Analogies in the teaching of chemical equilibrium: a synthesis/analysis of the literature

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This paper presents a thorough literature review of the analogies used to teach chemical equilibrium. The main objective is to compile all the analogies that have been found to be of service to the teacher and the student. Additionally, we categorize and analyze analogies in relation to the following aspects: representation of the dynamic nature of equilibrium, the equality of the rates of forward and reverse reactions, the reversibility of the reaction as the concept involved, the calculation of the equilibrium constant for a reaction, the application of Le Chatelier's principle; and the function of a catalyst in an equilibrium system. Some issues related to the use of analogies in teaching and learning are discussed, as are the misconceptions that can be erroneously introduced, reinforced or avoided with their use. Finally, some advice is provided about how the knowledge gained from this review could benefit practice.

Keywords: analogies, chemical equilibrium, teaching, learning, alternative conception

Introduction

The abstract nature of chemical equilibrium and the associated conceptual and procedure difficulties have been highlighted by authors such as Johnstone *et al*. (1977), Tyson *et al*. (1999), Kousathana and Tsaparlis (2002). These authors state that the most abstract ideas associated with this topic are: its dynamic nature, the distinction between equilibrium and non-equilibrium situations, the mental manipulation of Le Chatelier's principle; and some energetic considerations. Despite these obstacles, the teaching of chemical equilibrium is supported by the creation and use of analogies (Van Driel and Gräber, 2002).

In this paper 'analogy' has been adopted to represent the visualization of concepts through the analogical comparison between two fields: a known field and the scientific conceptual field. Thus, analogies include:

(a) An unfamiliar or unknown field (target, objective, object),
(b) A familiar domain (analogue, base, source) familiar to the subject who wants to learn and
(c) A set of relations established between (a) and (b) or a series of processes of correspondence between the components of both fields.

Thus, analogies make new, abstract information more concrete and easier to imagine by using what the student already knows and is familiar with, and linking it to new, unfamiliar ideas (Treagust and Chittleborough, 2001). As will be seen for chemical equilibrium, the analogue may exist in the learner's mind or may be presented by others by means of a game, an experiment, a story, a model, a device, etc.

Analogies may be considered to be a subset of models, as analogical reasoning is the comparison of structures or functions between a well known field and a new or partially new domain of knowledge. Models and modelling are key features of science, and consequently, of science education. In the case of the latter, there is an attempt to make scientific understanding accessible, and to provide some insights into scientific practice. Models are representations of ideas, objects, events, processes or systems (Gilbert and Boulter, 2000), and are particularly useful when we want to explain macroscopic nature in terms of the submicroscopic constitution of matter (Coll *et al*., 2005).

It is worth noting that several authors do not describe their proposals as 'analogies'. There is a great diversity in the use of terminology, with 'analogy' and 'model' sometimes considered synonymous, alongside the use of other terms such as 'analogical model.' In this paper 'analogy' has been adopted to represent the visualization of concepts through the analogical comparison between a known field and the scientific conceptual field. There is a tendency to use 'model' ('physical model' or 'mechanical model') when concrete materials are included. As an example of the diversity of terminologies used, the analogy of transferring water from one container to another was called 'experiment' by Sorum (1948), 'demonstration' by Hugdahl (1976), 'physical model' by Hansen (1984), 'model' by Pereira (1990), 'mechanical model' by Laurita (1990), 'simile' by Garritz and Chamizo (1994) and 'mechanical analogy' by Garritz (1997).

The use of analogies and models to support the learning process has been discussed over the past century. For example, Lewis discussed the analogies he used to teach the structure of matter, catalysis, chemical equilibrium and solubility product (Lewis, 1933). He asserted: "*many*

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students, in freshman classes, are not properly prepared for the conventional presentation of the subject matter; and since chemistry is a growing science, it is advisable to use analogies until the more rigorous mathematical presentation can be absorbed by students." Piquette and Heikkinnen (2005) included analogies as one of the four instructional strategies needed to achieve conceptual change. Grosslight *et al.* (1991) identified some of the characteristics that differentiate the expert from the novice in the pragmatic use of models. They recognised three 'levels' of understanding: a naive realist view in which a model is a copy of some aspect of reality; the meaning currently accepted by science, that considers modelling an imaginative attempt to represent an aspect of a phenomenon so that predictions can be made and tested; and a rather unclear intermediary level which has some elements of both the other two.

