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The nature and extent of analogies in secondary chemistry textbooks

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Abstract. This paper describes an analogy classification framework used with high school chemistry textbooks. The framework takes into account aspects of past research into analogies in science education to allow for a systematic classification of textbook analogies based upon nine criteria including chemistry content area. Many of the 93 analogies classified described abstract chemistry concepts such as atomic structure and bonding, however, the frequent use of simple analogies, and the scarcity of stated limitations, are likely to create learning problems for students. In some textbooks, authors made use of margin spaces to include more analogies and these marginalised analogies often contained a pictorial component. Recommendations for further research into analogies in science education and possible methodological approaches are suggested.

Introduction

In the last decade, much of the research that has been conducted in science education sought to address Shulman's missing paradigm of content knowledge (Shulman 1986). Further, examination of how teachers transform their content knowledge into pedagogical content knowledge has allowed for a careful analysis of effective teaching styles and strategies. Shulman proposed that the emphasis of research in education needed to change towards addressing questions about 'the content of the lessons taught, the questions asked, and the explanations offered . . . the sources of the analogies, metaphors, examples, demonstrations, and rephrasings' (p. 8). The use of analogies as an aid to instruction is proving to be one of many specific foci within the broader aspects of pedagogical content knowledge that are currently being addressed in educational research. A series of research studies related to the use of analogies in science education specifically, have been reported in this *Journal* (see, for example, Brown & Clement 1989; Curtis 1988; Curtis & Reigeluth 1984; Reigeluth 1983; Stepich & Newby 1988). This paper reports on a study that draws on the findings of some of these prior studies in an attempt to focus further research in this field.

Defining an analogy

There is a need to clarify what an analogy is so that it is not confused with

illustrations and examples. Glynn, Britton, Semrud-Clikeman & Muth (1989) provide a useful working definition:

> An analogy is a correspondence in some respects between concepts, principles, or formulas otherwise dissimilar. More precisely, it is a mapping between similar features of those concepts, principles, and formulas. (p. 383)

The analogy requires the selection of a 'student world' *analog* to assist in the explanation of the content specific *target* (or topic). The analog and target are subtly linked by the sharing of a concept that Glynn (1991) refers to as being 'superordinate'. The analog and target share *attributes* that allow for a relationship to be identified. A diagrammatic representation of the analogical relationship is shown in Figure 1.

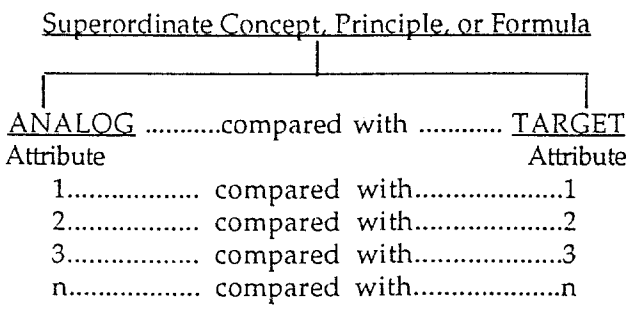

Figure 1. The analogical relationship between the analog and the target illustrating the sharing of attributes.
From *The Psychology of Learning Science* (p. 219) by S.M. Glynn, R.H. Yeany & B.K. Britton, eds., 1991, Hillsdale, NJ: Erlbaum. Copyright 1991 by Lawrence Erlbaum Associates. Adapted by permission.

