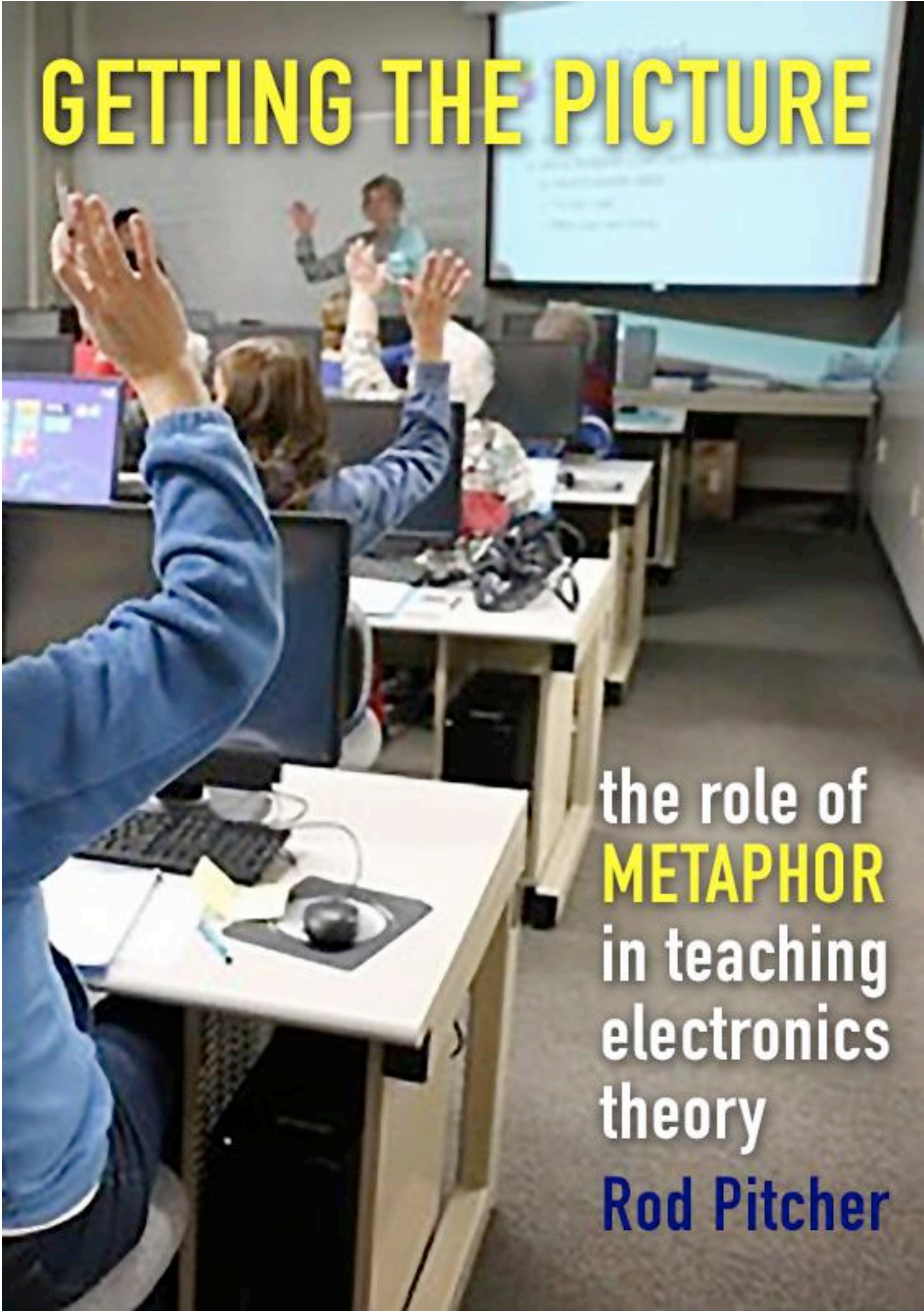

GETTING THE PICTURE

the role of METAPHOR in teaching electronics theory

Rod Pitcher

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INTRODUCTION

Metaphors are widely used in teaching electrical theory. Electrical flow and control is illustrated by referring to the flow and control of water in a pipe. Radio signals are propagated in 'waves', and communications are conducted via 'webs'. Some of these metaphors are so ubiquitous that they are known to people who have little interest in, nor inclination towards, learning electronics.

The metaphors used in electronics are the topic of this book: How they are used in teaching electronic theory, and how effective they are in imparting understanding of the subject. My aim is to understand how people using the metaphors -- the teachers and learners -- perceive the use of metaphors as learning aids, as useful or otherwise. I am looking for the subjective responses of my subjects rather than the statistical responses usually sought in such investigations.

For the purposes of this dissertation, I use the term 'electronics' to include electrical and radio theory. At the basic level, as used here, the theoretical considerations are the same. I have avoided technical terms where possible; those which I have found unavoidable but are not made clear by the context in which they are used, are explained at their first appearance. In discussing the teaching of electronics, I use the term 'teacher' rather than some more formal term, such as 'lecturer', and I use the terms 'student' and 'learner' interchangeably. This is done deliberately, since some of the learning I discuss takes place in fairly informal settings, and I wish to avoid any implications which might adhere to any more formal terms.

In the first chapter, I discuss three metaphors of which I have had personal experience in teaching and learning electronic theory. The first of these is almost universally used, the others, although less common, are sufficiently representative to warrant consideration. Taking a practical approach, I adumbrate on the ways the metaphors are presented, and how well, or ill, they illustrate the theoretical information which they are intended to complement. I also briefly mention another metaphor, of which I have had no experience, but which is of importance in one of the articles discussed in the following chapter.

The second chapter is a brief look at the theoretical background to the use of metaphors in science and technology. I discuss a number of articles and books which offer some insight into the meaning and use of metaphors, both as a means of extending understanding and comprehending new concepts, and as a means of imparting those new concepts to other people. I also give some consideration to an experiment in the effectiveness of metaphors in teaching basic electrical theory, and how metaphors influence the learners thought processes.