Sarantopoulos and Tsaparlis (2004) used analogies with a strong and familiar social context, such as the 'Dancing couples analogy'. The authors analysed the role of affective factors in relation to the cognitive objectives of teaching a topic (chemical equilibrium), question that has been neglected in the recent research literature. Two psychometric factors were analysed: developmental level and motivational style. They concluded that *"Enjoyment is a very important factor in effective learning"* and that analogies that involve a social factor can induce effective learning in the classroom.

Although analogies may motivate students or help them visualize abstract concepts, their use may be disadvantageous as the analogies can promote misconceptions, such as when:

(a) The analogy is assumed as the object of study, instead of the subject matter knowledge;
(b) Incorrect attributes of the analogue are assigned to the target;
(c) Only surface or picturesque aspects are found to be retained; and
(d) There is a lack of abstraction in the correspondence between the two fields covered by the analogy.

According to Treagust *et al*. (2000), the literature on the use of analogies in teaching/learning science is ambivalent on the validity of the presentation of single or multiple analogies as the best way to teach (Zook, 1991; Goswami, 1992). The view that the use of multiple analogies can only be mastered by experts or by the teacher was defended by Grosslight *et al.* (1991), but Garnett and Treagust (1992) and Harrison and de Jong (2005) have shown that some students prefer to receive more than one analogy for each learning occasion. Harrison (2003) experimented with a teacher who used ten analogies over three sessions in the teaching of chemical equilibrium.

To summarize, chemical equilibrium is a complex and abstract topic of chemistry education, and the ability of analogies to promote conceptual change makes them a useful everyday tool for teaching. The main objective of this review is to classify and systematize all of the references to analogies of use of the teacher and the student that have been presented in the literature. This classification and systematisation will take account of several important aspects of chemical equilibrium, including some of the difficulties associated with them. A full example of an analogy is explained (that of the hydrostatic equilibrium) where an application of the annotations in Table 2 is given.

Analogies found in textbooks

High-school chemistry textbooks contain an average of eight to nine analogies per book (Thiele and Treagust, 1994a), which is comparable to the 8.3 analogies per text reported by Curtis and Reigeluth (1984) for typical general science textbooks. It should be noted that some textbooks from these studies contained up to 22 analogies per book; however, as the average number of analogies per book is approximately 8, the majority of textbooks presented in these studies must contain fewer than 8 analogies per book. This number is substantially lower than the number of analogies (43.5) found in biology textbooks by Thiele *et al.* (1995), although recently Orgill and Bodner (2006) have found an average of 20 analogies in six textbooks of biochemistry.

Curtis and Reigeluth (1984) classified textbook analogies under three categories, based on the analogy's degree of complexity. These are: simple, enriched and extended. The most common is the simple analogy where the book says something like a metaphor *"the tendency of a system to re-establish equilibrium is like a rubber band after being stretched"* or the well known historical examples of Volta and Ampere by the *"representation of electricity as if it was like the pressure and flow of a liquid"* or the Rutherford solar system analogy for the atom. Type two, the enriched analogies, includes the reasons for the likeness; for example, "assembling a car is like the mechanism of a chemical reaction, because both proceed step by step". The difference lies in telling the students how the analogue is like the target. Type three, extended analogy, comprises multiple simple and/or multiple enriched analogies that describe and explain the same target. The elaborated "super-rubber balls in a box" analogy (Parry *et al.*, 1976) for the gas phase of matter is one of the extended type. Orgill and Bodner (2006) found that biochemistry textbooks include mainly simple and enriched analogies.

Thiele and Treagust (1994a) classified targets and analogues as concrete or abstract. The item is concrete if it is sensorial and directly observable and/or consistent with student's everyday experiences. They found that the analogue concepts that explain abstract target concepts are concrete in nature in 87% of the 93 cases of analogies found in textbooks. Because concrete concepts are thought to be easier for students to understand than abstract concepts, a concrete analogue is used, in most cases, to help students understand abstract target concepts (Curtis and Reigeluth, 1984).

