5 Analysis of Metals: A chemical unit of the Salters' Science curriculum

In Chapter 4, I described, analyzed, and compared the visionary, designed, written, and formal curriculum levels of the Salters' Chemistry course. My research there focused on the course *taken as a whole*, either on the Foundational course or on the GCSE exam course.

In this complementary chapter, I will perform a similar analysis but now focused on a course *unit*, namely on the chemical unit Metals of the Salters' Science course (1989), while extending the curriculum analysis to the interpreted, taught, and experienced curriculum levels of the unit. The process of developing the chemical unit Metals, and now also the process of teaching the unit in the classroom, will again be analyzed in terms of my curriculum theoretical framework, that is, in terms of the substructures pertaining to each curriculum level of school chemistry, the concept of curriculum emphasis and the concept of normal science education.

In section 5.1, I will give the rationale for performing a case study on the unit Metals, the method of analysis of the lessons of this unit, followed by a description of the design criteria and the pedagogical, philosophical, and substantive structures of Metals (1989).

Secondly, I will perform a consistency analysis on the unit Metals, taken as a C*hemistry through Technology* (CTS) curriculum unit, on the written curriculum as operationalized in the *lessons* of the unit Metals (5.2). This kind of analysis, performed at the level of specific lessons of a particular unit, makes it possible to see more precisely the extent to which the developers were able to fulfill in a *consistent* way the adopted design criteria.

Thirdly, I will describe and analyze how a teacher congenial to the Salters' approach *interpreted* the written curriculum as embodied in the lessons of Metals (1989), and *taught* the lessons of Metals thus interpreted in the classroom (5.3).

Fourthly, I will describe and analyze how the curriculum, as embodied in the lessons of the unit Metals (1992) and as taught by the teacher, is *experienced* by students (5.4).

Fifthly, I will compare the curriculum realized for Metals – at the written, interpreted, taught, and experienced levels – with, on the one hand the formal curriculum of Metals, and, on the other hand, with Normal Chemistry Education (NCE) as represented by O-level chemistry as it existed in the 1980s in England (Figure 5.1). Subsequently, I look back, both at the different articulations and operationalizations of the visionary curriculum of the Salters' Chemistry course, as discussed in Chapter 4, and at the analysis of the lessons of the written unit Metals (1989) and its different operationalization, as discussed in Chapter 5 (section 5.5).

5.1 Introduction

I will begin by giving my reasons for performing a case study on a unit of the Salters' Science course, Metals (1989), that is, for doing empirical classroom-based research on the teaching and learning processes, and for performing an in-depth consistency analysis of the intended and realized lessons of the unit Metals (5.1.1). Following that, I will describe and analyze the Salters' design criteria as formulated by the developers of Metals and the authors of the Teachers Guide (5.1.2). Subsequently, I discuss the problem of interpretation of the Salters' design criteria, and will give the interpretation I have chosen as a starting point for my consistency analysis of Metals (5.1.3). Next, I will describe the specific method I used for the consistency analysis of the content of the lessons of the unit Metals (5.1.4). Finally, I will give the content of Metals (1989) represented in terms of Schwab's categories (5.1.5).

5.1.1 Rationale of the case study of the Salters' Science unit Metals

As noted in section 4.1.2, I initially wanted to do curriculum research on two units of the Salters' *Chemistry* course (1987). This *central* chemistry-technology-society (CTS) course seemed at the time to be the best *theoretical* choice as well as to offer an excellent *practical* opportunity to test the effectiveness of a bold attempt to escape from Normal Chemistry Education in England. However, I was led to perform classroom-based research on two units of the Salters' *Science* course, modeled and developed after the Salters' *Chemistry* course (1987). For reasons explained below, one of these units, namely the unit Metals (1989), was subjected thereafter by me to the in-depth curriculum analysis reported on in sections 5.2, 5.3, and 5.4.

New developments in the educational system of England and Wales (Figure 5.1) interfered with my initial research plan. From 1990 on, it became mandatory for schools to follow the National Curriculum (DES, 1989) and, from 1992, the revised version thereof (DES, 1991).

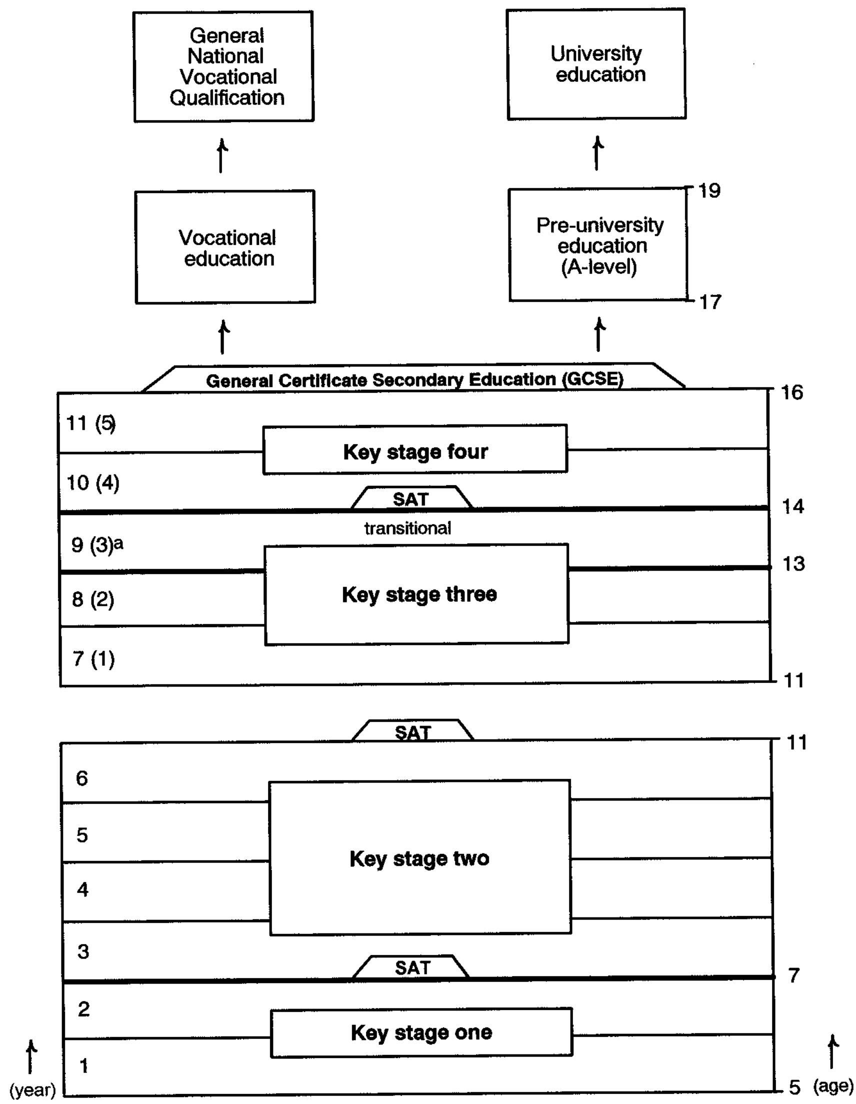
The National Curriculum required the provision of a so-called *balanced science* course, that is, a science course containing a balanced mix of biology, chemistry, and physics units. Many users (schools, departments, teachers) of the Salters' GCSE *Chemistry* course from 1990 on therefore transferred in increasing numbers to the Salters' GCSE *Science* course (Campbell, 1994). Many Salters' schools in the vicinity of the University of York also took up Salters' Science instead of Salters' Chemistry. I wanted to use York as a base to do classroom based research, to interview the developers and study the Salters' teaching materials. With the help of Peter Nicolson, Project Officer of the Salters' Science Project, I started looking around for a school with a chemistry teacher willing and interested to permit me into her/his classroom while s/he taught chemistry using *chemical* units of the Salters' *Science* course.

The structure and content of units of the Salters' Chemistry course (1987), Nicolson felt, were largely *retained* in the *chemical* units of the Salters' Science course, such as the Third Year unit Metals (1989). (For the differences between Metals, 1987, and Metals, 1989, see the analysis given in section 5.1.4, and also Figure 5.5.)

Furthermore, schools and science teachers had to comply with the requirements of the National Curriculum (DES1991) as to whether they would teach units of the Salters' Chemistry course (1987) or chemical units of the Salters' Science course (1989).

Although the external constraints for the development, trialling, and teaching of the Salters' Chemistry course differed (noted in Chapter 4) in some important aspects from

Figure 5.1 Educational System England and Wales within the National Curriculum



[a] Before the introduction of the National Curriculum (DES, 1989), Year Nine was referred to as Year Three.

those present for the development, trialling, and teaching of the Salters' Science courses, there was also some common ground. First, developers of both courses had to take into account *nationally* set criteria, the National Criteria for Chemistry in the former case, and the more constricting criteria laid down by the National Curriculum in the latter. Nonetheless, as the developers have stated:

> ... the *original* design criteria provided a viable means of making the major decisions about curriculum content *throughout* the development program (Campbell et al., 1994, p. 420).

Both courses, Salters' Science and Salters' Chemistry, set out to solve a similar problem, that is, to devise a science or chemistry course which would gain and retain the engagement and interest of children so as to provide the basis for scientific or chemical literacy for those who would finish their formal study at age16. Also, the respective courses aimed to increase the number of students choosing to carry on studying science beyond 16 (Campbell et al., 1994, pp. 418, 424). Further, year Three, or as it was later called year Nine, remained in a way a *transitional* year in which some kind of "foundation" had to be laid down for the last two years of science in the form of an *examination* course; in the first two years of their secondary schooling students received introductory or *general* science teaching.