The final chapter is an account of the results of the study that I undertook in gathering data about people's usage of, and responses to, metaphors. In relating my study findings I look at the presentation of metaphors from two different directions - firstly, from the point of view of the teacher, and secondly, from the point of view of the learner. I adopted this method since it allows the problem to be approached from two different directions. I also presented a sample of an introductory text on electrical theory to a group of people who had not previously learnt such theory, to find out their reactions. To supplement the data derived from my fieldwork, I also draw on many years experience in electronics, as learner, user, and teacher.

My study suggests that there is still much to be learnt about some of the long-term aspects of metaphors, particularly from a practical point of view. However, due to the limitations imposed on my study, I must leave those questions for someone else.

WATER, WAVES, AND WEBS

Metaphors are widely used in electronics, often using water as a parallel: electricity 'flows'; signals radiate in 'waves'. In this chapter I discuss three metaphors used in teaching electronics theory. The first - in which electricity is compared to water in a pipe - is used by almost all teachers, and appears in almost every text book, often with pictures (For example, see Phillips 1993). The other two are less common, but still widely used. They are examples of the type of metaphors used in illustrating the principles of electrical and radio theory.

Following the descriptions, I discuss some of the problems which might arise in using the metaphors, in particular I show where the analogy breaks down. In some cases probing beyond the immediate similarity can produce contradictions and hence confusion in the mind of the learner. Some problems suggested and discussed by other researchers in this area form part of the next chapter.

In learning basic electrical theory, students are encouraged to think of an analogy with water. The amount of water flowing through a pipe is presented as a comparison with current flowing through a wire. Water flows at a rate depending on the pressure applied by a pump of some sort, just as electricity flows at a rate depending on the electro-motive force provided by a battery or generator. Special devices can be used to measure these quantities - flow and pressure meters - the main difference being that water meters are usually mechanical whereas electricity meters are themselves electrical devices.

The metaphor can be carried further. If a pipe breaks then the water no longer reaches the point where it is to be used; a broken wire will stop electricity from reaching the appliance plugged into the socket. So, in both cases, a complete circuit is required for useful work to be done.

Taps are used to control the flow of water, reducing the flow and pressure by an amount to suit the work to be done.

Electric switches are a little bit different in that they are either on or off: they can stop or allow the flow but not change its rate. Perhaps a better comparison to the water tap is the type of dimmer control often used on lights, where the brightness can be adjusted from off to full on, or any point in between. However, the basic idea of control of the rate of flow still holds.

When water meets a division in the pipes, the flow divides up in a proportion which depends on the nature of the pipes. More water flows down a bigger diameter pipe than a small one, since there is less restriction and resistance. Similarly, electric current flow divides at a wiring junction, and the amount of current in each branch is inversely proportional to the opposition, or resistance, in that branch. Thicker wires can carry higher currents because their resistance is lower. Lower resistance means less loss of energy in overcoming it, and hence less heating effect.

Metaphors, such as taps and running water, thus provide a step from what may be taken as common knowledge for most people (at least in places where there are taps and running water) and used to introduce the new concepts associated with electricity.

Whilst the metaphor works to this extent, if taken further the correspondence begins to break down. Water can be seen flowing in a pipe made of a transparent material; but electrons cannot be seen, they can be detected only by their effects. If a pipe breaks or is cut, water flows out of the end; but electricity does not flow from the end of a broken wire, it simply stops. I have already mentioned the dissimilarity between switches and taps. Perhaps the biggest difference, and potentially the most dangerous, is that, whereas water is vital for life and is fairly innocuous, electricity in the form of high voltages is dangerous and can kill. Students who are accustomed to handling water without much thought or care, might suddenly find themselves badly injured, if not worse, if they take the same attitude to electricity.

Radio signals radiated from an antenna are said to propagate in waves, illustrated with the analogy of waves or ripples radiating from a stone dropped into a pool of water. The stone sets up a series of ripples which radiate from the impact point in all directions across the surface of the pool, are reflected by obstacles and the shore line, interacting, cancelling and reinforcing each other, until the energy of the impact has dissipated.

The high and low points of the wave in water correspond to the oscillations in the fields which form the radio signal. The amplitude of the wave is determined by the strength of the stimulus causing it, either the dropped stone or the radio frequency energy produced by the transmitter. The concepts of frequency - the number of cycles or waves in a given period - and wavelength - the distance between successive peaks or troughs in the wave - are thus amply illustrated by watching the ripples in the surface of the pond, and the use of simple measuring equipment, either in reality or the imagination.

Ripples in water may also have other sources, such as wind, or stones dropped by someone else. The ripples produced by those other sources might interfere with the ripples produced by the dropped stone in the above experiment. Similarly, there are other sources of radio waves that can interfere and interact with our wanted radio signals. These other signals might be naturally occurring - produced by stars or thunderstorms - or be radiated from faulty or badly shielded electrical equipment, or even other people's transmitters.

At this level the metaphor provides a useful visual analogy with the theory. However, if analysed in greater detail, it again has the potential for producing misconceptions.

Unlike ripples in a pond, radio signals do not show themselves by physical changes in location or relationship; rather they are alternations in magnetic and electrical fields propagated through an undetectable medium called the ether. Although the changes in these fields can be detected, they cannot be seen by the naked eye. The 'ripples' in radio waves are actually the changes as energy is rapidly transformed backwards and forwards between the two types of field.

The idea of a web is sometimes used to introduce the idea of the way in which different stations - such as radio stations or computers - are connected together for the purpose of communicating with each other. The image portrayed is that of a radiating network of interconnections through which data pass between a number of users.

A little thought will show that this metaphor is even more misleading than those discussed above. Even at a superficial level its relationship to the theory is tenuous.