Some other criteria have been used to classify textbooks analogies (Curtis and Reigeluth, 1984; Thiele and Treagust, 1994a; Orgill and Bodner, 2006), such as the analogical relationship between analogue and target (structure-function or function); the presentation format (verbal or verbal-pictorial); and position of the analogue in relation to the target (advanced organizer, embedded activator or post-synthesizer). In the final classification the first category occurs when the analogy is presented prior to the main text of the chapter containing the primary discussion of the target concept; the second when the analogy is presented in the main text of the chapter which contains the main discussion of the target concept; and the third one when the analogy is presented in a chapter after the main discussion of the target concept.

Proposed analogies for chemical equilibrium

A general survey

Analogies to date have been used to strengthen the teaching of chemical equilibrium, and they continue to appear today in journals of chemical education in a great variety of formats. For example, the use of an analogy of the game with coins moved from one pile to the other (Bartholow, 2006), eighty years after the forerunner hydraulic analogy of Rakestraw in 1926, or that of Karns in 1927.

In this review we have included those analogies offered in (a) Journals, (b) The three great projects of the 1960s: Nuffield (1967), CBA (1964) and Chem Study (1963) and (c) some textbooks, the most recent being *ACS Chemistry* (Bell *et al.*, 2004).

We have analyzed 77 articles and texts, and found 39 different proposals of analogies for the explanation of chemical equilibrium. Table 1 shows on the one hand the various aspects of chemical equilibrium included in them and on the other hand the existing difficulties or alternative conceptions promoted. For each aspect and difficulty, Table 1 shows the number of proposals that consider each aspect of equilibrium, along with the number presenting analogies which may lead to misconceptions.

Table 2 shows the classification of analogies for chemical equilibrium according to the main aspects of equilibrium covered, some misconceptions that may be induced (in the column of 'difficulties') and the bibliographic reference. This table was inspired by that initially presented by Pereira (1990). It is important for the teacher to know the main difficulties of the analogy prior to teaching it, to try to diminish its detrimental effects on students.

The analogies were classified into five categories thus:

1. Familiar analogues,
2. Games,
3. Experiments,
4. Flow or transference of fluids,
5. Machines.

Wood (1975) provided a precedent for the classification of analogies of chemical equilibrium and chemical kinetics. This author classified 'instructional models' as: (I) hydrodynamic models, (II) vibrating bead models, (III) verbal and mathematical models, (IV) analogue computer models, (V) digital computer models, and (VI) Monte Carlo models. The first three coincide with categories 4, 5 and 1 used here.

The following are amongst the aspects of equilibrium illustrated by the analogies mentioned in Table 2:

- Dynamic aspect
- Equality of rates of forward and reverse reactions
- Reversibility of the reaction as the concept involved
- Calculation of the equilibrium constant for the reaction
- Changes in equilibrium conditions (and/or application of Le Chatelier's principle)
- Function of a catalyst in an equilibrium system

These characteristics of analogies for chemical equilibrium have been frequently mentioned as key aspects of its teaching and that is why we decided to analyze and mark whether each one of the analogies fulfils these criteria.

Table 1 Number of analogies which show the aspects illustrated and which promote alternative conceptions (from a total of 39 proposals of analogies)

Chemical equilibrium aspects illustrated	Dynamic aspect	28
	Equality of rates	27
	Reversibility	37
	Calculation of the equilibrium constant	11
	Changes in the conditions	22
	Function of a catalyst	6
Difficulties or alternative conceptions that can be induced	Compartmentalized vision	28
	Difficult relationship with the molecular level	24
	Confusions in relation to chemical kinetics	30
	Equality of concentrations of products and reactants	12
	System is not closed	6
	Confusion of amount with concentration	15
	Anthropomorphic or animistic images	6

With respect to the 'dynamic aspect,' we consider only those analogies that demonstrate that reactions at equilibrium continue to occur in both directions, with the system maintaining a constant composition. Very few analogies of dynamic equilibrium account for the making and breaking of bonds at a molecular level. Those that do positively include the 'dancing couples' (Hildebrand, 1946) or the 'clips game' (Desser, 1996).

The improper teaching of an analogy can lead to confusion or to the alternative conceptions (Piquette and Heikkinnen, 2005) listed below and are included in the 'difficulties' column of Table 2. An example is provided for each*:*

(a) Compartmentalization of equilibrium: reactants and products are situated in different containers, reactants usually at left and products at right (Johnstone *et al.*, 1977; Gorodetsky and Gussarsky, 1986).

