Six Science Teachers' Use of Analogies: An International Perspective

Recent international interest in the use of analogies in science education has been centred around several aspects of analogy use including their instructional design characteristics, advantages and constraints, and the misconceptions that may result from their misuse. Despite almost a decade of research generated from this interest in analogies in science education, there have been few studies that have investigated or described the effectiveness of analogies presented in the natural environment of the classroom. Further, there is little research indicating how teachers and students use analogies in that natural setting - the focus of this present study.

Analogies can be presented to students in a variety of forms as is the case also for models, demonstrations and other sense making aids used by classroom teachers. Research into the instructional design characteristics of analogies used by teachers and in textbooks has contributed to the wider research agenda on analogies in science and science teaching. Within this research bulk, studies have produced the Analogy Classification Framework which allows researchers to classify and compare written analogies (Curtis & Reigeluth, 1984; Curtis, 1988; Thiele & Treagust, 1992). This framework has the potential for transference to classify spoken analogies also.

Studies relating to classroom use of analogies have tended to adopt qualitative research methodologies drawing heavily from observation and interview data. Within this framework, a number of studies (Arnold & Millar, in press; Brown, 1992; Brown & Clement, 1989; Clement, 1987; Zietsman & Clement, 1990) have been penetrating in that they have explored the way in which students reason when confronted with analogical situations in a science context. From a teaching perspective, Dagher and Cossman (1992) used observation methods to describe the nature of teachers' verbal explanations (some of which were analogical) from a large number of science lessons, while other studies have adopted a similar approach to examine teachers' explanations in chemistry (De Jong & Acampo, 1992), general science (Treagust, Duit, Joslin & Lindauer, 1992) and social science subjects (Tierney, 1988). The results of these studies indicate that, while science teachers do use analogies when explaining concepts to students, they tend to use them infrequently and less effectively than researchers consider they might have done. In addition, Treagust, Duit, Lindauer and Joslin (1989) identified that the infrequent use of analogies was despite the presence of analogies in the students' textbooks for the topics being taught. This is an interesting outcome especially given that some textbook authors believe that science teachers should explain to their classes the analogies contained in the textbooks (Thiele & Treagust, 1992).

Research Questions

Several reports on pre-service and in-service teacher education have argued that ‘cases,’ if properly documented, provide a powerful tool to help teachers come to know about teaching (see, for example, Carter & Richardson, 1989). McCorcle (1984, p. 206) proposed that the “unique advantage of the case method is its ability to examine a phenomenon in situ, in all the buzzing confusion that characterizes organizational life. In this way, connections can be made between the phenomenon and the context in which it occurs.” Similarly, previous research with exemplary

teachers of biology (Treagust, 1991), chemistry (Garnett & Tobin, 1989) and physics (Tobin, Deacon, & Fraser, 1989) provided useful data for informing teacher education from different vantage points of best practice in science education. From this perspective, the present study sought to conduct an interpretive examination of six teachers teaching chemistry in the natural environment of their classrooms, with a focus on why and how the teachers employed analogies in their explanations. It was anticipated that the setting, content being studied, personal interactions between teachers and students, and many other ‘uncontrollable’ factors would impinge on this analogy use, and that a description of analogy use would be most appropriately presented with the context in which that instruction occurred. In particular, the following three research questions guided the planning, selection of teachers and general research design:

1. Why did the teachers choose to use analogies when teaching chemistry?
2. What evidence was there of the planning or spontaneity of analogy use?
3. How did the teachers choose to present their analogies to their classes?

This study builds on those reported above in an attempt to describe how teachers of chemistry use analogies to explain abstract chemical concepts. It does not aim to measure the frequency of analogy use, but rather, to examine how and why teachers use analogies when they are teaching specific areas of the chemistry subject matter.

Method

Of particular interest to the researcher was the processes of analogy-inclusive instruction. Consequently, in keeping with the qualitative approach for research into teachers' and students' use of analogies recommended by Zietsman and Clement (1990), an interpretive approach design (Erickson, 1986) was used to address these interests. In investigative research in schools, access to the school and to classes, combined with the researcher’s credibility, does affect a study's credibility and dependability (Goetz & LeCompte, 1984). In this study, the researcher has been an industrial chemist, a practising chemistry teacher, science teacher educator, and has conducted research into the use of analogies in textbooks, and consequently, was familiar with the chemistry content matter and had developed skills in the recognition and classification of analogies as they are presented.

Selection and Description of Teachers

Six chemistry teachers, Craig, Julie, Lucas, Neil, Steven and Warren, were selected for the research study. Craig, Julie, Lucas and Steven each taught senior chemistry (Tertiary Entrance level) in Western Australia; Neil and Warren taught senior high school chemistry (A-level) in North Yorkshire, England. Data for the Australian teachers were collected from August, 1991, to March, 1992. Data for the English teachers were collected from October to December, 1992, while the researcher visited the United Kingdom as part of a study fellowship.

Due to the profile of the researcher in the Western Australian chemical education community, most of the Australian teachers knew that the research study was related to analogies prior to the commencement of the study. Hence, there was little advantage in attempting to conceal this. The teachers from England knew only that the study addressed how chemistry teachers explained

abstract concepts to students. Each of the six teachers, regardless of what they knew or suspected of the study, were continuously encouraged to teach in their normal style despite the presence of the researcher in their classroom.

Each teacher was chosen due to his or her good chemistry content knowledge, experience in teaching chemistry, locality to the research centres in a Western Australian and North Yorkshire city, teaching programme addressing appropriate content at a suitable time of the year and willingness to have a researcher observe them and their students for a three week period.