One analogy that has been used in chemistry textbooks to help explain aspects of the region of influence of an electron is that of a rotating propeller (Lewis & Slade 1981: 1). In this analogy, the target concept is an understanding of the characteristics of an electron's region of influence. The analog is a description, or diagram, of a rapidly rotating plane propeller. There are several shared attributes that are readily compared. When the propeller is rapidly rotating, it is not possible to state exactly where the blade is at any given instant and yet, if a person was to attempt to insert a stick into the general area, they would find that the propeller's properties are applied throughout the whole region. Similarly, the electron, due to its rapid motion and wave-like properties, manifests its presence throughout a large orbital region without being specifically present at any exact location at any given instant. This comparison of shared attributes is known as *mapping*. It involves a deliberate categorisation of those attributes that are shared between the analog and the target. It is also true that there are attributes of both the rotating

propeller system and the area of electron influence that are not shared. For example, the propeller is fixed in its orbit of rotation, whereas the electron is mobile within a probabilistic three-dimensional orbital. It must be considered that the analog and the target will have many attributes that are not shared. Good mapping should also give indication as to where this occurs so that unshared attributes, or *limitations*, are not ascribed to the target domain.

Different types of analogies

The literature (for a useful review see Duit 1991) highlights a range of types of analogies which include verbal, pictorial, personal, bridging, and multiple analogies. Further, in a study that included an analysis of 52 analogies from four American chemistry textbooks, Curtis & Reigeluth (1984) proposed several other criteria by which analogies may be classified by their integral parts. In developing these criteria, Curtis & Reigeluth have given further credence to the viability of analogy use in science education. These criteria include an analysis of the nature of the shared attributes (structural or functional), the degree of explanation concerning the analog, as well as the level of enrichment of the analogy (the extent to which the author mapped the shared attributes). It is also evident that the final presentation by the classroom teacher will have a considerable influence upon the mode of operation of an analogy. Thus, if research is to discuss and recommend different types of analogies and settings, there is a need for more empirical research to be conducted in this area.

Description of an analogy classification framework

A useful starting place for this research agenda is a systematic analysis of the analogies presently used in textbooks. A suitable mechanism for classifying these analogies will allow for more meaningful research and communication of that research. Curtis & Reigeluth's study (1984), reported in this *Journal*, is exceptional in that regard. They devised a systematic classification system from first principles having identified and collated 216 analogies from 26 science textbooks. This classification was done by using the analogies to determine the criteria rather than by using instructional design qualities or the findings of research studies. Hence, the classification criteria may be limited for some analogies that do not fit well into the existing criteria or for studies outside of the area of science, although it was used successfully by Curtis (1988) for a science – social studies comparison at a later stage. Based on these original criteria, an extended classification system, referred to here as the Analogy Classification Framework, was prepared for this study. The Framework (as shown in Figure 2) comprises nine criteria, six of which (c through h) were initially presented by Curtis & Reigeluth (1984).

While the researchers involved in this present study adopted the general

a) the *content* of the target concept – what aspect of chemistry is being considered by the target concept;
b) the *location* of the analogy through the textbook – at what stage of the curriculum is the analogy being presented;
c) the *analogical relationship* between analog and target – whether the analog and target share structural or functional attributes;
d) the *presentational format* – whether the analog is verbal or pictorial-verbal;
e) the *condition* or level of abstraction of the analog and target concepts – whether they have an abstract or concrete cognitive level;
f) the *position* of the analog relevant to the target – whether it is before, during, or after the presentation of the target, or whether it is presented in the margin;
g) the *level of enrichment* – to what extent is the mapping between analog and target domains done by the author;
h) the *pre-topic orientation* – is there evidence of further *analog explanation* of the analog domain and/or have the authors included any *strategy identification* that will indicate that the text has an analogical nature;
i) the presence of any stated *limitations* or warning which highlights to the students where possible attribute mis-matches may occur.

Figure 2. The Analogy Classification Framework used to classify 93 analogies from ten chemistry textbooks.

principles and structure of Curtis & Reigeluth's classification system, several adaptations and clarifications were made to the criteria to allow for more analogies to be classified and to allow for aspects of research into analogy use to be more easily addressed. Several verbal analogies were identified for concepts that were also supported by a pictorial *target* representation. In other instances, a picture clearly supported the *analog*. To avoid confusion, it was decided that an analogy would be recorded as pictorial-verbal only if the picture represented the analog domain, not the target domain. Secondly, while a stated limitation was still considered to be an example of enrichment, another classification criterion was added to the framework to specifically record evidence of either a general statement warning of the problems of analogy use or of a specific statement highlighting some unshared attribute or limitation. Thirdly, under the category of *Position*, a subcategory of *Marginalised* was added as the researchers discovered analogies that were positioned in the margin of the text. Further, the researchers also classified the content area of the target domain for each analogy as well as determining where the analogy was found with respect to its progress through the textbook as a whole. It was intended that this would provide information concerning the chemistry content areas where analogies were used most frequently and where these difficult concepts are presented through the whole course of the curriculum.