In a spider's web, information on the presence of prey is only transmitted from the periphery to the centre - the spider makes every effort not to signal back until the prey is irretrievably trapped; communications networks invariably move data both ways. A spider's web has only one centre, and has no connection to the webs of other spiders; communications networks often have a number of control centres or nodes, which are connected to each other, each with its own group forming a local network. Also, many spiders completely dismantle their webs for part of the day or night, and rebuild them, perhaps in a different location, as needed. No doubt the differences could be multiplied further, but I have described enough to make the point.

In the next chapter I discuss a test conducted by Gentner and Gentner, who used a moving crowd as a metaphor for electricity (Gentner and Gentner 1983). They suggest that this model is the one most commonly used, after the water-flow model. In it, electricity flowing in a wire is said to be analogous to a crowd of objects moving along a passageway. The number of objects passing a particular point, the pressure on them, and constrictions in the passageway correspond, respectively, to electrical current, voltage and resistance (Gentner and Gentner 1983:111). Since I, nor anyone to whom I spoke, had ever heard of this metaphor, I am unable to discuss it in any detail or comment on its effectiveness.

It would seem that the disadvantages discussed above might show themselves mostly amongst those learners who have more interest in the subject and more enquiring minds. Curiously, this would mean that those people who are most likely to be the best pupils are also those most likely to have trouble using metaphors. However, in actual practice the problem appears not to arise. It is usually not necessary for the teacher to point out those situations where the metaphor does, or does not, apply; the students seem to somehow know those limits without being told.

The rest of this dissertation is an account of my attempt to find an answer to the above dilemma. To do this, I had to find out how people feel about metaphors and their advantages or disadvantages as teaching aids. I begin by seeking an answer in the work of others, to see what they have said or thought on the topic. The next chapter is thus a review of the relevant literature.

MEANING, METAPHORS AND MENTAL MODELS IN SCIENCE AND TECHNOLOGY

In *Language For Teaching* (1966), Diack argues that words, in themselves, have no meaning. He stresses that "*...words do not carry meanings from one mind to another*." (Diack 1966:98. Italics in original). According to this argument, we can only attach meaning to any words we hear because the words stimulate memories and associations which are already present in our minds. What a word actually means to a person depends on what that person associates with the word. An individual's own experiences form the meaning, not what meaning anyone else applies to the word. Thus, Diack makes the point, we do not actually talk about 'things', we talk about our experience of 'things'.

It also follows that a word may, and probably does, have subtly different meanings for different people. Those differences might be slight, but they might also be large and have great consequences. An important point is that just how much difference there is in meaning is difficult, if not impossible, to determine, since we all have different experiences -- either great or small -- which we bring to bear on the meanings that we allocate to words, and the words themselves are the only way in which we can try to convey meaning to another person.

The differences in meaning that we attach to words are nowhere more important than when we try to introduce a person to a new area of knowledge. Since the person does not have any experiences in that area, he or she has nothing on which to build meaning. Many people, from Aristotle to modern day thinkers have argued that a new area of knowledge can only be learnt by building it onto a basis formed of knowledge in another area. The knowledge in that other area, however, must provide parallels which can promote understanding in the new domain. The old knowledge is often presented in a metaphorical form which will cast light on the new knowledge. The argument is that without the metaphor, there is no base on which the new knowledge can be built, and without that base, the words of explanation cannot be understood.

Metaphors, then, allow the experiences and understanding in one domain of knowledge to be used to give meaning to words encountered in another domain. "[M]etaphor [is] a way of seeing something in terms of something else and, thereby, extending our range of meaning" (Valle and von Eckartsberg 1989: xx).

Martin and Harre pose the questions: "How do metaphors work?" and "Why are metaphors necessary?" (1982: 89). The first question, they say, may never be answered, and it is, anyway, a problem for the psychologists. Their discussion of the second question is more useful and worth some consideration. However, Martin and Harre propose that each of the two questions may, in fact, provide insights into the other.

There are two main ways of explaining how metaphors work: the 'substitution' and the 'Gestalt' theories.

In the substitution theory, metaphors are just another way of saying something which could have been said just as easily in a literal way. According to Martin and Harre, this "reduces metaphor to the status of a riddle or word game, and the appreciation of metaphor to the unravelling of that riddle" (Martin and Harre 1982: 90). In other words, the substitution theory trivialises metaphor to little more than playing with words, and discounts much of its usefulness. Martin and Harre point out that this theory ignores the possibility of using metaphors to show correspondences in domains which have not previously been considered as being similar to each other.

Importantly, as they also point out, this would preclude much scientific use of metaphors in explaining new theories, which go beyond the bounds of current knowledge. If metaphors must have a literal reality, then they cannot deal with matters which are beyond present experience or knowledge (Martin and Harre 1982: 90).

A modified form of the substitution theory says that metaphors are only a form of comparison, between domains.

Although somewhat better, this explanation does not fit all uses of metaphors, particularly where they are used as teaching aids.

Gestalt theory disagrees with substitution theory mainly by saying that metaphors are not literal, but that they express ideas which cannot be said in literal, or indeed any other, terms. According to this explanation, metaphors provide a "new and unique agent of meaning" (Martin and Harre 1982: 90). Martin and Harre suggest that the correct answer is probably some combination of these two. They propose, as a definition, that:

> Metaphor is a figure of speech in which one entity or state of affairs is spoken of in terms which are seen as appropriate to another (Martin and Harre 1982: 96).

It is important that the function and nature of metaphor be established, according to Martin and Harre, so that an explanation may be sought for its success or failure, particularly in presenting new knowledge, as is its main function in science. Scientists have the need to explain things which ordinary people, and sometimes themselves, cannot experience directly, and in a way which can be referred to previous experience. The only way in which this can be accomplished is by referring to other things which can be experienced; that is, by using metaphors. As well, new terms can thus be introduced for concepts which were previously unnamed and even unknown to previous experience. Martin and Harre ask: "...under what [other] conditions such terms can be introduced into a language *so that they may be intelligible*" (1982: 96. Emphasis in original). The answer is that the term must be used in a way such that its new meaning can be deduced by the hearer, based upon past experience which has no connection with the new domain. Only a metaphor will satisfactorily fulfil that role (Martin and Harre 1982: 96-7).