Craig and Julie taught chemistry at the same church affiliated, independent co-educational high school located close to the city centre - a school in which the science staff were involved in several professional networks. This school had a predominance of girls in the senior chemistry classes due to the close proximity of a popular boys' school. In addition, the senior classes had a large population (around 80%) of students who were born in Asia. Craig had taught chemistry for five years and held an undergraduate degree in chemistry. For this study, his Year 12 chemistry class comprised eight students (six girls and two boys) although he also taught Years 8, 9 and 10 science and a Year 11 chemistry class. Julie had eight years teaching experience, including some teaching in the United Kingdom prior to migrating to Australia. She had completed postgraduate studies in chemistry, and had worked as an industrial chemist prior to entering the teaching profession. As Head of Science at her school, Julie had some administrative tasks as well as her Years 8 - 10 science and Year 11 physics teaching commitments. Observed by the researcher was Julie’s Year 12 chemistry class, consisting of eight female and three male students.

Lucas taught chemistry at a church affiliated, independent boys' high school, with exceptionally good science facilities. He held a doctorate in chemistry and his teaching experience spanned 18 years. Lucas had taught in several Australian states and he had considerable expertise in curriculum development. Lucas' was observed teaching his Year 12 chemistry class which consisted of 19 male students. He also had a class of Year 11 chemistry and had administrative duties in his school.

Steven taught chemistry at a church affiliated, independent girls' high school where the science department had a reputation for producing academic students and for their involvement in professional science activities. Steven had completed postgraduate studies in chemistry, physics, and soil science, had considerable experience in curriculum development and had been involved in syllabus determination at the Year 12 level. His teaching career spanned almost 20 years. For this research study, Steven was observed teaching his Year 12 chemistry class which consisted of 17 female students. He also had a class of Year 11 chemistry students and had administrative duties in his school.

Neil had 19 years teaching experience at the time of the study. He held an honours degree in chemistry and a postgraduate qualification in education. Neil had interests in industry-education links and he had helped organise industry visits for six years. Neil taught in an independent co-educational school in North Yorkshire - a school with a long history and a chemistry department that worked well together as a team. Neil, who was Head of Chemistry at his school at the time of the study, had chemistry teaching commitments at the Third, Fifth and Upper Sixth form levels as well as with the Lower Sixth (Year 12) chemistry class that he was observed with for the study. That class comprised 13 students (seven male and six female).

Warren had more than 25 years teaching experience and he held qualifications in both chemistry and education. Warren was interested in student learning and learning styles and had recently conducted in-service sessions for staff members at his school on related topics. His school was a government-run "Sixth Form College," which catered exclusively for students in their 12th (Lower Sixth) and 13th (Upper Sixth) years of schooling. Warren’s class for this study was an Upper Sixth (Year 13) class consisting of eight male and four female students. Although Warren taught a lower sixth form, the content being covered (volumetric analysis) at the time the researcher was in the region was considered not to be appropriate for the study. Warren also had some administrative duties at the college due to his work as a year coordinator.

While the numbers of students in Julie and Craig’s chemistry classes were small in comparison to the other classes, the researcher did not consider that the number of students would influence unduly the nature of the analogies used to explain the chemistry topics encountered. Hence, the low student numbers was not considered to be detrimental to the study. Similarly, four of the five schools in this study were independent, church affiliated schools and, while there is little evidence to suggest that this would influence the nature of teacher explanations, readers do need to be aware of the nature of the schools and the high standard of collegial relationships that existed between these teachers and the researcher. Hence, it is cautioned that this does provide a limitation against simple generalisability of the findings to other teachers and school types. Julie, Steven and Lucas were known to the researcher through professional contacts, Craig was introduced through Julie while Neil and Warren were introduced to the researcher through colleagues at a regional university in North Yorkshire. The researcher was keen to limit the number of teachers in this study to six so that he could ensure to be present for each lesson and so that all relevant data could be properly documented.

Documentary Resources

The corpus of material collected in this study included field notes and audio-tapes of lessons, interviews with teachers, students’ work, teachers’ teaching materials and audio visuals shown to students during their instruction. To effect this, the researcher was present for a sequence of lessons lasting approximately three weeks in which each teacher taught from the topics of atomic structure, bonding, reaction rates, energy effects and chemical equilibrium. A total of 64 lessons was observed comprising eight each for Craig and Steven, 10 for Warren, 11 for both Julie and Neil, and 16 for Lucas. This difference in observation frequency was indicative of the length of time that each school allocated to a teaching period and whether double and triple 'periods' were timetabled. The researcher did not attend when topic tests were scheduled or when the teacher was absent and a substitute teacher was present.

The researcher audio-taped the teachers' explanations and full transcripts of any analogical explanations were produced from the recordings. A total of 58 analogies were observed to have been used and names for these analogies are listed in Figure 1. Several analogies were used by more than one teacher. For example, both Warren and Neil used the water transfer analogy for chemical equilibrium. Where an analogy was used more than once, the frequency of use is displayed in parenthesis next to the analogy name in Figure 1. If an analog was used to describe different target concepts, it was classified by the researcher as being two separate analogies. Similarly, when Julie revisited an

analog after a few days to explain a different target concept, this also was classified as being a different analogy.

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Once each observation period had concluded, the researcher interviewed each of the six teachers. The interview, which lasted approximately one hour, involved the examination of one or more of that teacher's analogies to focus discussion on theoretical and technical aspects of analogy use and structure within classroom practice. In the interviews, it was the researcher's intent to determine why the teachers chose to use analogies in the manner in which they used them and to determine their beliefs as to theoretical aspects of analogical instruction and learning. The interviews were conducted at the end of the observation schedules so that the interview discussions would not influence the nature of the teachers' class-time explanations. Despite a time lag of up to six weeks between the commencement of the observation period and the interview, when prompted concerning a particular analogy used, no teacher appeared to have difficulty recalling the rationale for, and substance of, an analogy. Full verbatim transcripts were prepared of the six interviews and these data were considered in conjunction with the data from the classroom observations.

