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ABSTRACT

To determine whether scientific diagrams are helpful to students, researchers involved students in a mind probing investigation. Specifically, researchers wanted to know what goes on (and does not go on) in the minds of students when they encounter diagrams during science instruction. Based upon the results of these studies, suggestions are made on how best to use diagrams to help students learn science. (ZWH)

The Key Centre for School Science and Mathematics

What Research Says to the Science and Mathematics Teacher Number 3

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SCIENTIFIC DIAGRAMS: HOW WELL CAN STUDENTS READ THEM?

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TEXTBOOKS ALWAYS have played an important part in learning science. We know, for example, that one of the reasons why some students are less successful learners than others is that they have trouble reading their textbooks. In recent years, textbooks have changed a lot. The most striking change is today's emphasis on *visual* learning, shown by the relatively large number of pictures and diagrams used. While some of these, no doubt, are merely intended to attract the attention and interest of students, there seems to be a common view that diagrams make learning more effective.

'Reading' scientific diagrams is a demanding task

But are diagrams necessarily helpful to students, or can they actually introduce another kind of reading problem? To answer this type of question, we need to know more about what does (and does not) go on in the minds of students when they encounter diagrams during science instruction. The studies described in this publication involved how people think about diagrams, and suggest how best to use diagrams to help students learn science.

Recently, we have begun to develop a much better understanding of the skills that students need to read textbooks effectively. As a result, we now know some of the main reasons why students have trouble with the *written language* in science textbooks. However, little is known about the skills needed for students to gain maximum benefit from the many *diagrams* that these textbooks contain. My research suggests that the 'reading' of scientific diagrams is itself a demanding task that should not be taken lightly.

However this view doesn't seem to be widely held, if modern science textbooks and instructional practices are anything to judge by. The view that 'A picture is worth a thousand words' often appears to be accepted unquestioningly by textbook authors and publishers. It seems that scientific diagrams are simply seen as an effective way of clarifying the subject matter. Any potential barriers to science learning that diagrams may pose are generally not considered. In general, because we live in a world dominated by visual media, the issue of whether the information in one type of pictorial material (such as scientific diagrams) might be much less accessible to the untrained eye than information in other types receives little attention. All 'pictures' tend to be lumped together somewhat indiscriminately by producers of educational resources and treated as if they are 'a powerful instructional alternative' to textual presentation.

The general purpose of the studies discussed here was to question the assumption that diagrams necessarily help students learn science. More specifically, the aim was to find some clues as to what may be in the mind of a beginning science student when s/he interacts with a diagram. At issue is whether diagrams themselves pose special interpretative challenges over and above the challenges posed by the scientific subject matter which they are depicting. If they do pose special challenges, it would be important to know if there are particular types of knowledge and skills that might be required for effective use of diagrams in science learning.

If effective use of scientific diagrams does require special knowledge and skills, we might expect to find that those with different levels of expertise will treat diagrams in different ways when they encounter them. One way to explore this possibility is to compare the thinking of people who are highly experienced in working with diagrams with that of those who have little or no experience in this area.

Two studies of this type are reported here. In the first, the way that a group of year 8 students (beginning their high school science studies) interacts with a particular diagram is compared with the way that a group of university science graduates interacts with the same diagram. The second study compares the way that professional scientists think about diagrams with the way that adult non-scientists think about them.

FIRST STUDY

THIS STUDY (Lowe, 1987) explored the way in which a particular scientific diagram was perceived by two groups of students who differed in their levels of general experience with scientific diagrams. Thirty-eight university students who had just completed at least three years of science study at tertiary level made up the experienced group. Forty-eight Year 8 students with only six months of formal science instruction made up the inexperienced group. This inexperienced group had been studying air pressure and had been taught the role of aerofoils in flight during a previous lesson.