Martin and Harre argue for a difference between a 'model' and a 'metaphor'. Whereas a metaphor "is a figure of speech; a model is a non-linguistic analogue" (1982: 100). According to this argument, when using the concept of water in pipes as an aid to thinking about the way electricity acts in wires, the water is acting as a model, that is, it becomes a representation, seen in a relationship to some other object or relationship. But when one uses terms such as 'rate of flow' or 'electric current', one is constructing a metaphor based on the idea of fluid flow, and applying it to a new domain.

Whilst some writers support the view of Martin and Harre regarding the demarcation, others are not so particular about the difference between models and metaphors. Kittay sees the models used in science as "extended metaphors". However, she agrees with the importance of metaphors in scientific theory development, noting that "it is within a carefully conceived 'chaos' that metaphors attain an irreducible cognitive content and their special meaning" (Kittay 1989: 327). Gentner uses the cover-all term 'analogy' to include metaphors, models and similes (1982: 108).

As Martin and Harre further point out, 'rate of flow' and similar terms do not have strictly the same meaning when applied to water and electricity. These metaphorical terms assume new meanings when applied to the new domain of electrical theory, without implying a necessarily exact correspondence between the old and new uses of the terms (Martin and Harre 1982: 100).

Thus metaphors can provide new terms where none have previously existed, a process called 'catachresis'. This, according to Martin and Harre, is why the metaphor is so important in the explication of new scientific theories; as well as providing insights and explanations, it can provide new terminology for a newly developed field (Martin and Harre 1982: 101). The terms adopted in generating new scientific ideas, however, have a more important role to play than expressing the current state-of-play. They, and the images they portray can form the basis for new theoretical insights. These 'theory-constitutive metaphors' are then the basis for further progress and theory development in the field (Boyd 1993: 371).

As well, the metaphors that scientists choose to illustrate their theories can tell us a lot about the scientists, themselves. In discussing our propensity for making comparisons Beare, Caldwell and Millikan, make an important point, when they say that:

> It is [by making comparisons that] we make sense of our world, by comparing one thing with another, by classifying and linking qualities. Our values are most powerfully revealed by means of the comparisons we make (Beare, *et al*, 1989: 188).

When metaphors are used in science they are part of a way of thinking, they function as structure maps between two very different, complex systems. Often the target system is new and abstract: the base system is something which is already known and understood. The intention is that the relationships within the base domain or system can be applied to, and help understanding of and visualisation in, the target domain. By mapping the target domain on to the base domain, new insights will be obtained and developed.

Gentner notes that it is the relationships of the base domain which are carried over into the target domain. Attributes of particular objects are only carried over if they --either the objects or the attributes -- are sufficiently representative to contribute to understanding. Gentner thus argues that metaphors can not be understood, nor analysed, as simple comparisons between objects (1982: 109).

Gentner also discusses the factors which contribute to a good scientific analogy. If the metaphor is to be seen as a system of structural-mapping between the relationships in the base and target domains, then it is important to decide which relationships are crucial to the analogy. In other words, the structure of the metaphor itself is important (Gentner 1982: 113).

Reasoning must be based on a firm foundation if it is to have any validity, so the nature of the base domain is worthy of first consideration. It must be specifically chosen to represent the desired relationships. It must also be well enough understood that the relationships are clearly visible. A domain which is poorly understood will not illustrate the required relationships clearly, because the lack of knowledge will impede the usefulness of the metaphor. The base domain should be one which is understood clearly, and without conscious effort: in other words, it should be familiar (Gentner 1982: 113). However, familiarity itself is insufficient; there must be understanding, as well. If the rules of the base domain are not well understood, then the student will not be sufficiently informed of the way in which mapping between the domains is to be accomplished. A badly chosen base domain will not only not work in a metaphor, it may actually impede learning and understanding.

A second important consideration is the clarity of the metaphor in suggesting the degree of mapping between the domains. This defines not only what relationships are to be carried over, but how the mapping is to be applied to the target domain (Gentner 1982: 114).

If the way in which mapping is to occur is unclear, then the metaphor itself will be unclear. For instance, as Gentner (1982: 114) points out, mapping either one relationship in the base domain onto two or more in the target domain, or mapping two or more in the base domain onto one in the target domain will cause confusion, to say the least. The student will not be sure which attribute to use at a particular time, without further information to guide his or her choice.

Gentner explains a number of other characteristics, with the aid of diagrams illustrated with nodes and connecting lines. These go beyond the need to be discussed, here, being mainly of interest to psychologists and logicians. However, all are factors in the validity of the metaphor or analogy. A metaphorical comparison must be valid, else it will be misleading. The relationships and attributes imported from the base domain to the target domain must be appropriate, for the metaphor to work and produce understanding.

If, then, there are good and bad metaphors and analogies, what are the important differences? Gentner quotes from Paracelsus' writings on alchemy, where he attempts to map the solar system on to the chemical elements used in some alchemical process. Not only is the meaning of some of the terms unclear (although they probably would have been to Paracelsus' peers), but the mapping between the domains is presented as a mystery to be unravelled. In other words, the reader must have the knowledge which the metaphor is supposed to transfer, before the metaphor is, itself, of any use in understanding the new domain. One enters a circle of mis- or non-understanding. But then, alchemy, in Paracelsus' day, was seen as esoteric knowledge which should only be available to the initiated, and kept from outsiders. Metaphors, then, should not have an air of mystery if they are to have a wide application.

The example from Paracelsus is also unsystematic (Gentner 1982: 125-6). The base system does not form a coherent whole which can be mapped to the target domain. Some of Paracelus' comparisons do not work, because he mixes his base domains, and, at times, it is not clear which domain to use. The metaphors and analogies are therefore useless in understanding the physical processes described.

In Paracelsus' case, lack of clarity was probably deliberate. Gentner also shows that lack of clarity in the use of metaphors was not only an attribute of medieval writings, but also plagues some more modern ones (Gentner 1982: 126).