Data Analysis and Interpretation

The data were analysed and interpreted at three levels. The first level was begun during the classroom observations. This involved the writing of interpretive comments about what was occurring with respect to analogical instruction in the classroom. To assist in the triangulation of the data collection, and in accordance with the methodological position adopted, copies of student textbooks, work-sheets, notes and any supplementary materials, including audio-visual materials, were examined for evidence relating to the study (Mathison, 1988; Yin, 1989).

At the second level of analysis and interpretation, the field notes and the interview transcripts were carefully scrutinised and data were allocated to the three research questions described above. Having assembled the data according to these research questions, a third level of analysis and interpretation took place as patterns within the data set were organized under eight assertions. For each assertion, supporting evidence was identified to indicate the foundation for the assertion and, where possible, non-supporting evidence also included.

Results

The first three assertions related to the first research question concerning why teachers choose to use analogies when teaching chemistry. The fourth and fifth assertions provided evidence for the planning or spontaneity of analogy use, the second research question . Assertions six through eight describe the findings for research question three.

Why do teachers use analogies?

1. The teachers used analogies when they felt that the students had not understood.

There was evidence in the classroom observations that teachers used analogies when they were having difficulty explaining some aspect of the chemistry content. On occasions, students would respond to the teachers' questions with incorrect or inappropriate answers. Often, this was a prompt for providing an analogical explanation. For example, Lucas was observed to use analogies with individual students who had come to him at the end of the lesson to clarify a point with which they were unsure.

Steven commented, in the post-topic interview, that “you can see the strange looks ... and then you will grasp for analogy at that point to try to make the point clearer” while Craig's interview revealed that he believed he used analogies “in response to blank faces or slightly puzzled gazes." In a discussion of why he talked about jam butties to explain equilibrium rate and yield, Warren remarked that it was “an analogy borne of frustration” as he believed the concept was “glaringly obvious but it was very clear that one or two people still hadn’t grasped what we were getting at." All six chemistry teachers in this study appeared able to ascertain that the students were having difficulty without overt messages to that effect from the students. This was possibly a result of their past experiences teaching chemistry enabling them to anticipate which of the concepts would cause difficulties for the students. Remarks such as “I realize that a bit of extra clarification or explanation is needed” by Craig, and that analogies were “purely spontaneous reactions to a stimulus” by Lucas suggested that the ability to determine, on the spot, when students were not making sense of the instruction may have been an important clue to the opportunity to provide analogical assistance.

Neil commented that “if a group, or a student, is having particular problems, then one tries to search around at that moment to overcome the difficulties that [the] particular student is having.” Neil also believed that he used analogies more often for topics that he had problems with when he was a student.

There was evidence from the lessons observed that more analogies were employed for less academically able students. This may have been as a result of these students being less able to offer answers, or correctly answer, the teachers’ questions and hence their lack of understanding became evident. Indeed, Steven indicated that analogies would be less necessary with more academically able students when he suggested that, for these students “you may not need so many analogies because the message gets through at a level without using them." Although Neil thought that, “to a large extent, the less-able would probably want more analogies,” he reported that:
I just take the class in front of me and give them the analogies, give them the different models as is necessary and I think they need to pick it up. With some questioning, you can usually judge how well they have picked it up - who has and who hasn’t.

While the teachers may have felt that the analogies were presented for the benefit of the less academically able students, the researcher noted one occasion in Julie’s class where less able students showed some discomfort with the relationship that existed between an analogy and its target. This was despite the presumption that the analogy had originally been included for the benefit of those students.

2. The teachers considered that the analogies provided necessary additional visualisation.
The sub-microscopic processes and the abstract nature of molecular chemistry created the need for alternative

representations such as concrete models and analogies. In attempting to explain how ionic or molecular collisions must occur with sufficient energy for a chemical reaction to proceed, Lucas invited his students to put it in their own “frame of reference” by suggesting to them that they were “trying to visualise” the molecular system. While Craig used only five

documented instances of analogy, each one described sub-microscopic processes such as the dynamic nature of particles at chemical equilibrium, how increasing the concentration of a reactant would increase the reaction rate, and the minimum energy required for a reaction to take place.

Difficulties arose for students in Warren’s class as they attempted to solve Kp and Kc problems for the NO_2/N_2O_4 equilibria. When Warren said to the students, “Think of a gas syringe - sometimes a little thought picture will help,” the researcher expected that an analogy would follow. However, Warren went on to say:

How can you visualise this? [silent pause for several seconds] Well, to be honest with you, I have some trouble visualising this too. I tend to resort to a sort of mathematical approach by looking at the relationship between P and P^2.

Warren avoided using an analogy in the above instance, by opting to stay within a mathematical framework. Indeed, the researcher noted Warren’s mathematical approach to chemistry as a whole.

3. Some teachers believed that their own thought was predominantly analogical.

Data also emerged supporting the notion that Warren thought analogically also when he was asked the origin of the banking and reservoir analogies for chemical buffer systems:

Even as mature adults, I think, we tend to flip between concrete and abstract. I don’t think there are many of us who think entirely in the abstract and I think we are forever drawing upon analogies, concrete examples, and so I probably thought about those when I thought about buffers in the first place.

Other teachers, Julie and Lucas, indicated that they thought analogically and that this influenced their teaching methods. For example, Julie commented in the interview that she used analogies because that was the way she thought and she believed that the students primarily thought that way too. She stated that “most concepts are difficult for kids ... so you go with real life experience - they can grasp it then."

Evidence of the planning and spontaneity of analogy use

4. There was little evidence that the teachers pre-planned their

analogies.
Most of the analogies that were presented by the teachers appeared to be direct responses to subtle stimuli provided by the students as has been discussed above. Two of the Australian teachers, Julie and Lucas, had pre-planned some of the analogies presented early in the observation programme. This was possibly a response to the presence of the researcher in the classroom and partial knowledge of the research focus. After several observations, however, teachers appeared to use analogies more spontaneously. In the interviews, it was suggested by Lucas, Julie and Steven, that those analogies that were pre-planned tended to be those that they used every year in their teaching anyway.