There were also some differences. Before 1989 students could, as in the case of the Salters' Chemistry course, either choose chemistry for their GCSE examination or opt out at age 14. By the time the Salters' Science course had arrived, science had become a *compulsory* subject for *all* students till age 16.

Finally, a *balanced* science course, such as the Salters' Science course, often meant a course, which combined – but which did not necessarily integrate – physical, chemical, and biological units. As a rule teachers of a single science taught such a course within their own specialization (Hezeken, 1996). The National Curriculum also came to mean, in general, a greater emphasis on scientific content and processes, and a lesser emphasis on relevant contexts. So, a study of the development and teaching of Salters' Science units under constraints as set by the National Curriculum would also give me the opportunity to analyze the effects of these increasingly more constricting criteria on the content and structure of the course units and on their execution by the teacher. Such a study could shed some light on mechanisms of change under nationally imposed external criteria or constraints. Although from a strictly theoretical point of view, I would have preferred to do research on two units of the Salters' Chemistry course, perhaps one from Year 3 and one from Year 4, practical reasons led me to a compromise, namely, to perform *classroom-based* research on two *chemical units of Salters' Science*.

The analysis of the data collected by the classroom-based research (observation, interviews, questionnaires, and audio taping) turned out to be rather time consuming, as was the ensuing in-depth curriculum analysis. Therefore, I limited my research to a case study of Metals (1989), a Salters' Science Foundation unit from Year 3.This was the *first* unit usually taught to 13 – 14 olds, because, according to trial teachers:

> Teaching <u>Metals</u> first allows the introduction of a number of *basic* concepts at an early stage: elements, mixtures, compounds, reactions and reaction rates (OGT, p. 22).

Thus, this unit provided an educational situation furthest removed from examination constraints, probably the most favorable situation to investigate the question, to what extent a chemistry teacher congenial with the Salters' approach would execute a chemical unit in accordance with the Salters' criteria; that is, with fewer constraints present, whether external or internal, a teacher should have a greater chance of realizing the intentions of the developers. For example, there are probably more opportunities for a teacher to devote a substantial amount of lesson time to *relevant* contexts and topics in an early Foundational Year Three unit such as Metals, than in year Four or Year Five units, which are closer to the GCSE examination. Furthermore, the unit Metals (1984) was one of the prototype units of the Salters' Chemistry course, which makes possible a comparison with Metals (1987) and Metals (1989), given in section 5.2.8 (see Figure 5.14).

Since the unit Metals survived various trials, either as a Salters' Chemistry trial unit or as a Salters' Science trial unit, it must have been evaluated by the developers as a good example of the operationalization of the Salters' approach to school chemistry as defined by their design criteria. Compared to other Salters' Chemistry units, the unit Metals is considered by the developers as a typical unit with regard to the teaching activities deployed (see 5.1.2). As we will see below (5.4.4), students perceived the unit Metals as an average unit in terms of interest in science and understanding of everyday problems (Ramsden, 1992). For these reasons, the unit Metals is taken here as being a *representative* Salters' unit.[1]

5.1.2 Design criteria

Just as in the *Chemistry (Salters') Syllabus* (SLB) and the *Overall Guide for Teachers* (OGT), there is neither an explicit nor an implicit reference in course units such as Metals[2] to the first criterion, *no preconceptions*. The OGT (p. 16) advises teachers to become familiar with the course by considering, among others, the question: "What are the design criteria of the course?" Although the other four criteria are mentioned in the OGT, and in unit guides such as Metals, there is no reference to the first criterion. This is partly to be expected, since the developed units and the ensuing syllabus had to fit the constraints set by the National Criteria of Chemistry in order to get SEAC validation (see Chapter 4). Thus, in the end the developers had to conform, albeit reluctantly, to the preconception of school chemistry as contained in the National Criteria. Furthermore, the developers might have thought that this first design criterion was not of immediate concern for teachers *using* already trialled units in the classroom.

The second criterion, *relevance*, was formulated in the introduction to Metals (1989) as follows:

> It [the unit] should have its *origins*, and hence its *justification* for study, in *aspects of everyday life* with which students aged 13 – 16 years will be familiar either personally or through the media.

---

1 The second unit I considered for an elaborate case study was a Year Four unit, Transporting Chemicals (1987). My purpose would have been to see how a chemistry teacher executes a chemical unit at a conceptually later stage of the curriculum, in the first year of the Salters' Science GCSE exam course. It was recommended by the developers as a good unit to start the year because it "introduces atoms, molecules, formulas, and equations. If it is taught first in the fourth year, it allows the use of these concepts in later units." (OGT, p. 23). For reasons mentioned above, I limited the research to the unit Metals.

2 "Metals" usually stands for Metals (1989), a *chemical* foundation unit of the Salters' Science Course, produced as a limited edition for a full course trial by the Salters' Science Project (1989). I analyzed this unit (section 5.2) and observed its execution in the classroom as Metals (1992), that is Metals (1989) as interpreted and taught by the teacher (5.3) and experienced by the pupils (5.4). For purposes of comparison, I will occasionally refer to Metals (1987), the revised edition of the third year unit of the Salters' GCSE Chemistry Course, and to Metals (1984), a third year unit of the Chemistry (Salters' Project), trial edition 9/84.

The third criterion is formulated in the introduction of the unit Metals (1989) as follows:

> Scientific concepts and explanations should *arise naturally* from the study of these everyday situations and should *only be introduced when they are needed*. Social, economic, environmental, industrial and technological aspects of science are, therefore, *fundamental* to the whole course.[3]

The fourth criterion, *variety of teaching and learning activities*, is not mentioned explicitly in the unit Metals but has found explicit formulation[4] in both the SLB (p. 1) and the OGT (p. 9). From the activity analysis it is clear that a variety of teaching activities has been *used* by the developers in writing the course units. The following set of teaching activities (OGT, p. 39) is deployed in the unit Metals, see Figure 5.2.

Although traditional, teacher-led activities receive less attention in the OGT (section 4.6.2), inspection of Figure 5.2 seems to suggest that they occur at least as frequently as student-centered activities and other less familiar teaching activities.[5] Of course, only on the basis of empirical, classroom-based research of the lesson activities of the unit Metals (section 5.2) is it possible to ascertain whether traditional teaching/learning activities still take up a substantial amount of the lesson time in a student-centered, context-led unit of an CTS course such as Metals (1989).

A fifth criterion, *flexible, teacher-mediated use,* has been formulated in the course units in a section of the introduction called "Design of materials":

> The materials must be *flexible* enough to allow teachers to introduce *replacements and modifications* to parts of *lessons*, whole lessons or even *whole units* where they feel it is appropriate. A science department should be able to regard the course as a starting point from which they could develop their own teaching syllabus.

Consistent adherence to this criterion would put teachers squarely in the role of developers. This would call for an explicit statement and explanation by the developers of *all* design criteria, including the first criterion, *no preconceptions*, in the course units, the SLB, and the OGT.

In the next section (5.2), I will give a detailed content analysis of the *lessons* developed, focusing thereby on the second and third criteria, in order to determine to what extent the developers of Metals managed to *adhere consistently* to design criterion two, *relevance,* and to design criterion three, *context-led-development of concepts*.

The implicit role of the first design criterion is discussed in section 5.2.8, and the role of the fourth and fifth design criteria is exemplified in section 5.3.2, the Interpreted Curriculum. The analysis here is thus concentrated on design criteria two and three, with occasional reference to design criterion five. The latter criterion is discussed more fully

---

3 Metals (1987) gives, but for the word *chemical* replacing *scientific*, the same formulation of design criterion three. Design criterion two is worded exactly the same in Metals (1987) and Metals (1989).

4 Borgford (1992) notes that the categorization of teaching activities emerged during an INSET course. This seems a good example of the process of articulating or discovering a design criterion during, and as a result of, the developmental process (Campbell, 1994, p. 422).

5 Compared to other Salters' Chemistry units, Metals might be considered as a typical unit in this respect. Thus, a few units contain fewer student-centered activities, such as Burning and Bonding (1987), whereas some other units contain more student-centered activities. For example, the unit Buildings (1987) contains five student-centered discussions, and other units such as Transporting Chemicals (1987) contain alternative teaching activities such as a role play for pupils.

Figure 5.2 Variety and frequency of teaching activities used in lessons Metals (1987)

Teaching activities*	**M1**	**M2**	**M3**	**M4**	**M5**	**M5X1**	**M5X2**	**M6**
Teacher introduction/ explanation-led discussion	+	+	+		+			+
Teacher-student discussion	+	+	+	+	+		+	
Student-student discussion				+				
Reporting to class (orally or in writing)					+			
Role play								
Teacher demonstration			+	+	+			+
Class practical	+	+	+	+	+	+	+	
Exp. design/problem solving/ directed discovery			+	+				
Questions (including text-related activities)					+			+
Data search/collection/selection	+							
Data analysis/interpretation/ translation	+	+		+	+			+
Surveys/displays	+							
Numerical work				+				
Making/using models								
Using computers				+				

* The symbol (+) indicates that a lesson of Metals contains a specific teaching activity.

in sections 5.3 and 5.4, while the former criteria (two and three) can be considered, as I argue, as the two *central* design criteria.