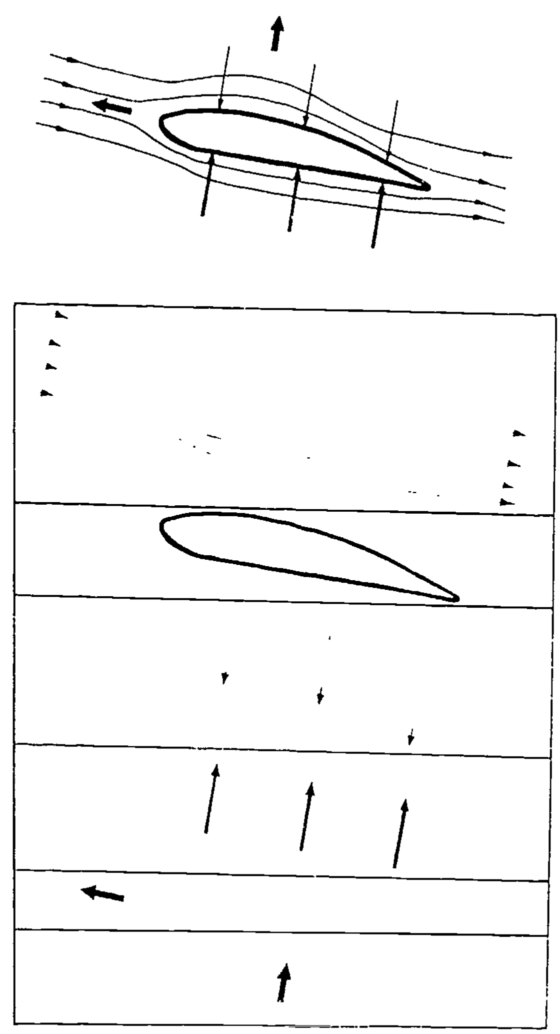

Figure 1: Diagram and Components

Each student was asked to write comprehensive explanations for each of six individual components of a diagram that was intended to show how the shape of an aircraft's wings helps it to fly (Figure 1). The identity of the six components had been established previously from the way in which experienced science teachers had divided up the original, complete diagram into segments when asked to identify its main parts. In addition to a segmented version of the diagram, subjects were supplied with a copy of the original whole diagram which had a descriptive caption but no labels.

The Findings

It seems that the experienced science students 'saw' the diagram in a different sort of way from the inexperienced students. It was as if the various pieces that made up the diagram held different meanings for the two groups. The differences in their comments cannot adequately be explained simply by assuming that the experienced students just knew more about the topic that provided the subject matter for the diagram. Rather, the experienced group had a much more sophisticated approach to the diagram itself than did the inexperienced group. Central to this difference in approach were the *knowledge-based* comments that the two groups gave about the diagram. The groups not only emphasized different *types* of knowledge, but they also appeared to have knowledge *organized* differently in their minds.

Degree of Abstraction

The explanations suggested the existence of big differences between the groups in the *degree of abstraction* which they used when thinking about this diagram. The inexperienced group tended to think about the diagram in terms of their concrete everyday experience, whereas the experienced group used a more abstract scientific framework. For example, despite four weeks of prior instruction on the topic of air pressure, the year 8 students tended not to explain the subject matter of the diagram in terms of air as a distinct scientific idea. Rather, they tended to explain diagram elements in terms of their more tangible and familiar everyday experiences. For example, the flow lines in the diagram would be referred to as 'wind' rather than as an 'air stream'.

Year 8 students tended to explain diagrams in terms of tangible, everyday experiences.

In addition, the inexperienced group tended to refer to constituents of the diagram in a more literal manner than did the experienced group. For example, they made frequent reference to 'lines' and 'arrows' whereas the experienced subjects tended to refer to what was meant to be *represented* by these marks on the page ('air-flow', 'pressure').

It seems that the experienced group dealt with the underlying scientific ideas in the diagram while those in the inexperienced group adopted a more superficial and less sophisticated approach.

Conventions and Relationships

There were other ways in which the comments of those in the experienced group reflected a more sophisticated approach to the diagram. One type of comment suggests that they paid more attention to the *conventions* used in the diagram than did the inexperienced group. A common convention in scientific diagrams is to use non-realistic views of the subject matter in order to depict aspects that are not readily observable in more realistic illustrations.

Cross-sectional views are widely used for this purpose. Those in the experienced group were much more likely to comment on the fact that the diagram was a cross-sectional view. They also made more comments about other conventions, such as the use of arrow thickness to signify the magnitude of a force. This regard for diagrammatic conventions is of course essential for an appropriate and comprehensive interpretation of what is depicted.

Experienced science students paid more attention to diagram conventions.

Another example of the experienced group's more sophisticated approach is illustrated by their comments on the wing's shape. Comments such as 'the top of the wing is more curved than the bottom of the wing' contain clear references to *relationships* present in the diagram. As well as considering relationships like this that were *within* individual diagram segments, comments were also made such as 'the pressure on the bottom of the wing is greater than on the top'. This example shows that relationships *across* several diagram segments were also considered. This suggests that attention was given to relationships over the diagram as a whole. In contrast, few such relationships were reflected in the comments of the inexperienced students who generally used a more fragmented approach.

SECOND STUDY

THIS STUDY (Lowe, 1989) sought more detailed information about the way in which experience and expertise in working with a particular type of diagram can influence the approach used in diagram-processing tasks. The processing approaches of a group of professional meteorologists and a group of adult non-meteorologists were compared as they performed a task involving a weather map. Participants were asked to reconstruct the total set of meteorological markings of a hidden weather map after only one third of these markings had been revealed to them. The areas of the map in which markings were to be revealed were chosen by each subject (Figure 2).