Julie acknowledged that she would never have written analogies down in her preparatory teaching notes as she changed them from year to year depending upon the students and their experience. Of the 17 analogies that Lucas was observed to use, he did have two analogies included in his teaching notes. One of these was a new analogy that he had recently discovered while examining the Salter's A-level Chemistry packages (Ramsden, 1992). He had been impressed with the analogy of the water flowing into a sink as a contextual introductory approach to the ozone layer and he had decided to use it with his chemistry class. This decision was made prior to him being invited to be involved in the study. The other analogy that he had recorded in his teaching notes was one that he had used in prior years.

Craig felt uncomfortable with the prospect of a planned analogy as he felt strongly that the success of analogy had more to do with timing and placement than with planning. He commented that "the idea of hitting on something on the spur of the moment can possibly be more effective because it is a response to ... an appreciated difficulty" and that "in response to a perceived difficulty, they [analogies] can be finely tuned at the time and made more relevant rather than 'Well, this is the analogy'." Neil supported this idea by arguing that analogies should be "short, snappy things" rather than complex things which will make life very hard for the students.. Despite this reluctance on the part of most of the teachers to document their analogies in their teaching notes, however, there was support for the notion that each teacher mentally maintained a working repertoire of analogies that were retrieved in response to stimuli from the students. Steven's interview remark, that "you build up a sort of knowledge bank of these [analogies] and then you modify it a bit" further emphasised this concept.

Those analogies that were spontaneously presented or generated often exhibited clear surface similarities which tended to be the source of analogical access structures. For example, the analogies for molecular collisions often drew an analog from another type of collision, the analogies for rates of reaction often drew from other rate-related analog domains and a similar occurrence was evidenced for concentration related analogies. As was to be expected, this was the case most frequently with functional analogies rather than structural analogies.

On several occasions, Julie invited her students to create and recall analogies on the spot to describe newly learnt chemical concepts. Students frequently began with a simple surface term, such as collision, rate, or concentration in the search for a suitable analog. These student analogies did share some appropriate surface similarities, however, they often lacked depth and had little potential to draw more powerful connections between the two domains.

5. The teachers tended to draw upon their own experiences or their own professional reading as a source of analog domains. All four of the classes that were observed in Australia used the same chemistry textbook. That textbook was examined in an earlier stage of the study and found to contain only two analogies which were in topics other than those being taught in the classes at that time. Both of the student textbooks used in the classes in England were scrutinized for analogies. While several were found in each textbook, they were not the same as those used by the teachers. Hence, for each of the six classes it was assumed that the normal student textbook had not supplied the teachers and students with analogies from which they could work.

Of concern to the researcher was the tendency of the teachers to draw upon analogies which employed an analog domain from the experience of the teacher more than the experience of the students. For example, Craig, who used the mountain pass analogy for activation energy and catalysis, described a mountain system in Switzerland rather than direct the students' thoughts to the hill regions nearby to the school. Another Australian teacher, Steven, used the activities of chipmunks in snow covered countries to describe endothermic and exothermic processes. While many students may have been familiar with these ideas, it is possible that other examples, akin to Australian conditions, may have been more relevant to the students. There were examples, however, of where the teachers did use analogs that were directly relevant to the students. In several instances, teachers referred to a forthcoming student dance or ball. This appeared to have a reasonably motivational effect, probably due to some added intrinsic interest for the students.

Lucas showed that his repertoire of analogies had been enhanced by his professional activities including his reading and viewing of chemistry related materials. As previously mentioned, one of his analogies had come from the Salter's A-level Chemistry packages he had reviewed. When Neil was asked the origin of the scaffold structure analogy for the molecular arrangement of ice, he commented that "it is something that I tend to use year in and year out but it has always occurred to me. Perhaps because of my interest in the construction industry. I always said I should have been a builder instead." Steven had developed a considerable repertoire of analogies over the years - many of which he had developed from first principles himself. He commented, during the post-topic interview, that analogies "come from your experience of everyday life and you see similarities in the system you are trying to describe." For these chemistry teachers, one of the experiences of "everyday life" was teaching other subjects such as Physics. Julie referred to the test scores of physics students on a graph to communicate the basics of the Boltzmann distribution. Lucas used several analogies that drew analog domains from physics or physical aspects of chemistry to describe or develop new chemistry concepts. For example, he contrasted the temperature dependent equilibrium constant with the nature of a physical constant in physics. Also, he compared the driving tendency of a reaction to reach chemical equilibrium with the tendency of objects to settle at the lowest possible gravitational potential energy. This, Lucas demonstrated by noisily dropping a plastic object to the desk from a considerable height.

On several occasions Lucas was required to explain chemical concepts to students who had given clear indication that they did not understand by their inability to answer questions correctly or by their asking questions directly to him. In some of these instances, Lucas was observed to look around him for some object or prop about which he could base an analogous explanation. For example, the plastic object mentioned above and an elastic band (in a later incident for the benefit of one student only) were used to describe how a system tends back to a state of equilibrium after a disturbance. Also, a white-board marker had its cap removed to describe how energy is required to break bonds in a chemical system. With the latter analogy, Lucas attempted an extension to show that energy is released as a system is restored with the formation of bonds (by replacing the cap). The researcher, identifying this extension as having a less suitable attribute match, discussed this analogy with Lucas during the post-topic interview and discovered that he traditionally snapped a chalk piece in two but, due to an update in the classroom facilities, there was no chalk readily available.