5.1.3 Interpretation of design criteria of Metals (1989)

In Chapter 4, I have described, analyzed, evaluated, and discussed the Salters' Chemistry curriculum as a whole while taking, initially in an implicit way, a *strong* interpretation of the design criteria. In section 4.7, I have given my reasons for taking a strong interpretation. In this chapter I will perform a consistency analysis of the lessons of the formal curriculum as operationalized in the chemical unit Metals (1989) of the Salters' Science course, while taking a strong interpretation of the Salters' design criteria right from the start.

Some of the teachers and developers involved at the early stages of the Salters' Chemistry project, including Francesca Garforth, took a strong interpretation of the design criteria, at least until the year 1989 when the National Curriculum began. The stronger or more radical interpretation of the Salters' design criteria is more interesting, certainly, from a research point of view. Thus, it is much more interesting to answer the question: *Does Salters' Chemistry escape from NCE?*, if the units of Salters' Chemistry are characterized by design criteria, interpreted in the strong sense. This way, the intended innovative school chemistry curriculum is considered as a *bold* attempt to escape from NCE, an attempt from which we can learn much about the external and internal constraints involved in the escape process, even if it fails to some extent.

If the developers take a *weak* interpretation of the design criteria, they will of course meet their design criteria more easily, either in the development of the units of the Salters' Chemistry course, or later in those of the Salters' Science courses (Campbell, 1994, p. 420), and the question of the escape from normal chemistry education will seem to lose its force.[6]

Thus design criterion one, *No preconceptions*, is to be interpreted in the sense that developers are supposed to get rid of any preconceptions, not only with regard to the *list* of chemical concepts, but also with regard to the *structure of school chemistry* as relating to chemical concepts and chemical relationships normally used in school chemistry for 13-16 year olds.

Design criterion two, *relevance*, is also interpreted in a stronger sense: the selected contexts should give rise only to those chemical concepts really needed to make sense of the CTS contexts (perhaps even introduce some relevant CTS content as well). Related queries are: Do the selected contexts for the lessons of the unit Metals (1989) or Metals (1992) all stem from a *coherent* theme of the unit, in this case the theme *corrosion*? Is the chemical content, deemed "worthy of study", as it says in Metals (1984), justified by the chosen CTS theme and contexts?

Again, design criterion three, *context-led development of concepts*, is interpreted in a strong sense, that is, "... introduce ideas and concepts *only as* they are needed" (Campbell et al. 1994, p. 419). This formulation implies that it will *depend* on the contexts used, and how frequent and in what depth concepts will be introduced and developed. This is a different, and stronger interpretation than the one reflected by the phrase, "only be introduced *when* they are needed", as used in Metals (1989), and the other units of the Salters' Science course. This latter phrase implies that developers will only *choose* the *time* of introduction or development of a concept, while the structure, sequence, and even the list of chemical concepts remains largely as given.

The interpretation of design criterion four, *variety of teaching and learning activities* varies, as we noted above (footnote 5). Based on information given by the developers (OGT, p. 39), the variety of activities of the unit Metals (1989) can be displayed as in Figure 5.2. Knowing that, it is possible to determine the extent to which a teacher executing the unit Metals in the classroom is interpreting, and/or able to use this level of variety to engage the pupils actively in class as intended by the developers. This will depend, of course, on how this variety is perceived or interpreted by those involved (sections 5.3 and 5.4).

The meaning of the last criterion, *flexibility*, is taken here in a strong interpretation. That is, it is taken to mean that teachers are allowed and encouraged "to introduce replacements and modifications to parts of lessons, whole lessons or even *whole units* when they feel it is appropriate" (Metals, 1989). Again there are queries. Should teachers be encouraged to make these changes at lesson and even unit level, while retaining the essence of the Salters' approach to chemical education as embodied in the adopted design criteria? Having done so, should they, if and when possible, trial any changes they have made in the course for effectiveness in their classrooms? In turn, would this imply that teachers are seen as co-developers, subjected to the same standards of empirical evaluation as the original developers? Are teachers free to use "the course as a starting

---

6 Some developers will take a middle position in that they see the Salters' Chemistry course, as "a unique hybrid" (Borgford 1992, p. 36) of a course for both academically and societally oriented pupils, preparing both groups adequately for their future science studies or societal roles.

point from which they could develop their own teaching syllabus" (Metals, 1989), whether or not their syllabus is in line with the Salters' design criteria? Should these changes, at unit or course level, be trialled for effectiveness?

The open and provisional character of the Salters' design criteria approach is a great asset to curriculum development. It can lead to a creative application of the adopted design criteria, resulting in the development of motivating and cognitively challenging teaching units by teams of researchers, developers, and teachers, and possibly of students. At the same time, though, it calls for a thorough *empirical* study to accompany the process of development. Ideally, we would like to research the processes of deliberation, articulation, and operationalization as they go on in, what could be called, the vision room and the designer room, (analogous to the research of the teaching and learning processes in the classroom). Failing such an empirical study of these processes taking place in the vision room and designer room, it is only possible to resort to interviews and document analysis, as we did in Chapter 4 for the Salters' Chemistry course. In the case of a concrete teaching unit, here Metals (1989), we can perform an *empirical* study of the teaching and learning processes in the classroom, followed by a consistency analysis of the content of the lessons of the unit Metals (1989).

5.1.4 Method of analysis of the lessons of the unit Metals (1989)

The analysis of the curriculum levels of the Salters' Chemistry *course* in Chapter 4 as well as the analysis of the design criteria (section 5.1.2) and of the formal curriculum of the *unit* Metals (section 5.1.5 below) was, and could only be, based on interviews with the developers and on formulations in publications, curriculum documents, and teaching materials. However, in the case of a particular course unit such as Metals (1989), it is also possible to analyze the content of concrete *lessons* in a unit, in order to see to what extent the design criteria of the course unit are adhered to *consistently* by the developers *designing the lessons* of a particular unit.

Each unit of the Salters' Science course (1989) gives a list of teaching materials (Figure 5.3). Most of these will be referred to throughout the analysis; for the lesson plans see Appendix 5.

Figure 5.3 Materials of unit Metals of Salters' Science (1989)

1. An overview (summary) of the unit.
2. An overall plan of the unit in the form of a flow diagram. Each box on the sheet represents one lesson (70 – 80 minutes).
3. A pre-planner indicating the less readily available materials and equipment that a science department may have to obtain in order to teach the unit.
4. A suggested plan for each lesson indicating the key ideas covered in the lesson. Key activities and techniques encountered during the lesson are also indicated.
5. Teachers' notes relating to teaching strategies, demonstrations, student activity guides, etc.
6. Student materials in the form of student activity guides (SAG) and student information sheets
(SIS). Care and safety in the laboratory is drawn to the attention of students at appropriate points in the SAG.
7. Sample assessment items for the whole unit.

Research questions

I will perform, in section 5.2, a detailed consistency *analysis* (see section 4.1.3) of the content of the lessons of the unit Metals.[7] The focus here will be on the two central design criteria of *relevance* and *context-led development of concepts*.

In the analysis of the lessons of Metals (1989), I will try to answer two research questions. The first research question stems from design criterion two: *relevance*:

1. Does each *lesson* of the unit Metals have its *origin*, and hence its *justification* for study, *fundamentally* in aspects of *everyday life*?

I have inserted the word 'fundamentally'. As the developers emphasized, these *everyday life* aspects or situations are related to "social, economic, environmental, industrial and technological aspects of science [which] are, therefore *fundamental* to the whole course".[8]

The second research question stems from design criterion three: *context-led development of concepts*, which can be put in the form of two sub-questions. The first of these is:

(2a) Do all chemical concepts and explanations, treated in the lessons of the unit Metals, *arise naturall*y *from* the study of these everyday situations?

This sub-question addresses the same point as question one if we take the meaning of the locution "arise naturally" as being similar to the locution "have its origin". The second sub-question addresses a different point, namely:

(2b) Are all chemical concepts and explanations, treated in the lessons of the unit Metals, *only* introduced *when they are needed*?[9]

The second research question addressed here is, therefore:

2. Are all chemical concepts and explanations, introduced in the lessons of the unit Metals *needed* for the study of these everyday situations?

In the previous chapter on the process of the development of the Salters' Chemistry course, I have analyzed the relations between dominant school chemistry (O-level) as it existed in England in the eighties, a form of NCE, and the structure of the Salters' Chemistry course. The latter, an alternative societally-oriented school chemistry

---

7 OGT (p. 9) refers to "each topic" and SLB (p. 1) to "each part" of the course in their formulation of design criterion two. It seems appropriate, therefore, to focus the analysis on the eight *lessons* of the unit Metals. Each lesson deals with a subset of topics or key points using a number of activities (see Appendix 5).

8 For this point about the fundamental emphasis of the course, see also SLB (p. 8).

9 The locution "only introduced when needed" seems to have an ambiguous meaning. Does it mean, that chemical concepts and explanations should be introduced only *as and when needed* for pupils on their way to citizenship, or, alternatively, that chemical concepts and explanations should be introduced as and when needed for pupils heading for a scientific/chemical career? Garforth (1982b) points to a similar ambiguity discussing the idea to teach pupils only the "essential chemistry" they need. She then asks herself: essential for whom, for future citizens or future chemists, for society or chemistry? Based on my description and analysis of the visionary curriculum (Chapter 4), I take it that, at least in the early stages of the Salters'

curriculum has been characterized by the fundamental emphasis that the developers wished to put on "social, economic, environmental, industrial and technological aspects of science" (Metals, 1989). In this chapter I will focus the analysis on the *lessons* of a particular unit of such a course, in order to compare the curriculum realized for the unit Metals – at the written, interpreted, taught, and experienced levels – with, on the one hand, the formal curriculum of Metals (1989), and, on the other, with NCE.