The procedure began by providing participants with a blank map of Australia divided into a grid of 30 squares From this map, the participant chose 10 squares, one at a time, which were to have their markings revealed. Once the markings on 10 squares had been revealed, the person was asked to complete the markings on the map.

Meteorologists

The meteorologists dealt with the map task in a manner that indicated a sophisticated and abstract view of this type of display. On one hand, they were able to 'see past' the conventional representations used as markings on the map and interpret them in terms of the real world. As the following extract shows, this meant that when necessary, they could think about the map in terms of the physical realities of a region's geography and weather:

> *'... this suggests it would be quite a hot day in the West because it's a summer pattern, north easterly winds, the high in the Bight, overland trajectory ...'.*

On the other hand, however, they were also very skilled at dealing with these conventional representations in powerful ways at a very abstract level, as shown by the next extract:

> *'The north-west/south-east orientation of the isobar ... indicates that we have got a trough tied in with the high there.'*

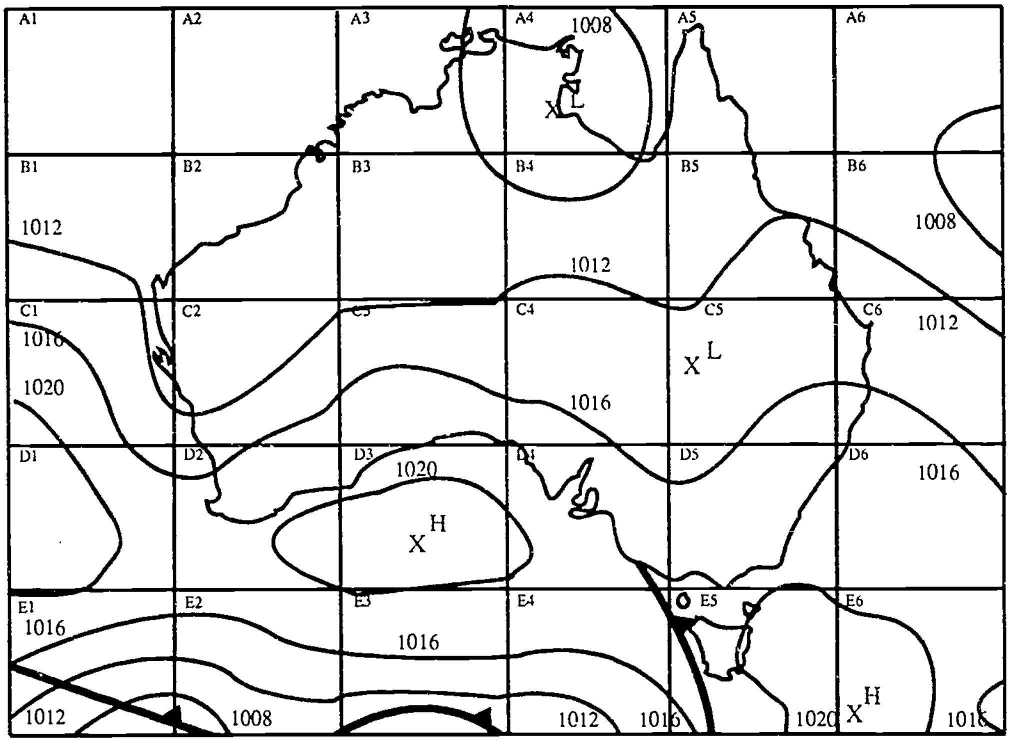

Figure 2: Weather Map (To Be Reconstructed by Participants)

This is something like the way in which a physics teacher can interpret a physics problem either in terms of its everyday reality or in terms of abstract principles of physics. It seems that the meteorologists' natural mode of thinking about the map was at this abstract level rather than at the level of marks on the page.

The patterns of square selection and the accompanying verbalizations suggested that the meteorologists had a clear idea of where key information was likely to be found on the map. They appeared to be using knowledge of various types of *relationships* between meteorological markings that comprise weather maps. Rather than working on the basis of individual markings, they tended to treat these marks as part of larger groups or 'chunks' that encompassed several markings. For example, they grouped together a number of otherwise discrete open isobars because of a trough or ridge pattern that ran across them. It also appeared that their knowledge of the way in which information is typically organized on weather maps was coherently structured across a number of hierarchically arranged levels. At one extreme, for example, they broadly divided all weather maps into Summer, Winter or Transitional maps. At the opposite extreme, they considered small irregularities in the path of a tiny isobar fragment as indicating a local geographic effect specific to a particular region and set of conditions. Their well-structured knowledge base seemed to guide their choice of information to be revealed and their later operations in completing the map from partial information.