Both of the teachers in England used the water transfer analogy to develop the concept of chemical equilibrium. In this analogy, the teachers arranged two glass bowls - one of which was originally half full of water. Taking two plastic scoops or beakers, they then began to transfer water from the left-hand bowl into the right hand bowl. Simultaneously they attempted to transfer water from the empty, right side bowl to the left. As this simultaneous scooping continued, the net flow of water from the left to the right eventually ceased such that an equilibrium position was maintained despite the continuation of the transference. Both of the teachers talked the students through the analogy and related it to the chemistry under study. In addition, each extended it to discuss the workings of either a catalyst or of increasing the temperature. Having discussed this analogy with the teachers during the interviews, the researcher drew the conclusion that this demonstration was commonly used by chemistry teachers in the U.K. when introducing equilibrium. Indeed, there was evidence from both of the lessons that some of their students had seen similar demonstrations in previous years and, in the case of Neil, some had seen it at a special chemistry Christmas lecture put on by the teachers at that school for students and interested parents. All of these “device” analogies were functional in nature and were somewhat more loosely fabricated than conventional ‘analog models’ such as ball and stick representations of molecular structures.

While the textbook used by Lucas’s students contained only two analogies, a short videotape on the topic of reaction rates that the students viewed as part of their instruction contained several analogies. When asked, Lucas recounted that the videotape was one that he used annually with Year 12 chemistry students. In Neil’s class, several computer simulations were displayed to the students as they studied the topic of chemical bonding. One page of text that accompanied some representations of atomic and molecular orbitals had the following display:

Hydrogen atoms are usually found joined or combined to other atoms. To separate a single atom of hydrogen, it is necessary to give it a lot of energy. So a single hydrogen atom, like this [indicating the accompanying diagram], will contain a large amount of energy, like a ball at the top of a slope. When a hydrogen atom combines with another atom, it usually loses energy (like the ball rolling down the slope). To enable it to lose energy, the atom can join with another atom of hydrogen so that the two electrons occupy the one electron cloud.

Despite showing the T.V. screen to the students, and commenting upon the pictures, the teacher made no reference of the presence of the analogical text on the display. Indeed, as the size of the text was too small to be read by students at the back of the class, some would not have been aware that an analogy had been included in their instruction.

How did the teachers choose to present their analogies?

While the nature and structure of the analogies used has been discussed above, it was considered important to also describe the manner in which the teachers used analogies and any particular strategies that they employed while using them.

6. Teachers tended to adopt a less formal manner when analogies were being used.
The researcher noted a lessening of the formal atmosphere in most classes when teachers used analogies. In some cases, the content and phrasing of the analogy was such that students would laugh or smile. This may have been due to the teachers indicating that this was a side issue to the target concept. Alternatively, the nature of the stories and the occasional use of students' names in the analogies seemed to increase general student motivation. As mentioned above, Warren's bicycle analogy had become a joke for the students as he continually referred back to it. In a teaching instance, Julie used the analogy of the school dance/ball several times to help students understand the factors affecting rates of chemical reactions. In doing so, she identified some students by name and included them in particular activities related to the dance. This drew these students into the concept which increased the relevance for students and hence, heightened motivation. These activities tended to occur more frequently with personal analogies.

Julie saw this type of teaching as being an important variation in her normal style. She commented in the post-topic interview that, while she saw analogy as "a less formal way to teach," there was a need for some humour as "to sit there, like the kids have to do, would drive [her] insane." Steven also said that when he taught with analogies he would "become a bit more animated and act out a role a bit and throw [his] hands a bit more, use [his] voice a bit more." Craig too, was prepared to act in a "more humorous way" when using an analogy although he didn't see this as a change in behaviour that was especially related to analogy use. Rather, it was another facet of his teaching behavior designed to attain particular learning outcomes.

In a similar manner, both Julie and Lucas saw analogy as a teaching strategy that was most effective within the context of a teaching environment where the teacher was well aware of the individual interests of students. The use of these interests in the analogy was considered to enhance their relevance and interest. Lucas suggested that, as he had just started teaching that class of students, he did not yet know their interests and that this lack of current knowledge influenced his use of analogy. Later in the year, he would know “which one is a basketball player, a rower, a debater” and be able to present the analogies to suit. Julie, who commented on student teachers that she had observed attempting to teach with analogies, remarked that the student teachers have “got to make sure that they are aware of where the students are coming from ... It’s worth investigating what the students’ likes and dislikes are, to get to know them” before you use analogies."

7. The teachers appeared to devalue the content of the analog to the students.
Possibly as a type of strategy identification, the teachers sometimes commenced the analogy with a statement to the effect that it was clearly an unreal situation. Lucas, who used an analogy of the rates of spread of good and evil forces through an isolated village community to illustrate competing forward and reverse rates within atmospheric ozone equilibria, introduced the analogy by remarking, “I will tell you a silly story." Later, before commencing another analogy for competing rates, he discussed with the students what they would do “before we move on to what some of you might consider a fairly trivial issue - our person going up a ‘down’ escalator." Steven used an analogy of feuding neighbours throwing bricks over each others’ fences to explain the same concept of competing rates at equilibrium. When the students laughed after the analogy had been shared with them, Steven suggested to them that it was a “silly one, but the silly ones are like cartoons and they stick there." Similarly, Craig proposed that “the more ridiculous [they are] the better, as long as they are accurate and effective."

When Craig was using the mountain pass analogy for the effect of a catalyst on reaction energy requirements, he initially described a personal event where he had difficulty climbing a high mountain in Switzerland. Later, he said to the students; “But, if Dawn were doing it, she would say ‘No, no, Mr. Jacobs. Let us go by an alternative pathway, let us go over the Saddle’“ - a nearby mountain pass. This had the effect of drawing all students (especially Dawn) in to the analogy which may have offset the lack of analog familiarity described above. Julie used several role plays that were analogical in nature (analog models using humans to model particles). This also involved the students though in an more active role.

Passive roles were also used as Julie fabricated stories related to human relationships to discuss reaction rates, by identifying the names of students in the class. Also, in relation to the personalisation of analogy, Julie was observed to make several anthropomorphic analogical statements such as comparing a chemical system at equilibrium to a sense of personal satisfaction and comfort. For example, she made statements such as “happy in equilibrium” and “we try to get back to what we like."