Gentner eventually concludes that the question of whether or not scientific analogies are metaphors can only have an equivocal answer (Gentner 1982: 128-9). However, there is little doubt as to their usefulness and effectiveness, if used properly.

Gentner and Gentner (1983) discuss the question of whether, when discussing complex phenomena in terms of analogy, we actually think in the form of analogies or simply borrow the words and terms of the analogical domain and apply them to a second domain, because it is convenient to do so. They consider the question in a realm which particularly applies to the questions addressed in this dissertation: electricity. Gentner and Gentner (1983) suggest that if it is to be accepted that this form of analogical reasoning is used as part of the thinking about, and understanding of, science and technology, then it must be shown that analogies have a definite effect on the way in which conceptions about the domain are formed.

Gentner and Gentner (1983: 99) note two lines of evidence which support the validity of this proposition: that analogies are used in teaching science and that scientists report using analogical and metaphorical reasoning in the development of theories. They also, correctly, warn that people are not always able to clearly understand their own mental processes, and so such anecdotal evidence must be used with caution (Gentner and Gentner 1983: 100).

Firstly, Gentner and Gentner argue that analogies and metaphors represent some aspects of what is already known on a particular topic, and have structural characteristics which can then be applied to a new domain (Gentner and Gentner 1983: 101). That a particular analogy is used does not imply that all that is known about that subject should be applied to the new area. Rather the successful use of the analogy or metaphor relies on the selection of which characteristics should be heeded. The domain from which the metaphorical comparison is taken has some overlap with the characteristics of new subject domain -- these might be motion, relative positions, or similar -- but the two domains are unlikely to be identical. However, the overlap should be sufficient to enable the student to easily see the connection. "The analogical models used in science can be characterized", according to Gentner and Gentner, "as structure-mappings between complex systems. Such an analogy conveys that like relational systems hold within two different domains" (1983: 102). Thus, this structure-mapping suggests that the relationships, and manipulations of those relationships, which can occur in the 'known' or 'base' domain (what is already known) can also be expected to obtain in the new or 'target' domain (where learning is to take place).

As I have discussed in a previous chapter, in relation to the use of metaphors in electronics, just how well the two domains correspond, and how well the student understands that correspondence, or lack of it, might have a considerable impact on the effectiveness of the learning process. As well, the level of knowledge of the student about the base domain would have to be considered, although it is often taken for granted that the student not only understands the base domain, but also how the metaphorical image is to be used.

Gentner and Gentner use the analogies and metaphors used in explaining electricity, they say, because "It is a familiar phenomenon; everyone in our society knows at least a little about it" (1983: 107). To my mind, that familiarity may itself distort the findings, in that it is difficult to know how much the student learnt from the metaphor, and how much was previously known; as well there is the problem that some of the 'common knowledge' is, in fact, distorted or simplified to the point where it can actually disrupt the learning process, by requiring the student to 'unlearn' some erroneous concepts before learning the correct ones. It follows, also, from the Gentners' statement, that the knowledge is culturally specific, and would almost certainly cause problems where teacher and student differ in cultural or ethnic background. I discuss some of these points further in other chapters, and Sticht (1993) briefly mentions a number of associated problems.

Gentner and Gentner use two different metaphors for electricity to test their theories: water and crowds of people. The water metaphor I have discussed above when describing some of the metaphors used in electronics. However, the crowd metaphor is one that, in many years association with electronics, I have never before seen or heard. Although it is possible that that metaphor is peculiar to the geographical area in which the Gentners work, I do not think it can be a common one. Such ideas tend to spread quickly, through magazines and journals, and the fact that neither I nor any one I spoke to had heard of it, tends to suggest that it is of limited distribution. On the other hand, if Gentner and Gentner can show that it is a useful metaphor for teaching electronic theory, then a case could be made for its wider dissemination. However, the important consideration, for my purposes, is its application in testing the effectiveness of metaphorical explanations. Further, as Gentner and Gentner point out, no analogy or metaphor can provide a complete correspondence for all features of the target domain, therefore a comparison of effectiveness can be realised by testing two or more metaphors as explanatory aids (Gentner and Gentner 1983:107).

In the water analogy, mapping is from the base domain of plumbing to the target domain of electrical wiring. Amongst other objects, a water pipe, a pump, and water flow are mapped onto a wire, a battery, and electric current, respectively.

Obviously, the metaphor is not meant to convey wetness, transparency, nor coldness (Gentner and Gentner 1983: 108), since electricity has none of those characteristics. Instead it is invisible and can deliver shocks. I have discussed some of these dissimilarities elsewhere.

When compared to a moving crowd, the image of flowing electricity is illustrated by a number of objects moving through passageways, which have restrictions, doorways and branches. Electrical current, resistors, and voltage relate to the number of objects, restrictions in the passageways, and pressure on the objects, respectively. Gentner and Gentner claim that the 'moving crowd' metaphor provides a superior understanding of electrical resistance, but does not provide a suitable analogy for a battery (1983: 111).

In their first test, Gentner and Gentner used subjects who already had a mental model of electricity either as an analogy of water or of a moving crowd. The subjects were asked to solve simple problems involving electrical circuits, and then questioned about the mental model that they had applied to the problems. Their results showed that:

> As predicted [by Gentner and Gentner], people who used the flowing-fluid model performed better on batteries than on resistors. The reverse is true for the moving-crowd people: they performed better with resistors, particularly in parallel, than with batteries (Gentner and Gentner 1983: 117).

These results suggest that people who use different mental models think differently about the problems presented to them. Gentner and Gentner claim that these differences are not simply associations between terms, such as 'flow', which are common to both domains, although having slightly different connotations in meaning (1983: 118). The results, they argue, are due to the structural relationships that the person sees between the base and target domains, and uses in inferring the properties of the target domain (Gentner and Gentner 1983: 119).