(b) Lack of explanation at the molecular level: the analogy does not give a submicroscopic image, *i.e.* atoms, molecules or ions in movement (Bradley *et al.*, 1990; Nakhleh, 1992; Garritz, 1997).

(c) Generation of confusions in relation to chemical kinetics: students erroneously assume that the forward reaction must be completed before the reverse reaction starts; the analogy does not illustrate the model of collisions between particles (Bergquist and Heikkinen, 1990).

(d) Equality of concentrations: when equilibrium is reached the concentration of reactants is the same as that of products (Hackling and Garnett, 1985; Huddle and Pillay, 1996).

(e) The system under consideration is not closed (Furió and Ortiz, 1983; Bradley *et al.*, 1990).

Table 2 Main analogies used in the teaching of chemical equilibrium

	Analogies	Illustrated aspects						Difficulties							References
		Dynamic aspect	Equality of rates at equilibrium	Reversibility	Calculation of the constant	Changes in the conditions	Function of a catalyst	Compartmentalized vision	Difficult molecular level	Confusions with chemical kinetics	Equality concentrations of products and reactants	System is not closed	Confusion of amount with concentration	Anthropomorphic or animistic images	
Familiar analogues	1. Dancing couples	√	√	√	-	√	√	-	-	-	-	-	-	√	Caldwell, (1932); Hildebrandt, (1946); Olney, (1988)
	2. Dancing couples	√	-	√	√	√	-	-	-	-	-	-	-	√	Battino, (1975); Baisley, (1978)
	3. Golf balls in a van	√	√	√	-	-	-	√	√	√	√	-	-	-	Chem Study, (1963)
	4. Two groups throwing balls/apples between them	√	√	√	-	-	-	√	√	√	-	-	-	-	Hambly, (1975); Dickerson & Geis, (1981)
	5. Person running on a treadmill	√	√	√	-	√	-	-	√	√	-	-	-	-	Mickey, (1980)
	6. Escalator/ crosscurrent swimming	-	√	-	√	-	√	√	√	√	-	-	-	-	Hill & Holman, (1978); Chem Study, (1963)
	7. Fish between two aquariums	√	√	√	-	-	-	√	-	√	√	-	-	√	Chem Study, (1963); Olney, (1988)
	8. Fish between two aquariums	√	√	√	-	√	√	√	-	√	-	-	-	√	Russell, (1988)
	9. Bees in a beehive	√	√	√	-	-	-	-	√	√	-	√	-	√	Olney, (1988)
	10. Two people with spades	√	√	√	-	-	-	√	√	√	√	-	√	-	Riley, (1984)
	11. Painting and sponging	√	√	√	-	-	-	√	√	√	-	-	√	-	Garritz, (1997)
	12. Juggler	√	√	√	-	-	-	-	√	√	-	-	-	-	Umland & Bellana, (2000)
	13. People (in cities, sports centers, etc.)	√	-	√	-	-	-	√	√	√	√	√	-	-	Lewis, (1933), Licata, (1988), Thiele, (1990), Chang, (1999)
Games	14. Wood blocks	-	-	√	√	√	-	√	√	√	-	-	√	-	Slabaugh, (1949)
	15. Paper counters	√	√	√	-	-	-	√	-	√	-	-	-	-	Lees, (1987)
	16. Spheres	√	√	√	-	√	-	-	-	√	-	√	-	-	Harsch, (1984)
	17. Spheres	√	√	√	√	√	-	-	-	√	-	-	-	-	Cullen, (1989)
	18. Beans	√	√	√	-	√	-	-	-	-	-	√	√	-	Dickinson & Erhardt, (1991)
	19. Clips	√	√	√	-	√	-	-	-	√	-	-	-	-	Desser (1996)
	20. Cards, matches, cubes, coins	√	√	√	√	√	-	√	-	-	√	-	-	-	Marzzacco, (1993); Huddle & Ncube, (1994); Ncube & Huddle (1994); Wilson (1998); Quílez *et al.* (2003); Edmonson & Lewis (1999); Huddle *et al.* (2000), Harrison & Buckley, (2000); Hanson, (2003); Bartholow, (2006)