8. There were variant expectations of how students should treat analogies.
While the researcher had anticipated that he would observe teachers using analogies, he was interested to see Julie invite students to put newly learnt chemical information “in their own words” and recount it analogically using their own experiences. At the conclusion of the topic, when questioned about the rationale for this approach, Julie suggested that if the student was able to transfer the target back into some analogical framework, then they had shown better evidence of conceptual understanding than if they had just repeated the textbook’s or teacher’s terminology in their responses. Over the years, this method had become an entrenched strategy in her teaching repertoire.

Of particular interest to the researcher were the expectations teachers had of students in respect to analogy use. The ability of the students to use the analogy at the moment of application and later, perhaps as a study device or aid, was considered to be related to this. There was evidence from the observations and interview that Steven saw the analogy as being only of temporary value. Steven expanded upon this in the interview when he suggested that the analogy is a means to an end and not an end in itself that it:

has no importance in itself. ... The only importance is to help you to know what to do in a chemistry problem situation. Once you know what to do, and the steps involved, then this is irrelevant and has no further purpose.

Julie’s expectations were similar. Having used an analogy of a student introducing a shy friend to a prospective dating partner, she instructed the students to ensure they “never write the analogy down."

In an attempt to determine if the students carried the analogy into their cognitive arrangement of the target, the researcher examined the students’ responses to several essay type questions on reaction rates that were written at the end of the topic.

These essays (each between one and three pages in length) were written by students of Julie and Craig. Of the 18 essays examined, only two contained any evidence of that analogies had been included in the instruction. This evidence was in the form of the metaphoric terms “activation energy barrier” and “alternative reaction path." However, these terms are used in the language of chemistry textbooks to such an extent that they are not usually considered analogical. A small number of the students used anthropomorphic statements to describe chemical systems such as “the system tries to keep its temperature constant” and “the system will try to partially counteract this change.” There was no indication that the anthropomorphic statements were related to the analogies employed or that they were more frequent as a result of the style of instruction.

During the post-topic interviews, Lucas, Neil and Warren all indicated that they saw a more lasting role for analogy and hoped that the students could retain the analogy for later use (pli06, jli08, pni08). There was disagreement, however, as to whether the students should copy the analogies from the white-board into their study notes. In fact, after using an extended pictorial analogy that had been thoroughly mapped, Lucas told the students that ... at this stage we should close the model.” He then proceeded to erase from the board all details relating to the elevator analog leaving only those target details that were concluded from the analogy. When the researcher questioned him about this strategy during the post-topic interview, Lucas remarked that it was not a prepared strategy and he could not recall having done it for any particular reason. Contrarily, Neil indicated to the researcher that he had included analogies into the handout notes for younger students and that he encouraged students to revisit these analogies if they were fruitful.

Conclusions

Eight assertions have been drawn from this study into chemistry teachers’ use of analogies to explain abstract concepts. The assertions are as follows:

1. The teachers used analogies when they felt that the students had not understood.
2. The teachers considered that analogies provide necessary additional visualisation.
3. Some teachers believed that their own thought was predominantly analogical.
4. There was little evidence that the teachers pre-planned their analogies.

5. The teachers tended to draw upon their own experiences or their own professional reading as a source of analog domains.
6. Teachers tended to adopt a less formal manner when analogies were being used.
7. The teachers appeared to devalue the content of the analog to the students.
8. There were variant expectations of how students should treat analogies.

The six teachers observed in this study each used analogies to illustrate the abstract nature of the chemistry that was being taught. While analogies were occasionally planned as part of the teachers' strategies for particular lessons, most were used as a response to stimuli from students or groups of students. These stimuli may have been puzzled looks on students' faces, questions from students or the students' inability to correctly answer a question proffered by the teacher. The students who provided the stimulation for an analogical explanation were often from the less academically able sub-group. This observation suggests that analogical explanation may be offered more frequently to less academically able students whom the teachers believed required additional visualisation. This supports the findings of Friedel, Gabel, and Samuel (1990) that analogies may be more effective for students of lower formal reasoning ability but not especially useful for the more capable students. For these students, teachers sought visualisation aids to represent abstract concepts. In some cases, analogies were demonstrated using specially provided equipment (the Winchester bottle and the water transfer apparatus); in other cases, the teachers used ‘device’ analogies to provide concrete representations of abstract concepts.

Comments by the teachers about their own thinking and learning suggests that much of the ‘abstract’ chemistry that the teachers know is based on an assortment of analogical structures. Indeed, it could be argued that most or all of our chemical knowledge is analogical. For the purposes of this study, however, that level of analysis was not considered by the researcher to be fruitful for the investigation of the stated research questions.

Be they spontaneous or planned, the analogies that were used for the topics of atomic structure, bonding, reaction rates, energy effects and chemical equilibrium were similar to those found in chemistry textbooks with some slight adaptations for context. However, the textbooks that were used by the students did not appear to contribute to the analogy repertoires of the teachers. While there was evidence that audio-visual and computer programmes shown in some of the classes did contain analogies, the teachers provided no elaboration of these analogies for the benefit of the students. On occasions, the students' names and their interests were used as a context for a particular analogy and this appeared to have a motivational impact upon the students. Analogy sources were varied with evidence that teachers’ a) own learning experiences, b) professional reading, c) curricular alternatives such as audio-visual devices and d) informal discussions with colleagues were all useful sources. The British teachers shared the water transfer analogy and, from speaking with other chemistry teachers in England, the researcher identified this as a common way to introduce or represent chemical equilibrium at the high school level. In Western Australia, however, this analogy remains relatively unknown. During the early 1990’s, the researcher conducted many seminars and workshops in Australia on the topic of analogies in chemistry teaching. During these meetings, in which many teachers have discussed their favourite and well-used analogies, the water transfer analogy has not been mentioned. The historic background of this analogy, and its resulting influence on students’ conceptions of chemical equilibrium, may prove an interesting sub-study. The other analogies used by the British teachers did not appear particularly country specific (jam ‘buttie’ aside), and given the great similarity between the chemistry curricula of the two countries and the culture of the two societies, this was not surprising.