The researchers' intent was to examine closely the nature and extent of analogy use in chemistry textbooks used by Australian high school chemistry students. For the purpose of the study, the following specific research questions were addressed:

1. With what frequency are analogies included in textbooks used by Australian chemistry students?
2. Is there evidence that analogies are used more frequently for particular sections of the content matter or at different stages of the curriculum?
3. What are the structures and types of analogies used most frequently in the textbooks?
4. Which analogical instructional strategies, that aim to directly assist the student to use analogies to aid understanding, have the textbook authors incorporated?

Method

Ten chemistry textbooks were closely examined and all of the analogies identified were photocopied and further analysed using the Analogy Classification Framework described above. The textbooks used in the analysis had been identified by state syllabus organisations as current, generally used textbooks for Australian senior secondary chemistry education. Only one of the textbooks was not published in Australia – that was a British publication. A list of the textbooks examined is found in an appended reference list.

A portion of text or a picture was considered to be analogical if it was aligned with the working definition stated above and/or it was stated in the text as being analogical. Each analogy was scrutinised concerning the nine criteria in the Framework (see Figure 2) and appropriate classifications were made.

Results and discussion

A total of 93 analogies were identified from the ten textbooks. The number of analogies found in each book varied considerably with five books having fewer than six analogies while the other five had between 12 and 18 analogies. Each analogy was further examined independently by the two researchers with an original agreement of 93% for the 837 (9 criteria × 93 analogies) classifications. The remaining 59 classifications (7% of 837) were agreed upon following consensus discussions.

Content analysis

The content area of the target concepts was classified into 13 categories. Table 1 indicates that a considerable proportion of the analogies (21, 23%) relate to 'Atomic Structure' – including electronic arrangement such as the rotating propeller analogy for the region of electronic influence as described above. Other areas in which analogies were used more frequently were found to be 'Bonding' (12, 13%) and 'Energy' – including collision theory – (11, 12%).

Table I. Analysis of the frequency of analogy use compared to target content area.

Content area	n	%
Acid & bases	6	6.4
Analytical methods	3	3.2
Atomic structure	21	22.6
Biochemistry	6	6.4
Bonding	12	12.9
Chemical equilibrium	5	5.4
Chemical processes	1	1.1
Energy	11	11.8
Industrial processes	1	1.1
Nature of matter	8	8.6
Organic	5	5.4
Periodic table	2	2.3
Reaction rates	3	3.2
Solutions	3	3.2
Stoichiometry	6	6.4
Totals	93	100.0

The submicroscopic nature of these target concepts emphasises the role of analogies for chemistry concepts requiring further visualisation. It was found that some of the analogies for collision theory (part of the *Energy* topic) were similar. For example, analogies were identified that described the energy required for a vehicle to traverse a large hill. It is not uncommon for teachers to use this type of analogy when describing the energy required for a successful chemical reaction to occur and it may be argued that the frequent use of analogies for this concept may be more a function of pedagogical tradition than of the nature of the content matter.

Analogy location in textbook

The page number of each analogy was used to determine a decile measure of the analogy's location within the textbook as a whole. Data shown in Table 2 suggests that the analogies tend to be used more frequently in the earlier stages of the textbook except for a number in the 6th and 7th deciles. This could indicate that conceptual targets are encountered in two phases – initially when the new work is being introduced and also, at a later phase, when more difficult concepts are being presented. Alternatively, the finding that half of the analogies were used in the first three deciles may support the assertion that analogies are viewed by authors as student friendly strategies that are more suited to the beginning chemistry student.