In their second test, Gentner and Gentner used the two different metaphors in teaching their subjects about electricity. The subjects were then tested on their problem solving ability and the results compared. Test questions were devised, some of which would be wrongly answered if a particular model was used in its solution, and which would therefore test whether or not the subject was actually using the analogy which he or she had been taught. Thus the method of inference could be discerned independently of the statements of the test subjects.

The results obtained supported the results of the previous test, by showing the relative superiority of a particular metaphor as an aid in solving particular problems.

However, some of the differences in responses were shown to be due to insufficient understanding of the base domain. Gentner and Gentner found by further questioning that many of the subjects did not have a clear understanding of, for instance, the way in which water behaves in pipes (1983: 124). That lack of clear understanding caused problems when inferring relationships in the target domain. They note that:

> Even a fully generative, rigorous structure-mapping process cannot produce correct distinctions in the target domain unless subjects have grasped these differentiations in the base domain. Our investigations bring home the point that an analogy is only useful to the extent that the desired relational structure is present in the person's representation of the base domain (Gentner and Gentner 1983: 124).

Gentner and Gentner cite a number of sources which show that people's mental models of even common phenomena are often inaccurate. These inaccuracies are then carried over into other areas when metaphorical reasoning is used to help understanding, leading to a misunderstanding or misapprehension of the new domain (Gentner and Gentner 1983: 126). Also, previously held ideas relating to either the base or target domains, may interfere with the appreciation or effectiveness of a metaphorical or analogical illustration (Gentner and Gentner 1983: 127).

Thus, to achieve the aim of conveying meaning, metaphors must be selected or constructed on the basis of their suitability, on the relationships which need to be conveyed from the base domain to the target domain, and on their validity. Also, the problems discussed above need to be avoided. Some of these problems relate to, and support, my conjectures in a previous chapter, particularly where limitations in the mapping between domains becomes apparent.

Short term effectiveness of metaphors in teaching scientific theory have been tested by Gentner and Gentner, amongst others. These show a positive result. However, the long-term effects appear to have not been investigated, nor the way in which people feel about using metaphors. In the next chapter, I recount the results of my fieldwork in investigating these two areas.

THE INVESTIGATION

In gathering the ethnographic data presented in this chapter, I spoke to a number of people. The discussions were in the form of unstructured, informal, interviews, rather than questionnaires. My interest was in the person's subjective appreciation of metaphors, rather than any statistical data: That has already been sufficiently gathered by others. Thus, I sought the subjects' subjective responses to metaphors -- how they felt about metaphors and whether or not they saw them as useful -- rather than a figurative measure of that response.

My subjects fell, generally, into two groups, with whom I dealt somewhat differently, as I discuss below. The purpose, then, of this chapter is to discuss the approach I used in my fieldwork, and the results of that fieldwork.

The first group comprised people who have acquired by various means a good knowledge of electrical theory. In discussing the results of these interviews, below, I divide the subjects into four categories, with each person falling into one or more category. I formed these categories on the basis of whether each person had taught as well as learnt electronics (obviously all teachers of electronics must have learnt the theory, but not all learners become teachers), and on whether the learning (or teaching) took place in a formal or informal environment. This largely meant the difference between professional and hobbyist, but I use the former terms to avoid any unwarranted connotations which might be associated with the latter terms. It is important to note that 'informal' does not necessarily infer a lower standard; for instance, an applicant for an amateur (ham) radio licence must demonstrate a level of theoretical knowledge which is at least equal to that of a professional electronics tradesperson. 'Informal' teaching and learning will often occur in clubs which cater for electronic or computer hobbyists, or in an individual's home; also, many hobbyists are self-taught. 'Formal' learning and teaching is that found in training establishments such as TAFE Colleges, and is aimed at providing professional qualifications.

In general, and wherever possible, I spoke to the people separately, although sometimes it was necessary to talk to a group. Since they already knew electronics, I asked them whether the 'water-in-the-pipe' metaphor was used in explaining the theory to them, and if so, whether it helped them understand the electrical theory. I also asked whether or not they experienced any problems relating the theory to the metaphor. In addition, I asked those who had done some teaching whether they found the metaphor useful as a teaching aid or found any problems.

As well as the data obtained from the interviews, I draw on my own experiences; learning (formal), teaching (informal), and working in electronics over a number of years, both as a hobbyist and as a professional. Although I do not remember explicitly whether or not I encountered metaphors in my training in electronics, I do remember where I first learnt basic electrical theory: it was in high school physics. Since the text book for that course (Smith and Smith 1961) uses metaphors, I can accept it as a foregone conclusion that I did, in fact, initially encounter the metaphors used in electrical theory in that course.

A first it caused me concern that I had forgotten that encounter with the metaphors, until I found, as described below, that I was not alone in doing so, and that, in fact, it is a common phenomenon. It appears that few, if any, people explicitly remember whether or not metaphors were used in teaching them electrical theory.

To simplify data gathering, and to avoid confusing my informants with a too-wide range of questions, I restricted my interviews to the topic of the water-in-a-pipe metaphor which is widely used in teaching electrical and electronic theory. Even so, there were a number of problems, largely because the people I spoke to seemed to be unconcerned about their own learning experiences. To some extent I anticipated that, at first, there would be little interest in metaphors, but hoped that my questions would provoke some interest and stimulate discussion.

This anticipation was partly based on my own response to the subject of metaphors in the teaching of scientific and technological theory when I began thinking about them for this book. I was surprised to realize that I did not have any definite ideas about my own learning of theory in electronics. I was, however, able to remember when and where I first encountered the metaphors used in electrical theory. The encounter occurred during my last year at high school, in the textbook for physics (Smith and Smith 1961). Whether or not the metaphor helped me understand or encouraged my interest is now unknown to me, although I did take up electronics as a profession.

Once I started thinking about the problems associated with metaphors and learning in science and technology my interest developed. I hoped that there would be a similar reaction when I introduced the problem to my subjects in my search for answers. As it turned out, the responses of some people were equivocal. However, I was able to gather sufficient information for some useful inferences to be drawn.