Pure chemistry versus chemistry-technology-society content

The lesson plans of all the units of Salters' Chemistry (1987) contain the following headings "TYPE OF ACTIVITY, ACTIVITY, REQUIREMENTS, OUTCOMES, SKILLS PRACTISED". The developers have further identified two types of outcome (Metals, 1987):

1. Fundamental chemical ideas, concepts, principles, patterns, etc. are preceded by an asterisk." (emphasis developers).
2. Social, economic, environmental, industrial and technological aspects of the subject are italicized".

A categorization of the unit Metals (1987), based on this distinction and the accompanying notation (asterisks/italics) is given in Figure 5.4.[10]

Figure 5.4 Lesson plans of Metals (1987), written unit of the Salters' Chemistry Course

Lesson		Key teaching points / Outcomes[a]
M1:	WHAT ARE METALS?	- *Metals are important materials in extensive use* * Characteristic physical properties of metals (2x) - Names of common metals (2x) * Each metal can be represented by a symbol - *Relationship between the use of a metal and its properties* - Using apparatus to test for electrical conductivity (P)
M2:	WHICH METAL IS USED TO MAKE A DRAWING PIN?	* Metals have similar physical properties - Chemical tests better than physical tests in distinguishing between metals - *Relationship between the properties of metals and their uses* - Testing for metals in solution (P)
M3:	WHAT HAPPENS WHEN METALS CORRODE?	- *Metals are often corroded* - *Corrosion occurs at the surface of metals* - *Corrosion produces a new substance* - *Some metal is used up to produce this new substance* * An element is the simplest possible substance * A chemical reaction involves the formation of a new substance * A compound forms when two or more elements combine

[10] The trial edition Metals (1984) contains a precursor of this distinction, namely, between "understanding of and ability to use CONCEPTS which are also met elsewhere in the course [and] understanding of the TECHNOLOGICAL, SOCIAL and ECONOMIC implications of chemistry" (emphasis developers).

Figure 5.4 Lesson plans of Metals (1987), written unit of the Salters' Chemistry Course (continued)

Lesson		Key teaching points / Outcomes[a]
M3X:	A closer look at corrosion and burning.	- *Air and water are both needed for rusting* - *Salt accelerates rusting* - *Iron is used up during rusting* - *A new substance is formed when iron rusts* * Elements can combine to form compounds, they cannot be made to weigh less
M4:	Do all metals corrode?	- *Air and water are both needed for rusting* - *Salt accelerates rusting* * The Reactivity Series - *Corrosion involves reaction with oxygen* * Gain of oxygen is called oxidation * Metals (elements) form compounds when they react with oxygen - *Importance of preventing corrosion* - *Methods used to prevent corrosion* - Testing for hydrogen (P)
M4X:	How can we prevent rusting	- *Rusting is prevented by excluding air and/or water* - Manipulating apparatus and materials (P) - Using chemicals safely (P)
M4X2:	Do other metals stop iron from rusting?	- Using a control (O) - Controlling variable (O)
M5:	What are metal alloys?	- *Methods used to prevent rusting* - *Importance of preventing corrosion* - *Metals above iron in the reactivity series slow down rusting; those below iron speed it up* - *An alloy is a mixture of one metal with one or more other elements* - *Forming an alloy changes the properties of a metal* - *The composition of an alloy determines its properties* - *Relationship between properties of alloys and their uses*

[a] Outcomes or key teaching points are stated on the lesson plans. Two types of outcomes have been further identified:
1. Fundamental chemical ideas, concepts, principles, patterns, etc. preceded by an asterisk.
2. Social, economic, environmental, industrial, technological aspects of the subject are italicized.
The skills practiced by students are coded on the lesson plan as follows: P – practical skills; O – other skills.

The first impression one gets from the distribution of these two types of outcomes is that the two kinds of "key teaching points", as they are also called (Metals, 1987), are addressed about *equally* in the unit. A number of key teaching points (9), though, are neither provided with an asterisk nor italicized. It will probably depend on the specific context of the lesson as to how these terms are to be interpreted, as fundamental or societal content, or whether they remain ambiguous. For example, the term *burning* can refer to a fundamental chemical context such as oxidation reactions or to a societal context such as the operations of a fire brigade (section 5.3). Assuming that these ambiguous key teaching points are divided about equally, the ratio between fundamental and societal content will remain about the same.

STS curriculum categorization by Aikenhead

A similar distinction to that made (above) by the developers for chemistry education has been made by Aikenhead (1994, pp. 47-59) for science education, namely, between traditional, or pure science (PS) content, and science-technological-society (STS) content. The distinction between PS content and STS content was made in order to devise a scheme describing eight categories of STS curricula. Category one of the curriculum spectrum contains hardly any STS content (*ca.* 5%), thus mostly PS content, while category eight of the spectrum contains mostly STS content (80% or more) and little PS content (ibid., pp. 55-56).

The Salters' Science Project is classified by Aikenhead in his curriculum spectrum as a category five curriculum, labeled "SCIENCE THROUGH STS CONTENT"; it contains about 30% STS content and about 70% pure science content. Campbell et al. (1994, p. 422) agree with a classification of the Salters' Science curricula, *including the* Salters' Chemistry curriculum, as a "Science through STS Content" type of curriculum. Aikenhead (1994, pp. 55-56), though, does not refer specifically to the Salters' Chemistry course. If we take (pace Campbell et al.) a strong interpretation of the design criteria characterizing the Salters' Chemistry course (5.1.3), the *chemical* units of the Salters' Science course such as Metals (1989), stemming from the former course, could be considered as examples of category six: "SCIENCE ALONG WITH STS CONTENT". This category is described as follows:

> STS content is the focus of instruction. Relevant science content enriches this learning. Students are *assessed about equally* on the STS content and the pure science content (Aikenhead, 1994, p. 56).

Following Aikenhead, I will draw a distinction between the pure *chemical* (PC) content of school chemistry consisting of chemical concepts, relationships, and techniques, and the chemical-technological-societal (CTS) content of school chemistry consisting of CTS concepts, relationships, and techniques. As we saw above (Figure 5.4) "fundamental chemical ideas, concepts, principles, patterns, etc. [and] social, economic, environmental, industrial and technological aspects of the subject" are addressed *at least equally* in the lessons of the unit.

As for the assessment, Smith (1988) arrived in his analysis of some trial units, e.g. Metals (1984), and of the draft syllabus and specimen papers of the Salters' Chemistry course (1986) at a degree of assessment of *ca.* 50% of *utilitarian* aspects (section 4.5.4). He concludes that the actual assessment of *utilitarian* aspects, in 1988, will probably be about the same level (ibid., p.112).

Although the trial unit Metals did undergo some minor revisions (section 4.5.3), the revised unit, Metals (1987), can, I think, still be largely considered as an example of a CHEMISTRY ALONG WITH CTS CONTENT unit (Figure 5.5).

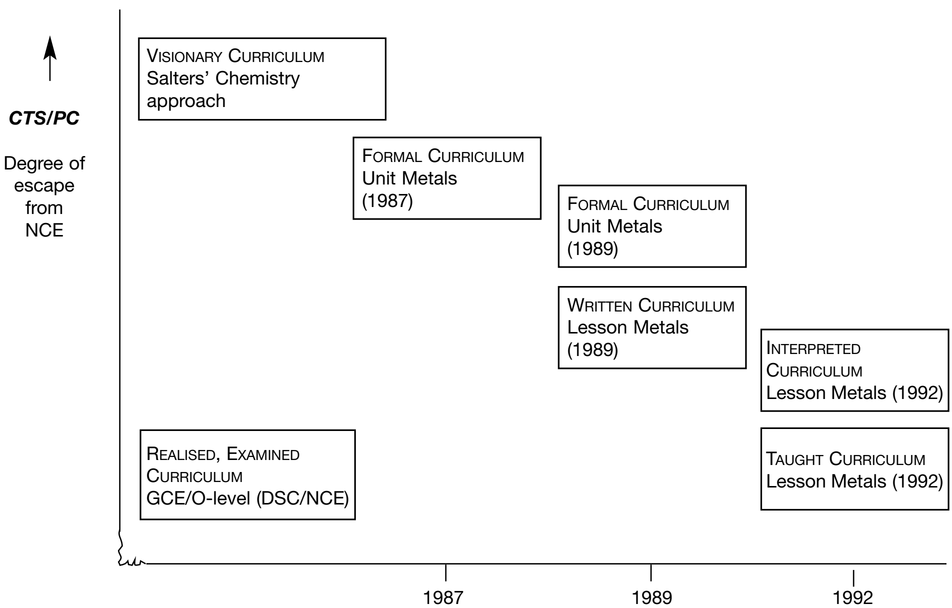
Put in Aikenhead's terms, CTS content is the "focus of instruction" and relevant PC content "enriches this learning" in the unit Metals (1987). Depending on whether one takes a weak or a strong interpretation of the design criteria of the Salters' Chemistry curriculum, the CTS/PC ratio varies thus between 30/70 % and 50/50 % (section 5.1.3). For the *comparison* of the CTS/PC ratio at the visionary, formal, written, interpreted, and taught curricula of the unit Metals, though, I will use the CTS/PC ratio in a *relative* sense, my argument not depending on the use of an absolute CTS/PC ratio (section 5.2.8).[11]

Figure 5.5 is similar to Figure 4.4. In Chapter 4, I described, analyzed, and compared the visionary, designed, written, and formal curriculum levels of the Salters' Chemistry course. My research there focused on the course *taken as a whole*, either on the Foundational course or on the GCSE examination course. Here I am extending the curriculum analysis to the interpreted, taught, and experienced curriculum levels of the unit Metals.