Analogical relationship between the analog and target

The relationship between the analog and the target may be one of either struc-

Table 2. Analysis of the decile position of the analogies in the textbooks as a whole.

Location (Decile)	n	%	Cum%
0	21	22.6	22.6
1	12	12.9	35.5
2	14	15.0	50.5
3	9	9.7	60.2
4	9	9.7	69.9
5	4	4.3	74.2
6	9	9.7	83.9
7	12	12.9	96.8
8	3	3.2	100.0
9	0	0.0	100.0

ture or function. In a *structural* analogy, the external or internal shape, size, or colour, etc., of the analog is shared by the target. In a *functional* analogy, the function or behaviour of the analog is attributed to the target. A *structural-functional* analogy is one that shares both structural and functional type attributes. Of the 93 analogies that were examined in this study (see Table 3), only 16 (17%) were classified as structural, with 45 (48%) being functional and 32 (35%) structural-functional. Researchers have concluded that the real power of analogy lies in the functional area from which more useful conclusions can be drawn (Duit 1991). The structural aspect of analogy, however, is believed to be important in providing initial access due to the obvious similarities between the analog and target domains (Gentner & Landers 1985; Tenney & Gentner 1985).

Verbal and pictorial-verbal analogies

As shown in Table 3, 44 (47%) of the identified analogies had a pictorial representation of the analog. Further analysis revealed that *pictorial-verbal* analogies are frequently positioned in the page margin. As Table 4 illustrates, however, *verbal* analogies are rarely found in a marginalised position. This indicates that authors may wish to use pictorial-verbal analogies more frequently but tend not to sacrifice copy space. Those authors writing texts with marginalised comments tended to make use of the opportunity to use this space for pictorial-verbal analogies. These assertions have been supported by the findings of a recent study (Thiele 1991) which investigated authors' views on analogies in textbooks. That study described the textbook authors' comments concerning the pressure they were under to keep copy space to a minimum and how one author placed analogies in the margin because they were non-essential things that, while useful for some students, should not break the flow of the text.

Table 3. Summary table of analogies showing their analogical relationship, presentational format, condition, and position.

		Analogical relationship			Presentational format		Condition			Position			
Book	n	Struc	Func	Str/ Fun	Verb	Pict/ Verb	Con/ Con	Abs/ Abs	Con/ Abs	Marg	Adv Org	Emb Act	Post Syn
A	17	2	10	5	8	9	1	0	16	7	1	7	2
B	1	0	1	0	1	0	0	0	1	0	0	1	0
C	5	1	1	3	3	2	0	0	5	1	0	4	0
D	3	0	2	1	2	1	0	0	3	1	0	2	0
E	12	0	8	4	1	11	0	0	12	7	0	3	2
F	4	0	2	2	3	1	0	0	4	0	0	4	0
G	14	6	7	1	11	3	0	4	10	0	2	12	0
H	14	3	6	5	13	1	1	0	13	0	2	12	0
I	5	2	1	2	2	3	0	1	4	0	0	5	0
J	18	2	7	9	5	13	5	0	13	14	2	2	0
Total	93	16	45	32	49	44	7	5	81	30	7	52	4

Table 4. The frequency of use of marginalised and pictorial analogies in the textbooks.

	Marginalised	Body	Total
Verbal	5	44	49
Pictorial	25	19	44
Total	30	63	93

Degree of abstraction of analog and target domains

The molecular nature of chemistry creates the requirement for explanation of submicroscopic processes and structures in a manner that is more meaningful to the students. Hence, it is expected that analogies employed in chemistry textbooks will frequently employ concrete type analogs to explain abstract target concepts.