It is relevant, here, to make two points. Firstly, everyone I spoke to was aware of the water-in-a-pipe metaphor and most had used it at some time or other. It is so common that I doubt that anyone could be found in electronics or radio who has not heard of it. My interest, however, is with those people who had heard the metaphor whilst learning electronics, rather than later.

Secondly, anyone discussing electrical or electronic matters implicitly refers to water as a metaphor for electricity when they refer to the 'flow' of electricity or to radio 'waves'. This implicit recognition of the metaphor is not relevant to my discussion of the metaphor in teaching electrical theory. The references are part of the language of electricity - it would be impossible to discuss electricity without those words - regardless of the way in which one learnt the theory.

One of the first things that struck me when I began talking to people about their experiences with metaphors when learning electronics was that no-one seemed to remember definitely whether or not the water-in-a-pipe metaphor had influenced their learning. Indeed, most could not even remember whether or not it had been used as a learning aid whilst they were learning. It seemed reasonable to me that most, if not all, of these people had actually come into contact with the water-in-a-pipe metaphor during their learning period, given the its commonness in books and teaching. Indeed, I could be absolutely sure about some of them, since I had taught them myself.

Probing into the responses, I came to the conclusion that this was not a deliberate forgetting: there was no resentment of my probing as there might have been if the memory had been consciously rejected for some traumatic reason. Rather there seemed a degree of puzzlement over my interest in the topic. It appeared that most of my informants had never really thought about the matter. In some ways this made it difficult to gather data, since I had to prompt their thinking in the direction I wanted without distorting their responses by giving them information they did not already possess or by telling them what answers would best suit my ideas.

Why my informants had forgotten about the use of the water-in-a-pipe metaphor is itself an interesting problem. As I indicated above, this seems not to have been deliberate. Although it was difficult to be sure, it seems that most people forget the use of the metaphor as soon as its usefulness is over. For instance, if the water-in-a-pipe metaphor is used to illustrate current flow in a wire, then as soon as the teacher develops the theory further the metaphor is put aside. How each person knows when to put it aside was impossible for me to establish, since that is outside my field of competence: it appears to be a problem for the psychologists. The only clue I have which might be relevant is that this putting aside may in some way be related to the teacher's reference to the metaphor itself. The metaphorical comparison seems only to be applied when the teacher specifically mentions it, otherwise the relationship is ignored. This would help to explain the fact that few people seem to find the inconsistencies in the metaphoric illustration confusing; the inconsistencies occur in areas where the teacher does not mention the metaphor.

When I came to talk to people who had had some experience teaching electronics theory, the responses I received produced altogether more useful information. Here there was no difficulty finding who used, or did not use, the water-in-a-pipe metaphor. All the people to whom I spoke could tell me whether or not they used it, and whether they found it useful. One person, who used the metaphor at some times but not at others, was able to tell me the way he decided whether or not to use it. All my informants had clear ideas and memories of their usage of the metaphor in their teaching. However, again there was little interest in the functioning of metaphorical reasoning nor the theory behind the use of metaphors. This was disappointing, but perhaps only reflects the fairly narrow interests of my informants.

I found that there were basically two different ways of teaching electrical theory used by my informants, and a single case which falls somewhere in the middle.

The first method has little relevance to my thesis, since it does not involve the use of the water-in-a-pipe metaphor. Some teachers simply teach their students the physical theory about electricity, -- atoms, electrons, and so on. This approach must assume that the learner has some background knowledge. It is possible that some of these students find mention of the metaphor elsewhere, and thus that it helps them understand the theory, unknown to the teacher.

Teachers using the second method use the metaphor at relevant places in the theory, as part of their explanations. The implicit assumption here is that the student has no pre-knowledge of electronics theory, and must have it presented in a fashion suited to that situation. One of the problems with this method is that time might be wasted recapitulating knowledge which the student already has.

The single case of the teacher whose use of the metaphor is dependent on the response of his students is similar to my own experience. Both of us use the approach of telling the students about electrons and electricity, firstly without the metaphor. If anyone does not understand, then the metaphor is used to clear away any difficulties. My informant and I both feel that this method allows the students themselves to dictate the method of delivery, and hence time is not wasted on unnecessary explanations. My informant also supported my own findings, that most students understand the electronics without the metaphor. Those students who do not understand at first are usually helped by the metaphor and almost invariably understand the electronics theory after the metaphor is used. Neither of us has ever found a student who is confused by the metaphor, neither amongst those who understand the theory without it nor amongst those who needed the metaphorical explanation. Anyone who, at this stage, is still confused about electronics is usually neither helped nor hindered by the metaphor.

A particularly important point is that between us, this informant and I were able to establish that at least five of the people in the larger group did benefit from the use of the metaphor. We were able to establish this fact because one or other of us had taught them electrical theory, as part of their studies for an amateur (ham) radio license. However, although we could establish this fact to our own satisfaction, none of our students could themselves remember that they had benefited from the use of the metaphoric parallel. Thus, we could say that this smaller group had heard of the metaphor, it had helped them, but that they had forgotten both facts.

To proceed further, then, in trying to establish whether or not people perceive any advantage in the use of metaphors, it was necessary to eliminate the delay between the learning and the questioning. To do this, I arranged to present the metaphors used in electronics with the basic theory which they are meant to clarify, to another group of people.

The second group I interviewed were people who have no interest in formally learning electronics. They all have, to some extent, a basic knowledge of electrical fundamentals - I was unable, in the time available, to find anyone who had absolutely no electrical knowledge. It appears that in an industrial society, electricity is something that most people learn something about as a simple part of living in the society (See, for instance, Gentner and Gentner 1983: 107, who found a similar situation). I selected these subjects particularly for their lack of formal education in electronics, to provide a reference level against which to relate the other group.

Of these people, three have little or no interest in science and technology, one other has a very good general knowledge of physics, mainly obtained by reading widely. Two were female, and two male: two have had a tertiary education, two barely completed high school: none of the three has received any formal higher education in any field of science or technology. Unfortunately, again due to time restraints, I was unable to deal with a larger group.