Table 2 continued: Main analogies used in the teaching of chemical equilibrium

Analogies		Illustrated aspects						Difficulties							References
		Dynamic aspect	Equality of velocities at equilibrium	Reversibility	Calculation of the constant	Changes in the conditions	Function of a catalyst	Compartmentalized vision	Difficult molecular level	Confusions with chemical kinetics	Equality concentrations of products and reactants	System is not closed	Confusion of amount with concentration	Anthropomorphic or animistic images	
Experiments	**Physical changes**														
	21. Phase change	√	√	√	-	-	-	√	-	-	-	-	√	-	Nuffield, (1967); Thiele, (1990); Caruso *et al* (1997)
	22. Solubility	-	-	√	-	-	-	√	-	√	-	-	-	-	Chem Study, (1963); CBA, (1964); Lees, (1987)
	23. Rubber band	-	-	√	-	√	-	-	√	√	-	-	-	-	Balckwill, (1976); Smith, (1977)
Flow	**Liquid transfer between containers**														Sorum, (1948); Kauffman, (1959); Carmody, (1960); Hugdahl, (1976);
	24. Small glasses	√	√	√	-	-	-	√	√	√	-	-	√	-	Martin (1976); Dunn, (1980); Laurita, (1990); Garritz & Chamizo, (1994); ACS, (2005)
	25. Small glasses	√	√	√	√	-	-	√	√	√	-	-	√	-	Smoot *et al.*, (1978)
	26. Graduated cylinders and pipettes	√	√	√	√	√	√	√	√	√	-	-	√	-	Russell, (1988)
	27. Siphon, hydrostatic equilibrium	-	-	√	-	√	-	√	√	√	√	-	√	-	Hansen, (1984); Donati *et al*, (1992)
	28. Pumps	√	√	√	-	-	-	√	√	√	√	-	√	-	Rakestraw, (1926)
	29. Pumps	√	√	√	-	√	√	√	√	√	√	-	√	-	Kams, (1927); Weigang, (1962)
	30. Gas flow between syringes	-	-	√	-	√	-	√	√	√	√	-	√	-	Thomson, (1976)
Machines	31. Movement of balls with water flow	-	-	√	-	√	-	√	√	√	√	√	√	-	Tucker, (1958)
	32. Movement of balls with air flow	√	√	√	-	√	√	√	-	-	-	-	-	-	Dainton & Fisher, (1969); Sawyer & Martens, (1992); Nash & Smith, (1995)
	33. Movement of balls with paddles	√	√	√	√	√	-	√	-	-	-	-	-	-	Alden & Schmuckler, (1972); Hauptmann & Menger (1978); Rämme (1995)
	34. Movement of balls with a vibrator	√	√	√	-	-	-	√	-	-	√	-	-	-	Fiekers & Gibson, (1945); Donaldson & Owens, (1964)
	35. Movement of flies through an opening	√	√	√	√	√	-	√	√	√	-	-	-	√	Runquist & Runquist, (1972)
	36. Seesaw	-	-	-	√	√	-	√	√	√	-	√	√	-	Russell, (1988)
	37. Scale with test tubes	-	-	√	-	√	-	√	√	√	√	-	√	-	MacDonald, (1973)
	38. System of pulleys	-	-	√	√	√	-	√	√	√	-	-	-	-	Thomson, (1976)
	39. Mechanical equilibrium laws	-	-	√	-	-	-	-	√	-	-	-	-	-	Canagaratna & Selvaratnam, (1970)

(f) Confusion of amount with concentration: the student uses the following terms indiscriminately: concentration (moles/L), mass (grams) or amount of substance (moles) (Wheeler and Kass, 1978; Furió and Ortiz, 1983).
(g) Anthropomorphic or animistic images: the analogy offers humanization of objects or animals in its description (Astolfi, 1994).

The images constructed by pupils (propositions, drawings, analogies) on chemical equilibrium phenomena after they have been taught the topic, and the implicit theories they developed were recently presented by Raviolo (2006), from the perspective of mental models. These ideas show that it is not appropriate to use the image of a pendulum to represent chemical equilibrium (de Berg, 2006).

Analogies in classroom practice

Thiele and Treagust (1994b) identified the analogies that were used in the classroom practice of four teachers when they introduced conceptually abstract topics such as chemical equilibrium. Most of the analogies arose from the teacher's response to a prompt by a student, such as a puzzled look or an interesting question. The analogies expressed by the teachers were similar to those presented in textbooks, supporting the claim that texts are one of the main sources of analogies. Some of the simple analogies used as part of the chemical equilibrium topic are presented in Table 3.