Application of Aikenhead's content distinction to Metals (1989)

The distinction and notation used by the developers in the unit Metals of the Salters' Chemistry course (1987) is *no longer used* in the units of the Salters' Science course (1989), which had to meet the criteria laid down by the recently implemented National Curriculum (1989). For the purpose of content analysis of the lessons of the unit Metals (1989), I will continue to use this distinction and notation, in a form consistent with Metals (1987) and with Aikenhead's STS curriculum scheme. While analyzing the unit Metals (1989) and the adapted unit Metals (1992), I will distinguish between CTS content and PC content in order to find the CTS/PC ratio of the different curriculum levels involved (Figure 5.5).

Figure 5.5 Process of development and teaching lessons Metals



[11] In this way account is taken of the remark that there are "limitations of counting outcome statements as a way to judge the relative importance of pure chemistry and chemical technology/applications" (W2001).

Although the PC terms are not given an asterisk in the lesson plans (Appendix 5) by the writers of Metals (1989), they will be identified as *fundamental* chemical ideas, principles, or techniques by comparison with Metals (1987) and, further, on the basis of the attention given to these terms in the teacher notes and the student activity guides. The identification of CTS terms, neither indicated in Metals (1989), proceeds along the same lines.

For the unit Metals (1989), a rough idea of the ratio between CTS and PC content can be obtained from an inspection of the overview given by the developers of the unit (Figure 5.6).

Figure 5.6 Overview, chemical unit Metals of Salters' Science (1989)[a, b]

This unit is concerned with:
– *the importance of metals,*
– *the relationship between the properties of metals and their uses,*
– *the problems of corrosion.*

The unit starts with a survey of *the surroundings* in which students familiarize themselves with the *names, *physical properties, and *uses of common metals*. The *use of symbols to represent metals is also introduced. Discussion of the *physical properties which metals have in common then leads to the idea that *different metals can be identified by their chemical properties. Students complete *simple qualitative tests on known metals and *use these tests to identify metals in common objects.*

After this initial study of the *chemical properties of metals, *the processes of corrosion* and burning[b] are investigated and this leads to an introduction of the terms *element, *compound, and *reaction.

Students go on to investigate *rates of corrodibility* and *the reactivity series is introduced. *Methods to prevent rusting* are considered in a homework exercise and further opportunities to study *the methods of rust prevention* are provided in two optional lessons.

Work on corrosion allows further discussion of the *usefulness of metals*; the unit ends with a study of *alloys* in which *solder is prepared* and *the properties of alloys are related to their uses*.

[a] Asterisks are added to denote pure chemical (PC) content; italics to denote chemical-technological-societal (CTS) content.

[b] As with Metals (1987), the meaning of some terms is difficult to decide without the context of the lesson, e.g., the term burning (see 5.3).

The first impression one gets from the distribution of CTS and PC terms in the overview of the unit is that CTS and PC content are addressed about *equally* in Metals (1989). Some CTS terms are addressed in the more detailed lesson plans of Metals (1989) but not in its overview. For example, some metal *is used up* in corrosion; corrosion occurs at the *surface*; air and water are both needed for rusting. Again, comparison of terms used in Metals (1989) with the CTS and PC terms used in the lesson plans of Metals (1987) proved helpful.[12]

Thus, it seems that CTS and PC content receive about equal emphasis if we look at the overview and the lesson plans of Metals (1989). Corrosion as a chemical-societal problem emerges as the leading theme or context, both in Metals (1989) and in Metals (1987). In view of the constraints, in particular the assessment procedures set by the

[12] Only a few PC terms, for example chemical properties, mentioned in the overview of Metals (1989) are not mentioned as such in the lesson plans of Metals (1987).

National Curriculum (1989), we can assume that the CTS/PC ratio for Metals (1989) is somewhat smaller than for Metals (1987). That is, prior to the content analysis of the lessons of the unit, Metals (1989) will be considered as an example of a CHEMISTRY ALONG WITH CTS CONTENT unit.

Using the distinction between CTS content and PC content, design criteria two and three, and the research questions one and two stemming from them, address the following relationships between CTS contexts, CTS content, and PC content.

- PC content *arises naturally* from a CTS *context*.
- PC content is used *only when needed* to make sense of CTS *contexts*.
- CTS *contexts* justify the introduction of CTS content and of PC content used in the unit.

In order to see whether the *prima facie* balance found so far between CTS content and PC content in Metals (1989) is operationalized and visible at the level of concrete lessons, a detailed consistency content analysis of the lessons of the unit Metals (1989) is called for. I analyze therefore in the next section (5.2) the *written curriculum* of Metals (1989), that is, the specific contexts, activities, and concepts treated in the eight lessons of the unit in order to see to what extent the relationships among CTS contexts, CTS content, and PC content stated above apply in a concrete case. In other words, I want to determine the extent to which the developers have been able to adhere *consistently* to design criteria two and three in a concrete unit, by answering the two research questions stemming from these design criteria.

Forms of consistency analysis

As we will see, the consistency analysis of the lessons of the unit Metals (1989) and the unit Metals (1992) will takes three, interrelated forms. In section 5.2, I will limit myself to the first two forms, giving only a rough outline of the third.

1) *Consistency Analysis*

Starting from the adopted set of design criteria, a *content* analysis is made of the *lessons* of the unit Metals (1989) in order to see the extent to which the design criteria in the chosen interpretation are consistently operationalized in the content (context, concepts, and activities) of the lessons. In one of the few studies I have found in which a similar analysis is performed, this method is described as follows:

> ... the method of this research entails *a content analysis of the material in the light of the objectives* as further specified by the original developers in interviews (Joling et al., 1988, p. 6)

As explained above,, for research purposes I take a *strong* interpretation of the Salters' design criteria which is shared by some but not all of the original developers.

2) *Reversed design analysis*

The lessons are analyzed, as it were in reverse, from content to design criteria. Starting from the content used in the lessons of the unit (contexts, concepts, and activities) an analysis is made in order to uncover any design criteria used implicitly or tacitly by the developers, which might have led to unintended, unforeseen, or, perhaps, unwanted consequences (Van Berkel, 1999).

As we saw in Chapter 4, the various developers felt they had to design the Salters' Chemistry course in accordance with the "structure of school chemistry as they all perceived it" (L92); this goes against their design criterion one, *no preconceptions,* interpreted in the strong sense.

3) *Redesign*
Starting from the screened set of design criteria, that is, screened for consistent and tacit use of design criteria, an attempt can be made to redesign the unit. Such an attempted *design sketch* has of course to be trialled for effectiveness in teaching and learning; as with any other design or redesign, it must be trialled first in the designer's room, then in the classroom.

5.1.5 Pedagogical, philosophical and substantive structures

Finally, I give here a representation of the *content* of the unit Metals as it resulted from the development process guided by the adopted design criteria (Figure 5.7). This is done in the usual format, that is, in terms of the substantive, philosophical, and pedagogical structures. The same format has been used in previous chapters for school chemistry *curricula* such as Dominant School Chemistry in Chapter 2 and the Salters' Chemistry curriculum in Chapter 4. The content specifications were taken from the Foundation Unit Metals (1989), a limited edition produced by the Salters' Science Project for full-course trial, using in particular the key teaching points as stated on the lesson plans (Appendix 5). Figure 5.7 is thus a representation of Metals (1989) in terms of the content specifications as given by the developers.

The consistency analysis of the content of the lessons of the unit Metals will reveal the extent to which the key teaching points, as stated by the developers on the lesson plans, are actually addressed in the lessons of the unit, or whether and how the written curriculum of Metals (1989) differs from the formal curriculum. In brief, this will establish whether the CTS/PC ratio will change. The actual design of the unit Metals(1989) can be considered to have *escaped* NCE to the extent that the developers have been able to operationalize in a consistent way the design criteria guiding the development of the lessons organized around the theme *corrosion*.

5.2 Analysis of lessons of curriculum unit Metals (1989)

In this section, I will perform a detailed consistency analysis of the content of the lessons of a *chemical* unit, Metals (1989) of the Salters' Science Foundation Course (see Figure 5.8 below).

I performed the content analysis of the lessons together with the late Dr. Wobbe de Vos, my 'co-promoter' at the time, under the supervision of Prof. Adri Verdonk, both renowned researchers in chemical education. The supervision of my research was taken over by Albert Pilot, the current Professor of Chemical Education at Utrecht University, who is now my 'promoter'. The results of this analysis will show the extent to which the developers were able to fulfill in a consistent way the adopted design criteria in this particular unit (sections 5.2.1 – 5.2.7).