The analog and target domains of each of the analogies were classified as being either concrete or abstract. A domain was considered to be concrete if it was capable of direct sensory observation or considered by the researchers to be consistent with the life experiences of most chemistry students. As expected, 81 (87%) of the analogies were classified as *concrete/abstract* – that is they comprised a concrete type analog domain and an abstract target domain. Only 5 (5.4%) of the analogies employed an *abstract/abstract* analogy while the remainder (7, 7.5%) comprised a *concrete/concrete* analogy. These results, as shown in Table 3, lend credence to the proposition that analogies are usually drawn from concrete type domains that are believed to be familiar to the students.

Analog and target placement on text pages

While there is a lack of empirical studies supporting the preferential placement of analogies in various text positions, researchers have postulated that the efficacy of an analogy may relate to whether the analog is presented before or after the target domain. For example, Glynn's Teaching With Analogies model for instruction using analogies (Glynn et al. 1989; Glynn, Duit & Thiele, in press), proposes that the analog domain be presented after the introduction of the target domain yet prior to conclusions being drawn about the target. When in this position, the analog has been placed as an *embedded activator* (Curtis & Reigeluth 1984). Where a clearer separation between analog and target domains are required, however, the analog domain may be introduced prior to an examination of the target concept (*advance organiser*) or following a complete treatment of the target as a *post synthesiser*. As mentioned previously, it is also possible for textbook writers to employ the margin space – where present – in the textbook to present analogies in a *marginalised* format.

An examination of the 93 analogies identified in this study revealed that most (52, 56%) were presented as embedded activators (see Table 3) while 30 (32%) were marginalised. This marginalised position was used extensively in three textbooks that had margin spaces; the other textbooks showed scarce evidence of marginalised analogies. The infrequent use of analogies as advance organisers or post synthesisers (7 and 4, respectively) could be due to the attempts of authors to enhance the enrichment of the analog – target relationship that is facilitated when analogies are presented as embedded activators.

The extent of mapping

The extent of mapping that is done by the textbook authors was classified using Curtis & Reigeluth's (1984) criteria of *level of enrichment* as follows:

a) *simple* – states only 'target' is like 'analog' with no further explanation;
b) *enriched* – indicates some statement of the shared attributes or limitations; and
c) *extended* – involves several analogs or several attributes of one analog used to describe the target.

Although the textbook analysis found that the use of simple chemistry analogies was still fairly common (42, 45%), research reports suggest that students require assistance when relating the correct analog attributes to the target (Gabel & Sherwood 1980; Webb 1985). Only 35 (38%) of the analogies were enriched while the remainder (16, 17%) were extended. Further, with reference to Table 5, three of the five textbooks having 12 or more analogies contained considerably more simple analogies than enriched analogies.

Elaboration of the analog domain (analog explanation)

To avoid the problems of analog unfamiliarity and incorrect attribute transfer, some textbook writers provide background information concerning the relevant attributes of the target domain. This *analog explanation* attempts to ensure that the student is focussing upon the appropriate attributes at the time of analogical transfer. The explanation may constitute a simple phrase of only a few words through to a paragraph thoroughly explaining the relevant analog attributes. Figure 5 shows that 56 (60%) of the analogies had some analog explanation – 11 of which had both analog explanation and strategy identification as discussed below. This compares favourably with the results of prior studies (Curtis & Reigeluth 1984; Thiele 1990) which have found between 66% and 69% of the analogies had some analog explanation.

Limitations

Given that analogies can be misconstrued by students, it has been suggested that textbook authors should include some warning about the *limitations* of

Table 5. Summary table of analogies showing their level of enrichment, pre-topic orientation, and limitations.

		Level of enrichment			Pre-topic orientation				Limitations	
Book	n	Simp	Enrich	Extend	Anal expl	Strat ident	Both	None	None	Specific
A	17	10	6	1	7	0	0	10	17	0
B	1	0	1	0	1	0	0	0	1	0
C	5	0	3	2	1	0	4	0	4	1
D	3	1	2	0	2	0	1	0	3	0
E	12	8	3	1	5	0	3	4	12	0
F	4	1	3	0	2	0	1	1	4	0
G	14	4	9	1	5	4	2	3	13	1
H	14	9	3	2	6	0	0	8	13	1
I	5	3	2	0	4	0	0	1	4	1
J	18	6	3	9	12	0	0	6	14	4
Total	93	42	35	16	45	4	11	33	85	8

the analogy or the analogical process. Subsequently, each analogy was examined to see if it included:

- a general statement of the limitation of analogy use; or
- a statement relating specifically to the unshared attributes in the analogy.

