ruler). The purpose is to start with something familiar. From this activity the first simple concept map is constructed using descriptive terms provided by the class (Figure 5). This clearly links the new information to the ideas that the students already have. The development of the course then proceeds using concept maps to show the way in which each new piece of information is linked to that which has come before.

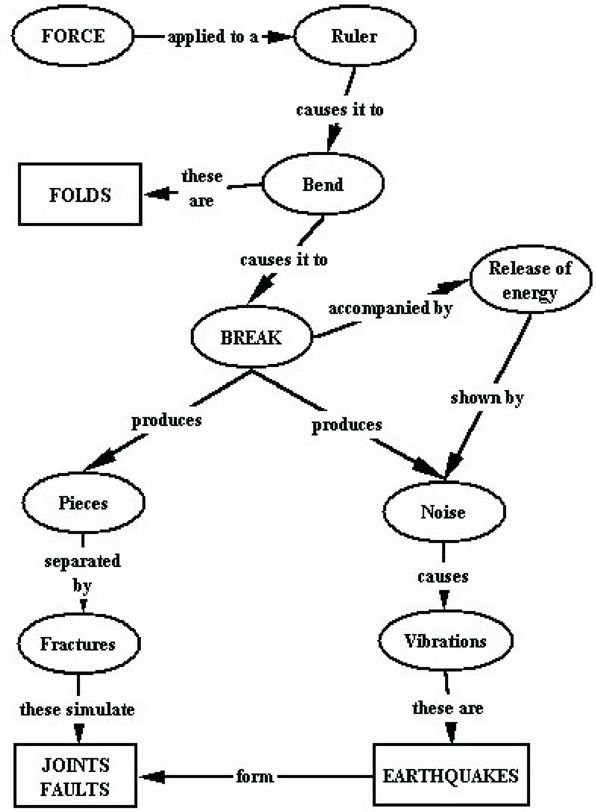

Figure 5 A concept map constructed from terms used by students (in ellipses) to describe what they saw when a plastic ruler was bent and then broken. Terms in rectangular boxes were introduced to relate observations to course topics.

Concept Overload - Another outcome of using concept maps during the planning of the course has been the reduction in the overall number of concepts that are introduced at any one time and a reduction in the amount of detail that students are expected to retain. Ideas and thinking skills are emphasized at the expense of specialized vocabulary and memorized procedures such as mathematical proofs. Sets of ideas are chosen that not only make satisfying sense in relation to students' prior experience, but which also provide a lasting foundation for further learning. Despite the overall reduction in detail we feel that students do not exit the course any less competent in structural geology than students of previous years. In fact they are more likely to retain the knowledge that they have acquired and be better prepared for lifelong learning. Although this contention is difficult to prove, it is based on the performance of students at the mapping camp that follows this structural geology course and their performance in the advanced structural geology course that most students take in the following year.

Support for the rationale behind these changes can be found in Bransford, Brown and Cocking (2000, p. 20) who recommend replacing superficial coverage of all topics in a subject with in-depth coverage of fewer topics. There is a temptation to load more and more into the curriculum, in the belief that it will adequately prepare graduates to practise and to maintain currency. In fact, heavily loaded curricula often leave students with a fragmented and disjointed view of the field rather than an understanding of its essentials (Candy, Crebert and O'Leary, 1994).

CONCLUSION

The use of concept maps as part of the constructivist approach to teaching is widely accepted as an effective way to aid student learning. We have found that using concept maps during the initial planning of a detailed curriculum in structural geology can be very effective in promoting such a constructivist approach. Because many new concepts are introduced, their overall relationships with each other are not immediately apparent, especially to students. The construction of concept maps by the instructors during the syllabus planning process showed these relationships and a sequence for their introduction, thus ensuring that the new concepts could be linked to concepts that had already been presented.

Another outcome of using concept maps is that they reveal that what may appear to be the logical sequence for the presentation of new ideas in fact may not take into account the links among the concepts that have already been introduced and those which are about to be introduced. The apparent logical order may also not take into account what the students already know. Concept maps have aided us in overcoming these obstacles to effective student learning by clarifying the links among concepts, showing the hierarchical structure of the concepts, and demonstrating the most logical sequence for delivery of these concepts.

An important outcome of using concept maps to help plan the syllabus was a change in the order of presentation of topics to take into account the hierarchical nature of the concepts to be taught. This apparently more logical order is not that followed by most structural geology textbooks.

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