When considering how these teachers used analogies, I argue that two key competencies were demonstrated by these teachers which, when functioning together, facilitated the provision of useful analogical explanations for some of the abstract concepts that were part of the subject matter being studied. The first of these competencies lies in the teachers’ good content knowledge; the second in their experience with how students learn and the need for alternative representations for some students. It was evident to the researcher that these teachers' ability to use an analogy to the advantage of their students, to map clearly, to extend the analogy when appropriate and to provide suitable limitations, was dependent upon their skills with respect to these two competencies. In addition, each of these teachers had a good relationship with their students and the students generally appeared to be attentive to the instruction and actively involved in the class. The proposition that beginning teachers, and/or teachers who do not have a strong subject matter knowledge and may be less aware of the students' prior knowledge, may encounter difficulties when attempting to teach with extended or more complex analogies is one that warrants further investigation.

Limitations

In this study, the presence of the researcher in the six classrooms would have influenced both how the teachers taught and how their students responded to instruction. As the researcher was an experienced chemistry teacher and a trainer of student teachers for the disciplines of physics and chemistry, the presence of the researcher in the classroom may have caused the teachers to be more careful in both their content use and their pedagogical approaches knowing that they were being observed by an experienced peer.

For the Australian teachers, it is likely that their partial knowledge of the research focus would have resulted in analogies being used more frequently and in a more elaborated manner. This researcher would argue, however, that this limitation does not significantly devalue the findings of the study. Support for this position comes from two sources. Firstly, frequency of analogy use was not part of the research focus of this study which investigated how and why teachers use analogies in their chemistry teaching. Secondly, the findings for the Australian teachers were similar to the results for the British teachers with respect to how the analogies were presented. Despite these arguments, there is little doubt that the better research design was the one used with the British teachers where they knew only that the researcher was interested in observing how teachers explain abstract concepts to their students.

As mentioned above, interpretive research of this type is subject to the nuances of the researcher/s at the time of data collection and through subsequent analysis iterations. This was especially the case for observations of what was happening with the students in the classroom - information that was not readily able to be re-analysed as it was not picked up on the tape recorder. An alternative approach would have been to use a video camera to record classroom incidents and explanations but this would have caused greater deviations from ‘normal’ behaviour by both teachers and students.

Finding schools in which to conduct classroom-based research of this type is often difficult. Invariably, teachers who are selected or willing to be involved in like studies are often people having prior contact with either the research centre, the researcher or some professional networks or associations. Hence, these teachers tend to be of the sub-group who are interested in being professionally developed and in professional development - a sub-group which in some teaching communities may not represent the majority of members. Not only were most of the teachers involved in this study involved in many professional activities, but the schools in which they were based tended to be independent schools that were well resourced. How these teacher explanations differ from those in government and/or less resourced schools is unclear. Similarly, how novice teachers or teachers lacking good chemistry content knowledge use analogies in their chemistry teaching is not described in this study. While this may be an area for further, fruitful research, the reader needs to be cautious if attempting to generalise these findings to other educational settings or other, less developed teachers.

Finally, readers should note that this study does not directly investigate whether the analogies used by the teachers resulted in positive outcomes with respect to student learning. It could be inferred, as these experienced teachers were using spontaneous and planned analogies in response to the realisation that an initial explanation had been partially unsuccessful, that the teachers believed that the analogies resulted in positive learning outcomes for the students. As their skills develop,

teachers feel able to ascertain student ‘understanding’ by the glance around the room, the look in the eye, or the shifting of the body and these data, while difficult to document at an appropriate level, are powerful indications to the practitioner whether or not learning has occurred.

Implications for teaching and teacher education

By observing how experienced teachers use analogies as part of their normal teaching repertoire, much information and many ideas can be learned to inform both preservice and inservice teacher education. The utility of this kind of information is currently provided in research reports elsewhere which deal with case studies of teachers in different contexts (Carter & Richardson, 1989).

The findings of this research with six experienced teachers of chemistry, each of whom had excellent content knowledge and a broad repertoire of teaching skills, can be used in a similar way to inform preservice and inservice teacher education about the use of analogies in classroom practice. The three implications from this research relate to (a) the need to develop a personal repertoire of useful analogies, (b) the necessity to select analogies which can relate to students' own experiences, and (c) the importance of mapping the attributes in an overt manner and identifying limitations.

The six teachers in this study each used analogies when students were considered not to have understood an initial explanation. In response to this consideration, in most instances the analogies were not pre-planned. However, each teacher had been teaching chemistry for between 5 and 20 years and during that time had used analogies during their teaching of the same content, albeit to different groups of students. So, while not pre-planned, the analogies were within the repertoire of the teachers, having been built up and practised over many years experience. Our contention is that analogies have great merit in teaching science, especially in non-observable aspects related to chemistry. Consequently, for chemistry teachers who develop a personal repertoire of useful analogies, it is likely they will attain an increased ability to enable students to understand complex concepts: concepts shown by research to be difficult for students. The development of teachers' analogical repertoire can be promoted with the provision of manuscripts which document useful analogies for a range of chemistry topics. One such example of this is the Applications and Analogies section that frequently appears in the Journal of Chemical Education (introduced by De Lorenzo, 1980). Alternatively, teachers may find it beneficial to "share" as a way to further their own repertoires and to have others comment upon the particular analogies presented.