Fabiao and Duarte (2005) investigated the difficulties experienced by trainee science teachers when they tried to produce analogies of chemical equilibrium. Particular difficulties were identified in the use of analogies to explain changes to the equilibrium system and Le Chatelier's principle (Quílez and Solaz, 1995). The greatest problem arose when selecting the analogue and/or the correspondence established between analogue and target. Some of the selected analogies induced or reinforced alternative conceptions. For example, the analogy of two connected globes transmits the idea of equilibrium compartmentalization. Other analogies highlight students' ignorance of the characteristics of an equilibrium system (closed system, constant composition). In general, the analogies selected by students allow us to establish superficial correspondences between analogue and target. The analogy of the 'pot with boiling water' proposed by a group of students, constitutes the well known strategy of the introduction of chemical equilibrium through phase equilibrium.

Harrison and de Jong (2005) presented the development of Pedagogical Content Knowledge (PCK, *"the subject matter knowledge for teaching"* in words of its creator, Shulman, 1986) of an expert chemistry high school teacher in Australia in three chemical equilibrium lessons. In this short period he discussed ten analogies, including the 'school dance' once in a short version and again in an elaborated version. The authors conclude that *"this is an instance of PCK in action"*. Interesting strategies present in this teacher's PCK include his negotiation of the limitations of some analogies with the students and that he invited lower achievers to retell analogies in their own words.

Table 3 Analogies introduced in the classroom on chemical equilibrium (Thiele and Treagust, 1994b)

Analogue	Target
Breaking apart a pen and its cap	Energy required to break chemical bonds
Water flowing in and out of a sink	Constant dynamic properties in a steady state open 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
People moving in and out of a shop	Rates of forward and reverse reactions for equilibrium
Person walking up and down an escalator	Competing forward and reverse rates of reaction

Thinking about the effect of this study for teaching by using analogies

This review of chemical equilibrium analogies will be useful for the teacher-reader because it provides an extensive repertoire of analogies to teach the topic, stressing several of the key aspects of the phenomenon (such as the strengthening of the dynamic aspects of equilibrium; equality of forward and reverse rates at equilibrium; reversibility inside the analogy; the appearance and calculation of an equilibrium constant; and the system reaction attained through changes in the conditions of equilibrium. It also identifies the alternative conceptions that can be generated in the students).

The usefulness of this study will be reinforced if teachers develop a convenient methodology for presenting the analogies. Jarman (1996) highlighted the lack of practical advice to introduce teachers to the use of analogies in teaching.

As a result of experience and research, didactic sequences to teach analogies have been suggested. For example, the sequence TWA (Glynn, 1991) comprised six steps:

1. Introduce the target concept.
2. Cue retrieval of the analogue concept.
3. Identify relevant features of both target and analogue.
4. Map similarities.
5. Indicate where the analogy breaks down.
6. Draw conclusions.

This sequence of steps can be varied, but it is vital that all steps are taken. Since the effectiveness of the analogy is indicated by the progress of the student in assimilating the set of relations established between the target and analogue domains, the exploration of the analogue concept is important. The idea is to take advantage of the student interest and motivation that the use of analogies represents. This can be enhanced by asking students to present and explain supplementary analogies. Several researchers asked students to produce their own analogies (Pittman, 1999; Harrison, 2003; Harrison and de Jong, 2005) and concluded that this activity can be used as a formative assessment of the comprehension of additional concepts, because students' explanations were enhanced. This type of active participation encourages autonomy, self-esteem and motivation in the students (Sarantopoulos and Tsaparlis, 2004).

Harrison and Coll (2008) have recently presented the FAR guide (Focus-Action-Reflection) that incorporates a pedagogical reflection at the end of the activity with analogies in the classroom. The steps contained in this guide are:

Focus

Concept: Is it difficult, unfamiliar, or abstract?

Students: What ideas do the students already know about the concept?

Analogue: Is the analogue something your students are familiar with?

Action

Similarities: Discuss the features of the analogue and the science concept, and identify the ways they are alike

Differences: Discuss in what way the analogue is unlike the science concept.

Reflection

Conclusions: Was the analogy clear and useful, or confusing? Did it achieve your planned outcomes?

Improvements: In the light of the outcomes, are there any changes you need to make for the next time you use this analogy?