It was found that no general statements concerning analogy use were made in any of the textbooks. In addition, only eight specific warnings or limitations were expressed with four of the eight stated limitations included in one of the textbooks. The infrequent use of stated limitations would suggest that authors are either assuming that the students are capable of effecting the analogical transfer themselves or that the teacher – in the course of normal classroom teaching – will assist in this regard.

Further, it was found that only 15 (16%) of the analogies included any statement identifying the strategy as 'an analogy' or 'analogous'. It could be considered that if *strategy identification* was used more frequently, then the effect would be similar to the addition of a warning in that it will direct students towards the correct cognitive procedure (Glynn et al. 1989).

Conclusions

From this study of analogies in chemistry textbooks used by high school students in Australia, it is possible to draw conclusions with respect to the nature of chemistry and the effect that this has upon the presentation of the analogies in chemistry textbooks. Analogies were found to be more frequently employed in the content areas of atomic structure, bonding, and energy. These content areas are characterised by unobservable processes and structures that are often reported as being troublesome to students. The considerable use of both pictorial-verbal analogies and concrete/abstract analogies, adds support to the proposition that the explanation of an abstract chemistry concept is assisted by analogies which promote visualisation processes or which present some student world comparison of the target concept.

It was also determined that analogies were more frequently used towards the beginning of a textbook. Abstract concepts such as atomic structure and bonding are frequently introduced early in the textbooks as they are generally considered to be prerequisite to many later concepts. The finding that analogies are used more often at the start of a textbook, however, could indicate that the authors are trying to use more 'student friendly' strategies for students towards the commencement of their senior chemistry course.

Simple analogies were found to comprise a substantial proportion of the total number of analogies and the use of stated limitations or warnings by the authors was infrequent. It is possible that textbook authors may be underestimating the difficulties that students are reported to encounter when attempting analogical transfer. Research suggests that authors and editors should employ enriched, rather than simple, analogies for all but the most

elementary relationships if the target concepts are to be better understood as a result of using the analogy. It is possible, however, that the authors have assumed that the classroom teacher will accept that responsibility, but there is little research to document either the existence or the outcome of this occurrence.

Further research is required if we are to understand more fully the mental processes that students employ when using analogies. Future studies focusing on both teachers' and students' use of analogies will allow for better curricular design that includes analogies to further aid students' understanding of chemistry concepts. In addition, these studies should report not only on the end result of analogy use (such as those by Gabel & Sherwood) but also on the processes as they occur (see, for example, Treagust, Duit, Joslin & Lindauer 1992). For this reason, interview and observation techniques will be most applicable. Further research is needed on how students use analogies in learning complex chemistry concepts, so as to advise textbook authors and teachers concerning the more effective use of analogies both in textbooks and in the classroom. This advice to authors should command a high priority because, while it is generally assumed that teachers' repertoires of analogies are primarily derived from their reading of textbooks there is a considerable lag between research and practice due to the time taken to produce textbook materials.

References

Brown, D.E. & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science* 18: 237–261.

Curtis, R.V. (1988). When is a science analogy like a social studies analogy: A comparison of text analogies across two disciplines. *Instructional Science* 17: 169–177.

Curtis, R.V. & Reigeluth, C.M. (1984). The use of analogies in written text. *Instructional Science* 13: 99–117.

Duit, R. (1991). On the role of analogies and metaphors in learning science. *Science Education* 75: 649–672.

Gabel, D.L. & Sherwood, R.D. (1980). Effect of using analogies on chemistry achievement according to Piagetian level. *Science Education* 64: 709–716.