Non-Meteorologists

In contrast, the behaviour of the non-meteorologists suggested that they had little idea of what were likely to be important and unimportant areas of the map. In addition, they tended to work only at the level of individual markings with no apparent higher-level conceptual knowledge guiding their exploration of the map. There appeared to be no awareness of organizational principles that might specify relations between these markings and allow them to be grouped into meaningful chunks. Their choice of squares to be revealed was generally poor compared with that of the meteorologists because they tended to miss key information that would have provided a basis for useful inferences about the remaining markings on the map. Even when they did stumble across information considered highly useful by the meteorologists, they were unable to appreciate its significance and use it to advantage.

CONCLUSIONS AND IMPLICATIONS

THE TWO STUDIES described here sound a note of caution for those who are tempted to assume that scientific diagrams have some sort of privileged status in terms of their effectiveness as tools for science instruction. Just as there is a difference between reading scientific text and 'everyday text', there could also be a difference between reading scientific diagrams and 'everyday pictures'. Although the results discussed are necessarily quite limited in their scope, they do suggest that reading diagrams effectively is not as straightforward as has often been assumed. Hence, it should not be taken for granted that all students have the knowledge and skills required for effective reading of diagrams.

Effective reading of scientific diagrams should not be taken for granted

People with different levels of experience and expertise with the types of scientific diagrams examined in these studies appear to treat the diagrams quite differently. In general, the results of these studies suggest that these differences involve (a) the degree of abstraction with which the diagram is treated, (b) the extent to which the diagram is seen in terms of relationships and (c) the fluency with which diagram conventions can be handled during the 'reading' process. If similar results occur for other kinds of diagrams, perhaps we will need to give more thought to the use of diagrams in science education.

For example, we might need to teach students how to interpret diagrams rather than assume that they already are able to do this. Rather than seeing diagrams as unproblematic aids to better science learning, it could prove useful to give much greater emphasis to the development of diagram-processing knowledge and skills than is currently the case. Instead of being seen merely as an adjunct to science learning, scientific diagrams would form an object of study in themselves. However, before such a change in approach is warranted, a much clearer and more complete understanding of the processes involved in effective diagram reading would be required. The results presented here suggest that this is an important and rich area for further research.

From the results above, there follow some implications for classroom science teachers. It seems that we should not automatically expect students to gain the same things that we do from a given diagram. The skills that children have developed for the interpretation of everyday pictures are not necessarily sufficient or appropriate for the interpretation of scientific diagrams. As a consequence, we might need to include explicit instruction in diagram-processing skills as a normal part of the science curriculum. We cannot assume that all students will pick up such skills incidentally any more than they would pick up other science skills. It is especially important that we question the widely held assumption that, for lower-achieving students, diagrams provide a more accessible alternative to text. Diagram processing often requires a degree of sophistication and skill that is similar to that required to process text and therefore might not necessarily be any better developed in lower-achieving students than is text processing.

What suggestions can we make from the studies described here concerning how classroom teachers might help students make more effective use of diagrams in their science learning? Initially, it seems important to help students develop a good working knowledge of the more common conventions found in scientific diagrams. While science teachers take for granted that explicit teaching of diagram vocabulary and syntax is necessary for certain 'special' types of diagrams, such as electronic circuit diagrams, this is not usually their approach with many other forms of scientific diagrams. However, many of the characteristics of these other more 'normal' forms of diagram can also be 'special' as far as beginning science students are concerned. Students need to see that there can be a great range of possible meanings for a particular diagrammatic symbol and that its intended meaning in a specific diagram is heavily dependent on the context. The varied uses of arrows in diagrams provides a good illustration of this point.

We might need to teach students how to 'read' scientific diagrams

As well as understanding that a variety of special meanings are possible for the symbols found in diagrams, students should also be encouraged to look for patterns of organization (relationships) amongst symbols. The capacity to group the symbols that make up a diagram into meaningful chunks at various levels seems to be characteristic of people who are skilled in diagram processing. By showing students the ways in which the numerous individual symbols found in a diagram can be related and so treated as larger groups, understanding of the major scientific ideas in the diagram can be developed. In contrast, a student who sees a particular diagram only in terms of a collection of unrelated individual elements would be unlikely to grasp the author's intentions fully. Teachers themselves know a great deal about the way that information within diagrams 'hangs together'; however they do not always make this knowledge explicit to their students. More attention to helping students form meaningful chunks of information from the material in a diagram could benefit students in terms of both understanding and recall.

There is a variety of ways in which the knowledge and skills described here could be developed in the science classroom. I have described some specific teaching activities designed for this purpose in a number of recent articles (Lowe, 1986, 1988). Although these activities are based upon several specific diagrams, the principles they embody could easily be transferred to other types of diagrams. By directing more attention to the way in which students interact with diagrams, science teachers have the opportunity to make much more effective use of these potentially powerful components of science instruction.

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