As competent as the six teachers were in developing opportunities for students to understand the chemistry concepts in the curriculum, there were several instances when opportunities for understanding were lost, or at best were limited, because the teacher chose to use an analog from his or her own experience rather than from the experience of the students. During events that unfold in the classroom, as observed by each of the six teachers, the time to use an analogy may be because of puzzled looks from the students and so it needs to be presented immediately. The implication from these observations are that, without a repertoire of suitable analogies and knowing how to use the analogy or analogies effectively, this opportunity may not be taken appropriately. The researcher's experiences conducting

workshops and seminars on the uses of analogies in teaching for both preservice and practising teachers strongly indicates the value of having some kind of teaching model to guide the use of analogies in science teaching. One model under development by the Analogy Research Group at Curtin University of Technology (Treagust, Thiele, Venville, Harrison & Stocklmayer, 1993), takes students' experiences into account in an overt manner and trial evaluations have been well received by teachers. Further, the experiences of that team have lead them to encourage teachers wishing to use analogies to select analogs that are well known to their students and to engage their students in some aspect of the analogy formulation or generation where this is feasible. It also will assist students if teachers develop non-threatening classroom environments where students feel free to express dissatisfaction with an alternative explanation that has been proffered for their assistance.

In this paper, the researcher has described two key competencies that he believes are related to good analogy use: well founded content knowledge and understanding of how students learn. From the perspectives of teacher education, the trade-offs between specific (e.g., chemistry) versus general (multidisciplinary science) content courses and between content-based and education-based courses will continue to be a source of frustration to teacher educators and preservice teachers alike. It would appear that little can be done in this regard in the short term. The second competency, however, is more achievable in the short term. Two decades of research into the conceptions that students bring to their science instruction and the conceptions that they adopt as a result of instruction, now informs teacher education courses worldwide. 'Methods' textbooks and accompanying volumes encourage preservice and inservice teachers to apply a range of new techniques to discover the nature and extent of learning in science (see, for example, White and Gunstone, 1992). Evaluation of this type enables teachers to monitor the effectiveness of their alternative explanations from the perspective of student learning and efficacy.

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ANALOG DOMAIN
TARGET DOMAIN

Atomic Structure/Bonding
Ball on top of hill High energy of atomic orbitals
Dumb-bell shape Shape of p-orbitals
Shells and orbits Orbitals

Taking photographs Theorised electron positions at any instant
Scaffold structures Molecular arrangement of ice
Musical cymbals Arrangement of an atomic lattice

Energy Effects
Academic ability of Physics students Fraction of molecules with energy greater than activation energy
The student ball/dance Activation energy
Pole vaulter attempting a vault Activation energy
Pushing a car over a hill Activation energy
Role play of student couples Formation of an activated complex
Car precariously balanced at the top of a hill High energy of the activated complex

Reaction Rates
Students hurdling hurdles of different heights Rates of various reactions having different activation energies
Student relationships The effect of reactant mixing on reaction rate
Marathon runner cooling off by lying in a cold bath The effect of increasing surface area on the rate of reaction
Collisions between children in the playground The effect of increasing concentration on reaction rate
The student ball/dance (2) Increase in molecular velocities causing an increase in the number of collisions
Coconut shy fairground attraction Effect of increased

concentration on the number of successful collisions
The student ball/dance Decrease in the reaction rate as it proceeds in one direction
Climbing through Swiss mountain passes Effect of catalysts on reaction mechanism and rate
Pushing a car around a side road Ease of catalysed reaction mechanism
A pig fixed on a barbecue spit Specific fixation of a reacting species to a catalytic site
Chipmunks storing food before winter Exothermic and endothermic reactions
Personal banking and savings Exothermic and endothermic reactions
Breaking apart a pen and its cap Energy required to break chemical bonds
One of the "products" of an exothermic reaction being heat Release of energy in exothermic reactions
People moving around Particle motion

Chemical Equilibrium
Water flowing in and out of a sink Constant dynamic properties in a steady state open system
A recycling tap/sink/drain water system Constant dynamic properties in a steady state closed system
A "stalemate" Constant dynamic properties in a steady state closed system
Gravitational effects on a body Tendency of a chemical system to revert to equilibrium
Elastic band returning to its original size Tendency of a chemical system to revert to equilibrium
Saturated sugar content in coffee Processes at chemical equilibrium
Iodine in alcohol and water Processes at chemical equilibrium
Not "frozen" Processes at chemical equilibrium
A physical equilibria with iodine in various solvents Chemical equilibria and reversibility
Water/water vapour in a closed system Chemical equilibria and reversibility

People moving in and out of a shop Rates of forward and reverse reactions for equilibrium
Water being transferred between two bowls Rates of forward and reverse reactions for equilibrium
Good and bad missionaries rate of evangelisation Competing forward and reverse rates of reaction
Person walking up a down escalator Competing forward and reverse rates of reaction

Pushing down the accelerator of a car   Changes in the rate of the forward reaction
Actively moving body to stay warm Response of an exothermic system to a decrease in temperature
Person walking up a down escalator Effect on yield of favoured forward or reverse rates of reaction
Constants in the discipline of Physics The dependence of the equilibrium constant on temperature
Having an ace to play, an ace card Advantage of using a catalyst in a commercial equilibrium process
'Jam butties' on a conveyor belt   Advantage of using a catalyst in a commercial equilibrium process
Members of a family sharing a car Compromise between reaction rate and yield in an industrial exothermic process
Water reservoir   Chemical buffer systems
Lots of money in a bank account   Chemical buffer systems

Miscellaneous
The fine print of a legal contract Conditional statements relating to the equilibrium constant
The visible spectrum   Colour mixtures of transition metal ions
Getting a prickly pear to beat someone with Danger of trying to correct ozone problems by releasing chemicals into the atmosphere
Sibling rivalry   Competing ionic species in equilibria
Domestic spin drier for clothes   Extraction cone for crystallisation of ammonium nitrate pellets
Wobbling jelly in a bowl Temporary delocalisation of electrons

Figure 1. Analogies used by the chemistry teachers during the lessons observed by the researcher.

Six Science Teachers' Use of Analogies:
An International Perspective

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