Figure 5.7 Structure of the formal curriculum unit Metals (1989) – a chemical unit of the Salters' Science Course

Categories	Codes	Specifications used by the developers
SUBSTANTIVE STRUCTURE	[SUB]	IMPORTANCE, USE AND REACTIVITY OF COMMON METALS
Pure chemical concepts	[PC]	Physical and chemical properties of metals Element as simple substance, compound, chemical reaction Pure metal Atoms/symbols; mass/weight Corrosion and burning involves reaction with oxygen: oxidation Metals reacting with water; metals reacting with acid Composition; alloys as mixtures of metals
Chemical-societal concepts	[CTS]	Problems of corrosion, iron is used up at surface Role of air, water, and salt; rate of rusting, 'rust stoppers' Uses of common metals in things; cost, annual production
Pure chemical relationships	[PC]	Reactivity series, involving reactions of metals with water, oxygen Word equations: starting reactants and final products Relationship between composition alloys and properties of alloys
Chemical-societal relationships	[CTS]	Order of corrodibility of metals Relationship between properties of metals/alloys and their uses Role of impurities in alloys
Pure chemical/physical techniques	[PC]	Chemical analysis, i.e. tests to identify metals in common objects Chemical test for hydrogen, using a chemical balance Electrical conductivity
Chemical-societal techniques	[CTS]	Methods of rust prevention: (i) greasing, painting, coating, plating (ii) protecting a metal with other, more reactive metal (iii) making new alloys: different composition/ properties/uses Preparing alloys (e.g. solder)

Figure 5.7 Structure of the formal curriculum unit Metals (1989) – a chemical unit of the Salters' Science Course (continued)

Categories	Codes	Specifications used by the developers
PHILOSOPHICAL STRUCTURE	**[PHIL]**	**APPLICATIONS OF CHEMICAL KNOWLEDGE**
Foundations of science	[FS]	Social, economic, environmental, industrial, technological emphasis (e.g. galvanizing iron in 'Hot Dip Process')
Methodology of science	[MS]	Practical/experimental skills, e.g. lab. investigations, controlling variables, using a control, interpreting data. Focus on recognizing patterns; some predictions Foundations of chemistry
	[FC]	Word equations summarize a process: starting materials (the reactants) or one side, the final material(s) or the other side (the products)
Methodology of chemistry	[MC]	Macro explanation, e.g. of differences in corrodibility of metals Analyzing/testing of materials made of metals Making new materials made of metals
PEDAGOGICAL STRUCTURE	**[PED]**	**JUSTIFICATION FOR STUDY IN ASPECTS OF EVERYDAY LIFE**
Aims	[A]	To understand how chemistry affects daily life: describe/explain corrosion in order to control it; prevent or treat corrosion; make new alloys
Teaching approach	[TA]	Everyday situations lead to introduction of chemical concepts/ explanations, as and when needed, in order to explain other daily life contexts or to give reasons for use of chemically made artifacts Spiral approach: macroscopic, qualitative introduction
Learning approach	[LA]	Motivation/active learning through relevant contexts and variety of practical work Ask students to present their own ideas, if possible, e.g. on rusting

I will focus the analysis on design criterion two, *Relevance*, and design criterion three, *context-led development of concepts*. In this analysis, I will try to answer the following two questions.

1) Does each *lesson* of the unit Metals have its *origin*, and hence its *justification* for study, *fundamentally* in aspects of *everyday life*?

2) Are all chemical concepts and explanations introduced in the lessons of the unit Metals *needed* for the study of these everyday situations?

In section 5.2.8, I will summarize the results of the consistency analysis of the lessons of Metals (1989), compare the analyzed written curriculum with the formal curriculum of

Metals in terms of CTS and PC content, and discuss to what extent the developers of Metals escaped from (a part of) Normal Chemistry Education. For the purpose of the lesson analysis of Metals (1989), I have given in Figure 5.8 the overall plan of the unit Metals, while Appendix 5 gives the full lesson plans of Metals (1989). For the list of teaching materials and the overview of the unit, see Figures 5.3 and 5.6 above.

At the beginning of my analysis of each lesson (5.2.1 – 5.2.7), I reproduce the lesson synopsis. I further quote relevant excerpts from lesson plans (LP), teacher notes (TN), student activity guides (SAG), and student information sheets (SIS). Occasionally, I will refer to editions of the unit Metals developed earlier, namely Metals (1984) and Metals (1987), and also to the so-called student book (Hill et al., 1989, pp.1-11). The first chapter of this book is titled "Metals", the book can be used in the classroom as a supplementary teaching resource.

Figure 5.8 Metals (1989) – The Overall Plan[a]

M1 WHAT ARE METALS? Investigation of the properties of metals. comparison with properties of plastics. Symbols.	**M5 DO ALL METALS CORRODE?** Investigation of the reactions of metals with air and water. Order of corrodibility (reactivity) of metals. Oxidation.
M2 WHICH METAL IS USED TO MAKE A DRAWING PIN? Simple chemical tests for metals. Metals used to make common objects.	**M5X1 HOW CAN WE PREVENT RUSTING?** Methods used to prevent the corrosion of a bicycle. Investigation of the effectiveness of rust stoppers.
M3 WHAT HAPPENS WHEN METALS CORRODE? Examination of corroded metals. Investigation of rusting of iron. Idea of a chemical reaction.	**M5X2 DO OTHER METALS STOP IRON FROM RUSTING?** Investigation of the presence of other metals on the corrosion of iron.
M4 A CLOSER LOOK AT CORROSION AND BURNING Investigation of the changes during the processes of corrosion and burning.	**M6 WHAT ARE METAL ALLOYS?** The effect of alloying on the properties of metals. Uses of alloys.

[a] Each box of the flow diagram represents a double period lesson (70 – 80 minutes). The lessons M1, M2, M3, M4, M5 and M6 are core lessons, while the lessons M5X1 and M5X2 are so-called *optional enrichme*nt lessons.

5.2.1 Analysis of lesson M1

The synopsis of the first lesson of Metals: WHAT ARE METALS? reads:

> Students complete activities to become familiar with the *names*, *general physical* properties and *uses of common metals*. *Symbols* are introduced.

Metals, common metals or common objects made of metals

In the TN of lesson M1 with regard to the first activity, a survey, it is suggested to "ask students to look at *items* in the *laboratory* and list those they think are *made of a metal*". However, in the overview (Figure 5.6), the developers mention a broader context to start the unit with, namely: "a survey of *the surrounding*s in which students familiarize themselves with the names, physical properties and uses of *common* metals". This broader, chemical-societal context is addressed later in this lesson in a so-called "individual student activity" (LPM1, Appendix 5). This activity, though, is optional, that is, "If there is time available, students could be asked to make a list of the metals *they know* and note what they look like, whether they are hard or soft, heavy or light, etc." (TNM1). This optional activity seems to be more consistent with design criterion two, *relevance*, than the *laboratory* survey.[13] Therefore, one would have expected that lesson M1, and with it the unit Metals as a whole, would have *started* with an activity similar to the optional one. For example, one could ask students to make a list of *common objects made of metals* as present in their *surroundings*.[14]

It should be noted here that common objects present in the surroundings or in homes are in many cases very complex *mixtures* of substances. When they are made of metals they often consist of *alloys*. The latter concept is treated in the last lesson of the unit M6: WHAT ARE METAL ALLOYS?[15], both as a chemical concept in relation to the concepts of mixture and composition and as a chemical-societal concept in relation to use and purpose. I will return to this important point, when analyzing and discussing lesson M2, especially lesson M6.

Properties of metals, and their relation to use

The next activity (SAG M1.1) consists of laboratory-based practical work, and concerns a "comparison of the properties of metals and plastics based on experiments using a metal spoon and a plastic spoon". The experiments deal with the following *general physical* properties: clangs when struck, dense, shiny, reflects light, malleable, good conductor of heat, good conductor of electricity (the *chemical* properties of metals are treated in M2). The last activity of this lesson (SAG M1.3) introduces some *economic* aspects of metals such as cost and annual production. Many of the general physical properties and the economic aspects of metals introduced here can be said to have their *origin,* and hence their *justification* for study, in aspects of *everyday life*. On the other hand, the *differences* in properties of *concrete* objects like a metal and a plastic spoon

---

13 It would also more *actively involve* pupils, and be more consistent with design criterion four, *variety of learning activities*. Metals (1984) calls this type of lesson optional, while Metals (1987) refers to *optional enrichment* as does OGT (p. 13).

14 The chapter Metals in the student book (Hill et al., 1989) seems to offer more in the way of a contextual, relevant introduction and treatment of metals (see also next note). For example, in the section "Things to do" (p. 11), pupils are asked to "identify five *objects* in your *home* which you think are made of metals" or to "identify, with the help of older members of your family, three *objects* which used to be made of metals". It is important to remember that the student book is not a regular textbook from which the course is taught and learned (4.4.2), but a supplementary resource for pupils. The assessment items of Metals (1989), too, refer to pupils' surroundings. The pupils are asked to "look around the *room* ... and name three *objects* made of metal, which you can see in the room" (item 11) or to "name three *things* you use at *home* or at *school* which could be made of <u>either</u> metal <u>or</u> plastic" (item 16; underlining theirs).