Harrison and Coll used this guide to present the 'school dance analogy' (dancing couples) for chemical equilibrium, and highlighted the necessity of illustrating the analogy and explaining an unshared attribute of the analogue and the target, *i.e.* the closed-system concept.

As an example of how Table 2 can be of assistance in the teaching of chemical equilibrium, the analogy of hydrostatic equilibrium (Donati *et al.*, 1992) is developed below (Figure 1). This highlights the simile analogue-target, the central aspects of the analogy and the limitations related to the generation of alternative conceptions.

The aspects of chemical equilibrium that this analogy illustrates are (they are included in Table 2):

- The system reaches the equilibrium spontaneously.
- Equilibrium is attained from: (a) reactants only (water in R receptacle, valve closed, Figure 1A) (b) products only (water in receptacle P) and (c) different amounts of reactants and products (different levels in both receptacles).
- The analogy allows the calculation of an equilibrium constant (equal to 1 in this case).
- The system can return to equilibrium after a perturbation, *e.g.* after adding more water into receptacle P (Figure 1B).
- The rate at which equilibrium is reached can be increased by widening the diameter of the duct between the two receptacles.

Amongst the analogy's most evident limitations are:

- Reactants and products are located in different receptacles (compartmentalization of equilibrium).
- It does not offer a submicroscopic image of chemical equilibrium.
- It generates confusion in relation to the rate of reaction (water flows only in one way each time some is added).
- It shows an equality of 'concentrations' of reactants and products in equilibrium.
- The chemical equilibrium constant is equal to 1.
- It generates confusion between amount and concentration.

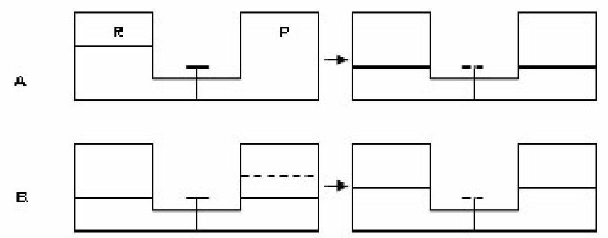

Fig. 1 Hydrostatic equilibrium analogy. On the left hand side diagrams the valve is closed, on the right it is open. In A there is water only in receptacle R and then the valve is opened. In B the equilibrium position is perturbed by adding water in receptacle P and then the valve is opened.

If students identify the analogy's limitations then the teacher can see whether the analogy has been well understood or not, and whether the students have been able to transcend the analogue. These examples clearly show the advantage of presenting several analogies of the concept simultaneously.

Analogies in the development of science

It is worthwhile emphasizing in the classroom that analogies are often used by scientists in their effort to comprehend the world around us and to elaborate and communicate their ideas. As van Driel and Gräber (2002) have stated for the particular case of chemical equilibrium, in 1867 Pfaundler reformulated the idea of Williamson (that explains equilibrium as two simultaneous opposing reactions), based in the molecular explanation given by Clausius in 1857 for the evaporation of a liquid. Pfaundler reasoned in terms of moving and colliding particles, whose kinetic energy is spread around a certain mean value related to temperature. This analogy is used by Caruso *et al.* (1997) to construct the idea of equilibrium from the well known and meaningful event of water evaporation.

Conclusions

Analogies constitute a valid strategy for the teaching of chemical equilibrium because of the complexity and abstraction of the idea and the ability of analogies to promote conceptual change. Both the reversible and dynamic nature of chemical equilibrium can be visualized through analogies.

When chemical phenomena are presented in the classroom, relationships between the macroscopic, symbolic and microscopic levels are established, although students often incorrectly transfer properties from one level to the other; for example, they transfer ideas about properties of macroscopic bulk to atoms, ions and molecules. If this occurs frequently with a scientific concept, it is probable that it will also occur when the analogue, a different phenomenon, is applied.

Many of the analogies proposed illustrate an equilibrium state with constant, although static, composition. Very few demonstrate the dynamic nature of the reversible reaction, with breaking and formation of bonds or redistribution of atoms among molecules. That is why it is advisable to include the teaching of analogies such as 'the school dance' or 'the clips game'.

We have gathered the references for a large set of analogies that may be used in the teaching of chemical equilibrium and their characteristics and limitations have been identified. It is important for teachers who decide to use analogies to teach chemical equilibrium to be aware of the response of their students, their newly acquired conceptions and the effectiveness of analogies to support their learning.

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