I spoke to each person in the group separately, and at different times. To reduce the risk of influencing the subjects, either by presenting different data or presenting the same data differently, I used photocopies of three pages taken from a basic book of electrical theory (Phillips 1993: 4,6,13.). Each subject was given the photocopies and allowed as much time as she or he required to read and digest the material. I made no effort to help by providing any further information or explanations.

My first questions served to establish that all the subjects had understood the electrical theory: I found that all had done so to a reasonable extent, although there is a possible exception, as I discuss below. I then asked whether or not the metaphor had helped in that understanding and discussed any subjective responses the subject either made or brought up for discussion. Again, I deliberately allowed the subject to direct the discussion as far as possible, to avoid influencing the responses. Only when the subject paused did I prompt for more information.

One person said that the metaphor did not help in understanding the theory, and two said that it did. The remaining one responded that the metaphor actually caused her more confusion than if it had not been present. This response caused me some concern, because it was a reaction that I had never seen before. I was unable to decide exactly why it should have happened, although the responses to further questions suggested that it was the topic and the way in which it was presented, rather than the use of the metaphor, which caused the problem. I found that she had a somewhat negative attitude to science and technology in general, which seemed associated with her political views.

These responses seemed to me to be unrelated to any of the gender/education categories of the people to whom I spoke. However, the group was too small to be statistically significant so

I shall refrain from drawing any conclusions on that basis. My interest is more with their subjective responses.

Obviously, since I spoke to the people immediately after they had read the provided material, all of them remembered that metaphors had been used. Their evaluation of the effectiveness of the metaphors has already been mentioned. That the metaphors had made an important impression was also obvious, since all, at one time or another in the discussion, referred to the metaphorical image. This was not simply the use of words such as 'flow', which are part of the jargon of electronics and were used in the material which they had just read. In demonstrating to me their grasp of the concepts of electrical theory, all made some passing reference to the water analogy.

This suggests that the metaphor had had a suitably strong impact on the subjects, whether or not the particular person perceived any advantage in its use. I also gained an impression, although I could not confirm it, that, even when the subject claimed that the metaphor had not helped in understanding the material, in actual fact it had helped, to some slight extent, perhaps unconsciously.

These results suggest some tentative conclusions. The metaphors used in teaching electronics do make an impression on students. The impact is sufficiently strong that they notice the effect and form an impression of the effectiveness of the metaphor in illustrating the important concepts in the target domain. However, the recollection of the use of the metaphor fades after a time, and the student cannot remember whether or not it was used. This is rather curious; it appears that both types of memory -- of the use or the none-use of the metaphor -- are equally volatile, and both disappear. Apparently, neither event makes a suitably strong, long-lasting impression, which would cause memory of it to be retained.

One possible explanation for the fading of the memory might be that it protects the student from the effects of any inconsistencies in the metaphor between the base and target domains. In a previous chapter, I discussed some of these inconsistencies and the problems they might cause. When the student proceeds to more advanced concepts, such inconsistencies are more likely to be noticed and also more likely to cause confusion. Thus there would be an advantage in forgetting the metaphor and its associations in the base domain.

Further, if this explanation is correct, then there is the problem of deciding the point at which the metaphorical image is jettisoned from memory. The simplest explanation is that that point occurs when the gain from using the metaphor as an aid to thinking or understanding reaches zero or become negative. That is, when the metaphor becomes useless, or worse, starts causing confusion, it fades from memory, perhaps from lack of use. By that time the student should have sufficient understanding of the topic to no longer need the use of the metaphor, anyway. People who have spent some time using the concepts and objects of electronics rarely use metaphors in their speech about it, except, perhaps, when explaining something to someone who might not understand the concept, due to unfamiliarity. That the memory fades appears not to be a problem: most people seem not to even notice, and appear surprised when it is drawn to their attention.

Most of the literature, as previously discussed, relates to the immediate effects of metaphors. Testing is usually done immediately the metaphor and the concepts to be learnt are presented. The results of the tests are also usually presented as statistics. I have looked more at the way people perceive metaphors as an aid to learning, and their long term responses to metaphors. I can give no statistics since I investigated the subjective rather than the objective responses.

CONCLUSION

The literature discussed above points to the importance of metaphors in learning about science and technology, and in visualising scientific concepts in the formulation of new theories. It also shows that the particular metaphor used as an illustration influences the way a person thinks about any problems encountered. A badly constructed or inappropriate metaphor can cause problems in future learning in the same area. Problems with the cultural specificity of metaphors was also mentioned.

These problems have hitherto been investigated as short-term phenomenon. When I attempted to find long-term data on them, I ran into the problem that students rarely remember whether or not metaphors were used in their early instruction. The elapsed period for those to whom I spoke ranged from months to years, but seemed to make little difference. Even when I was able to establish, through independent sources, that metaphors were used, the student professed to not being sure. Further, most seemed to be not concerned about, even dismissive of my interest in, the role of metaphors when they learnt their basic theory.

Thus, whilst learning, most students have a positive attitude to metaphors, even when they claim that metaphors did not help their understanding. However, this attitude soon appears to change to indifference.

I can suggest that this change of attitude might result from the shortcomings of metaphors. The literature shows that a metaphor is, usually, only useful up to the point at which the structure-mapping between domains begins to break down. Beyond that point it becomes a liability. In electrical theory, this point would soon be reached, as I discussed in the chapter on metaphors used in teaching the theory. At some point the discord would start to become a distraction. This point may be different for different students, but would, I believe, be reached sooner or later by everyone.

I suggest, then, (and, unfortunately, only as a conjecture) that people forget all about the use and nature of metaphor used to teach them electronics, perhaps as an unconscious process which removes the risk of confusion as knowledge outgrows the metaphor. With the metaphor deleted from memory, the student is free to go on learning, hopefully without confusion, and with an uncluttered mind.

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