15 The student book (Hill et al, 1989), though, mentions alloys right at the start of the chapter Metals (p.1), saying that "Now it is possible to obtain specially prepared *mixtures* of metals called **alloys** which have *suitable properties* for *making* everything from a spoon to a spaceship" (about half of the terms in boldface in the student book denote pure chemical concepts, about half denote chemical-societal concepts).

with regard to beauty or taste relevant for situations in everyday life, for example eating, are not addressed.[16] The questions when, where, and for what *purpose,* a metal spoon or a plastic spoon is used are not raised. So, contrary to design criterion two, *relevance*, the everyday aspects of objects such as a metal or a plastic spoon are not fully exploited in this activity; the comparison is not fully set in a CTS context.[17]

Chemical names or symbols

The student activity, titled "HUNT THE METALS" (SAG M1.2), concerns the "completion of a word search for metals" with the help of a list of seventy names and symbols of metals as given in SIS M1.1. With regard to teacher-student discussion 3, the TNM1 read:

> Introduce the idea of a *chemical shorthand* – using *symbols* for metals. You may wish to mention that the symbol for a metal actually stands for <u>one atom</u> of the metal. Hence when writing about metals, it is wrong to put "some Cu" etc. (underlining theirs).

With regard to the latter suggestion, it should be noted that from a chemical point of view it is not wrong to say "some Cu". Chemistry as a science, is not limited to a corpuscular context, but deals with thermodynamic or phenomenological contexts as well. In the latter contexts the locution "some Cu" refers not to one or more atoms, but to an amount of the pure substance copper or element copper (Cu). So, why should school chemistry then be limited to only corpuscular contexts?[18]

In SIS M1.1 it says that the *ten* metals in the list of seventy which carry an asterisk (Al, Ca, Cu, Fe, Pb, Mg, K, Na, Sn, Zn) "are those which you will meet most often in the course". This raises the question whether the other sixty metals listed are really *needed*, in view of design criterion three, *Context-led development of concepts*, in this or other lessons of the unit Metals.

In the last activity (SAG M1.3) students perform a "data analysis and interpretation to explain the *reasons for certain uses* of metals". Students have to answer a number of questions, set in daily life contexts, concerning the *differences* between metals in relation to their *use,* on the basis of a data table containing *economic* properties (cost, annual production) and *physical* properties (density, melting point, best conductor of heat, best conductor of electricity) of nine metals. For example, one question reads: "Give <u>two</u> reasons why we don't use this metal [silver] to make saucepans", and the last question of this activity reads: "For what uses have plastics replaced metals? Why do you think this has happened?" TNM1 lists as answers: "Plastics are lighter, cheaper, more resistant to *corrosion*. Supplies of some metals are dwindling." Coming back to the point made above about the properties of spoons related to the their use, it would have been appropriate to add a question such as: For what uses have plastic spoons replaced metal spoons?

This could then lead into specific daily life properties of spoons in relation to eating.

---

16 It is interesting, that lesson plan M1 of Metals (1984) states in its outline of activity 4 that "pupils are supplied with two *similarly shaped and sized objects* and investigate the differences in properties between them" . The *abstraction* from shape and size favors the treatment of *general* properties of metals and plastics over that of *specific* differences in *use or function* of metal or plastic concrete objects.

17 The chapter Metals in the student book (Hill et al., 1989) offers supplementary contexts to the economical and technological ones treated in the unit Metals (1989), for example, poisonous metals are set in a social/biological/environmental context, and aluminum production is set in an industrial context.

18 For a similar point see De Vos et al (1994), where the use of *broken* coefficients in equations is discussed. Although not allowed in a corpuscular context, it is not uncommon among chemists to use broken coefficients in a thermodynamic or phenomenological context.

Summary

Regarding the latter activity, the first research question mentioned in section 5.2 takes the form: Do the introduced concepts *chemical shorthand* and *atom* have their *origin* or arise *naturally* from the study of *everyday* situations?

The answer appears to be negative. Students are *told* something about the concept *atom*, as we saw, and are *given* a list of seventy symbols for metals to help them with their metal 'hunt'.

The second research question mentioned in section 5.2 takes the form: Are the concepts *chemical shorthand* and *atom* only introduced when they are *needed*? Again, the answer is 'no'. All that seems to be needed to make sense of the nature of daily life objects made of common metals such as food cans, of things familiar or *known to students*, is a small set of about ten metals, and their names and relevant properties. The introduction of an almost complete list of symbols of metals as *known to chemists* is thus not needed. The short list of ten *common* metals will probably not include metals such as potassium or sodium. As the writers of the unit say (TNM1): "They are unlikely to be mentioned by students at this stage". We will see, though, that students will meet these metals nevertheless, in lesson M2 and especially in lesson M5. Thus, the concepts *chemical shorthand* and *atom* are introduced in M1, but are not really needed to make sense of daily life aspects of metals.

Some of the contexts used in M1, "laboratory survey" and "comparison of the properties of metals and plastics", do not fully develop fundamental daily life aspects of metal objects such as their composition as alloys and the properties of spoons related to use like eating. Other contexts of M1, "students list metals they know" (optional) and "explain the reasons for certain uses of metals", do address the relationship between the properties of metals and their uses in a sufficient manner.

Thus, judged by criterion two, *Relevance,* and design criterion three, *Context-led development of concepts*, and taken in a strong interpretation, CTS content is not fully developed, and PC content is developed more than needed in lesson M1.

5.2.2 Analysis of lesson M2

The synopsis of lesson M2: WHICH METAL IS USED TO MAKE A DRAWING PIN? reads:

> Students are introduced to *simple tests* for some common metals and then use these *tests to identify* the metals in *common objects*, e.g. a drawing pin.

The key activity (SAG M2.1) of this lesson concerns laboratory-based practical work. Students perform "*simple* qualitative tests on known metals" and identify thereby "the *dominant* metal in a drawing pin", as it says in lesson plan M2 (LPM2). The key point of this activity is that "chemical tests are *often* better than physical tests at *distinguishing* between metals" (LPM2).

The practical work is preceded by a teacher-student discussion in order to help students "recall that metals have common physical properties and many look alike" and to start a "discussion of possible ways of *identifying* different metals" (LPM2). The teacher then suggests "that it is worthwhile to investigate whether chemical tests might give additional information" (TNM2).

At the end of SAG M2.1, students perform a SPECIAL INVESTIGATION (emphasis developers), in which they apply what they have learned in the laboratory in a daily life context.

> Using the *tests* you have just learned, try to discover which metals are used to make the *everyday objects* (e.g. drawing pins, paper-clips, etc.) you have been given.

The last activity of M2, a second teacher-student discussion which comes back to the first teacher-student discussion, addresses the key point that "the use of metals is related to their *chemical* properties" (LPM2). It is recalled from M1 that "the use of a metal is also related to its *physical* properties". TNM2 suggests: "Bring out the idea that some metals are *more reactive* than others. This will therefore affect the ways in which they can be *used*."[19] Thus, the important "relationship between the properties of metals and their uses" (LPM2) is reinforced. (See also the overview in Figure 5.6 and Hill et al., 1989).[20] With regard to lesson M2, the first research question takes the form:

1. Does M2 have its *origin*, and hence its *justification* for study, in aspects of *everyday life*?

Although SAG M2.1 ends with an everyday life context (SPECIAL INVESTIGATION), it does not start in such a context. It is in a *laboratory context* that students are introduced "to the idea that a more *precise identification* [of metals] can be made through the study of their chemical reactions" (LPM2). The following point made by the developers is pertinent for the analysis.

> The qualitative tests have been *confined* to the metals iron, copper and lead since there are many *common simple objects* in which these are the *dominant* metals (TNM2).

And students are instructed accordingly:

> You will *first* perform this *test* on *pure* metals and *then* use the same test to identify the metals used to make a drawing pin (SAG M2.1).

The focus of this activity is on *pure* metals, on the identity of metals, not on their use. The chemical tests are not introduced in relation to the use of simple objects made of metals. Furthermore, it seems to be taken for granted that the chosen laboratory context prepares students adequately for applying these chemical tests to everyday life, that is, to the identification of the metal constituents of common simple objects. But this involves, in fact, many assumptions (or reductions) in order for the chemical analytical identification to succeed:

---

19 Instead of pointing this out at the end of M2, it would have been more appropriate to do it instead at the end of M3, that is, after students have had some *experiences* with differences in reactivity or corrodibility of metals.

20 The relation of properties and use of metals is formulated by Hill et al. (1989, p. 7) as follows: "Although metals have a lot of similarities, they also have a lot of differences. These *differences* are *important* when deciding which metal to *use* for which *purpose.* For example, some metals are stronger than others, some are heavier than others and some are *more resistant to attack by air*".

1) A *small* sample of a daily life object is required, such that fits in a test tube. A bridge, an airplane, or even a spoon as a whole are difficult to analyze.

2) A *sample* is taken form the *bulk* of a metal object, not from its surface which might be coated or corroded.

3) A sample should consist of one dominant metal, while other metals present should not interfere with the identification of the *dominant* metal.[21]

4) A small pre-selected number of *pure* metals are analyzed in order to form a "confined" or closed group of metals distinguishable by simple, qualitative chemical tests.

These assumptions about the *analytical route* from surface, bulk, sample, pure metal, closed group to precise identification are hardly addressed in TNM2. Thus students are not made aware that the chemical tests they perform in SAG M2.1 are less easily applied to common metal objects such as a bridge, plane, or spoon. The CTS context of common objects gives way to an analytical context introducing pure chemical concepts.

As pointed out above, most objects used in everyday life are quite *complex* mixtures or, in the case of metal objects, consist of alloys. In view of design criterion two, *relevance*, and design criterion three, *context led development of concepts,* one would have expected that the concepts *mixture* and *alloy* would have received more attention in the first lessons of the unit.