Gentner, D. & Landers, R. (1985). Analogical reminding: A good match is hard to find. Paper presented at the International Conference on Systems, Man, and Cybernetics. Tucson, AZ.

Glynn, S.M. (1991). Explaining science concepts: A Teaching-With-Analogies model, in S.M. Glynn, R.H. Yeany & B.K. Britton, eds., *The Psychology of Learning Science* (pp. 219–239). Hillsdale, NJ: Erlbaum.

Glynn, S.M., Britton, B.K., Semrud-Clikeman, M. & Muth, K.D. (1989). In J.A. Glover, R.R. Ronning & C.R. Reynolds, eds., *Handbook of Creativity: Assessment, Theory, and Research* (pp. 383–398). New York: Plenum.

Glynn, S.M., Duit, R. & Thiele, R.B. (in press). Teaching science with analogy: A strategy for transferring knowledge, in S.M. Glynn & R. Duit, eds., *Learning Science in the Schools: Research Reforming Practice*. Washington, DC: AAAS.

Lewis, P. & Slade, R. (1981). *A Guide to H.S.C. Chemistry*. Melbourne: Longman Cheshire.

Reigeluth, C.M. (1983). Meaningfulness and instruction: Relating what is being learned to what a student knows. *Instructional Science* 12: 197–218.

Shulman, L.S. (1986). Those who understand: knowledge growth in teaching. *Educational Researcher* 15(2): 4–14.

Stepich, D.A. & Newby, T.J. (1988). Analogical instruction within the information processing paradigm: Effective means to facilitate learning. *Instructional Science* 17: 129–144.

Tenney, Y. & Gentner, D. (1985). What makes analogies accessible: Experiments on the water-flow analogy for electricity, in R. Duit, W. Jung & C. von Rhöneck, eds., *Aspects of Understanding Electricity* (pp. 311–318). Kiel, Germany: IPN/Schmidt & Klaunig.

Thiele, R.B. (1990). A review of literature and text materials to examine the extent and nature of the use of analogies in high school chemistry education. Unpublished manuscript. Perth, Curtin University of Technology.

Thiele, R.B. (1991). Analogies in secondary chemistry education textbooks: The authors' views, in M. Hackling, ed., *Proceedings of the Sixteenth Annual Conference of the Western Australian Science Education Association* (pp. 133–143). Perth, Australia: Edith Cowan University.

Treagust, D.F., Duit, R., Joslin, P. & Lindauer, I. (1992). Science teachers' use of analogies: Observations from classroom practice. *International Journal of Science Education* 14: 413–422.

Webb, M.J. (1985). Analogies and their limitations. *School Science and Mathematics* 85: 645–650.

Reference appendix (textbooks analysed)

Ainley, D., Lazonby, J.N. & Masson, A.J. (1981). *Chemistry in Today's World.* London: Bell & Hyman Limited.

Boden, A. (1986). *Chemtext.* Marrickville, Australia: Science Press.

Elvins, C., Jones, D., Lukins, N., Ross, R. & Sanders, R. (1990). *Chemistry in Context*, Part One. Melbourne: Heinemann Educational Australia.

James, M., Derbogosian, M., Bowen, S. & Auteri, S. (1991). *Chemical Connections.* Melbourne: The Jacaranda Press.

Bucat, R.J., ed. (1983). *Elements of Chemistry*, Vol. 1. Canberra: Australian Academy of Science.

Bucat, R.J., ed. (1984). *Elements of Chemistry*, Vol. 2. Canberra: Australian Academy of Science.

Garnett, P.J., ed. (1985). *Foundations of Chemistry.* Melbourne: Longman Cheshire.

Hunter, R.J., Simpson, P.G. & Stranks, D.R. (1981). *Chemical Science.* Marrickville, Australia: Science Press.

Lewis, P. & Slade, R. (1981). *A Guide to H.S.C. Chemistry.* Melbourne: Longman Cheshire.

McTigue, P.T., ed. (1979). *Chemistry – Key to the Earth.* Melbourne: Melbourne University Press.