As we will see, the central theme *corrosion* of the unit Metals is not introduced until lesson M3. Differences in corrodibility or reactivity between metals, and thereby important chemical and societal properties of metals, are not treated earlier in the unit.[22] It would have been more consistent with design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, if students had first gained the CTS *experiences* of lesson M3, and subsequently had performed the laboratory-based practical work. This would have *justified the need* for the introduction of the chemical analysis in relation to the theme *corrosion*.

Specific to this lesson, the second research question takes the form:

2. Are the chemical concepts introduced in M2 *needed* for the study of everyday situations?

As argued above, the central context of this lesson is a classical chemical analytical context, namely, identification of a set of pure metals, and the related chemical concepts (chemical test/property/reaction, dominant/pure metal) are introduced for that reason.

---

21 This point is addressed briefly in the teacher notes: "Since some objects tested may be alloys or plated, you may prefer to refer to the dominant metal so that contradictions are not made later when referring to alloys (emphasis theirs)". When referring to the composition of a common object such as a drawing pin, the developers often use the plural, i.e. metals, while the title of the lesson refers to the singular, i.e. to metal. The title of this lesson, therefore, seems to presuppose the concept *dominant metal*.

22 In Metals (1984), lessons M3 and MX3.1, students do gain some relevant experiences with chemical reactions of aluminum, iron, and copper. In this way the conclusion: "Metals have *different chemical properties* and cannot all be extracted in the same way" (MX3.1), is supported by empirical evidence.

These concepts do not *arise naturally* from the study of *common simple metal objects*, and are, therefore, not needed to make sense of them.[23] Secondly, the chemical names and terms mentioned in the lesson (dilute nitric acid, sodium hydroxide, decant and precipitate) are not needed. These systematic names and chemical terms can easily be replaced by *common* names such as acid and base, and the technical term precipitate by the locution "a solid in a liquid" (SAG M2.1).

Summary

The main concept in this lesson, chemical analysis, does not arise from the context of the chemical properties of metal objects as they occur in daily life. The analytical concepts appear as it were *sui generis*: chemical concepts and terms introduced such as *identification*, *dominant metal*, *pure metal*, *precipitate* are not justified in relation to everyday life aspects of metals.

The concept of *analytical route* is not developed, nor are the concept of *alloys* and the relationship between the properties of metals/alloys and their societal use (CTS content).

Thus, judged by criterion two, *relevance*, and design criterion three, *context-led development of concepts*, taken in a strong interpretation, CTS content is underdeveloped and PC content is overdeveloped in lesson M2.

5.2.3 Analysis of lesson M3

The synopsis of Lesson M3: WHAT HAPPENS WHEN METALS CORRODE? reads:

> Students consider what happens during *corrosion* and this leads to an introduction of the terms <u>element</u>, <u>compound</u> and <u>reaction</u> (emphasis developers). The rusting of iron is then investigated practically.

The unifying theme of the unit Metals, *corrosion* (SLB, p. 8), is addressed in lesson M3 for the first time.[24] This CTS theme is introduced by the teacher in the context of a set of corroded metals, and is elaborated by students in another CTS context, that is, the exploration of a *specific* case of corrosion, namely, the rusting of iron.

M3 starts with a teacher-student discussion in which "samples of corroded metals are displayed". (LPM3). The teacher should "Have ready a display of as many *corroded metal items* as are available. Students can look at the display and suggest where such samples might have come from" (TNM3).

Students are not invited to think about or to organize a display of *corroded metal*

23 The student book (Hill et al., 1989) discusses differences of chemical reactivity in the context of toxicity of metals as well as in the context of corrosion of metals, but does *not* deal with differences in chemical properties in the context of chemical identification.

24 In lesson M1 the theme *corrosion* only surfaces in the answer given to question 9 (SAGM1.3): "Plastics are lighter, cheaper, *more resistant to corrosion*." (TNM1). In lesson M2 there is no reference at all to corrosion despite the focus of the lesson on chemical properties and reactions. As we saw, the focus there is strictly on chemical properties relevant for chemical identification.

items that they can find or have used in their own surroundings at home.[25] Such an activity would have been more fully in accordance with design criterion two, *relevance*, and would also more *actively involve* students (design criterion four). It is further to be noted that the corroded forms of *pure* metals (rusty iron, tarnished copper, corroded zinc) have been chosen as samples of corroded metal *items*. The teacher demonstrates the "removal of corrosion by rubbing with an emery cloth" (LPM3) and directs the attention of students to the color of the *surface* "before and after rubbing" (TNM3). The key point of this activity reads, therefore, "corrosion occurs at the *surface* of metals". It is noteworthy, that in this activity *visual inspection* seems to suffice, whereas in M2, as we have seen, the technique of chemical identification, directed at *bulk* properties such as the composition of pure metals, was invoked. Thus, the technique of chemical identification introduced in M2 is not used in M3 (or in other lessons of the unit) which seems to underline the conclusion in M2 that it is not *needed.*

In the teacher notes (TNM3) are stated the purposes of the teacher demonstration:

1. to show that corrosion produces a new substance and to establish the idea that corrosion is a <u>chemical reaction</u> (emphasis theirs).
2. to explain that, when the corrosion is removed, a substance remains (the metal) which cannot be made any simpler. This substance is called an <u>element</u> (emphasis theirs).
3. to explain that the new substance(s), which form during corrosion, is called a <u>compound</u> (emphasis theirs).
4. to show that when the corrosion occurs, *metal is used up*.

Firstly, it is to be noted, that the theme *corrosion* is addressed in this lesson in two different contexts: (i) in a purely chemical context, that is, as just an example of a chemical reaction involving the formation of a *new* substance, a compound derived from the pure metal; (ii) in a chemical-societal context, that is, as a socially unwanted chemical change occurring at the surface of metal objects. The phrase "*metal is used up*" which turns up frequently in the unit Metals is very intriguing but also ambiguous. In one sense, the metal is *not really* used up during corrosion. The metal is only converted but at the same time conserved. This implies a concept of *element* as a *principle of conservation*, that is, the metal element is conserved in the corroded substance or compound. In another sense, metal is used up, namely, part of the metal is converted to another substance, losing its luster and gaining a socially unwanted rusty surface. The phrase "*metal is used up*" appears to imply the second sense of the concept of element, described by the developers as a substance "which cannot be made simpler" (TNM3). Since corrosion appears to occur mainly at the surface of metals, (part of) the original *surface* of a metal object is no longer available: the metal *surface* is *used up*. Corroded metal objects are often no longer useful for the purposes for which they were originally designed and used.

Looking at corrosion from a CTS point of view leads quite naturally to another worthwhile chemical-technological-societal context, namely the recycling of metal objects. For example, corroded piles of scrap metal ("used up") can be processed by chemical and physical means in order to win back the valuable metals they still contain.

---

[25] Hill et al. (1989, p. 7) refer to the use of metals in "countless everyday objects used in the home, at work and in leisure pursuits".

The context *recycling metals* teaches clearly that corroded metals have been converted and at the same time conserved, which would *justify the need* to introduce the concept of the conservation of elements.[26]

Secondly, the observations made available to students in the teacher demonstration: changes in color and texture ("pitting", "thinning") seem not to be sufficient "so that the *conclusions* stated [1-4] above can be made" (TNM2). With regard to the second conclusion, it does not follow from the ability of a metal material to corrode that it is an element. It could also be a compound or an alloy. The conclusion that a metal is an element only follows from its inability to decompose. Neither is it possible for students to decide on the basis of these observations whether the corroded metal is a compound or maybe a mixture/alloy (conclusion 1), or whether the metal has undergone a chemical reaction or another physical process (conclusion 3). Conclusion four is reasonably supported by the visible evidence presented to the students, but only if we take the phrase "*metal is used up*" in the second sense discussed above.

The wish of the developers to address in lesson M3 both the *basic* chemical reaction concept and the *fundamental* CTS theme *corrosion* introduces two tensions discussed in general terms in Chapter 4: (i) the tension between *concept and context*, which shows up in the two different meanings of the concept corrosion and in the conceptually ambiguous phrase "metal is used up"; (ii) the tension between *concept and process,* which shows up in a certain lack of evidential teaching with regard to the conceptual development of the fundamental chemical concepts element, compound, and reaction.

In the next activity, laboratory-based practical work (SAG M3.1), "students set up an investigation into the *extent and rate of rusting of iron nails* in the presence of combinations of air, water and salt" (LPM3). Prior to that, students are asked, in teacher discussion 2, to suggest "what sort of substances *the metals* might be reacting with when they *corrode* and suggesting what type of investigations might be carried out to test their ideas." This question is phrased in a rather *general* way which might make it difficult for students to answer. Which metals react with what substances during the process of corrosion can differ from case to case, often involving water and/or carbon dioxide and/or oxygen. The *rusting of iron*, the central topic of this activity, is a very *special* case of corrosion, both in its chemical and in its chemical-societal effects. It should therefore be treated accordingly.[27]

The investigation is set up as depicted in Figure 5.9 (left). For the sake of comparison I have added a similar experiment (Figure 5.9, right) taken from a traditional textbook, "General School Chemistry" by Clynes and Williams (1960). In this textbook the conclusion of the rusting experiments is simply *given*, as is the reasoning leading to it.

---

26 The theme of recycling is addressed in other units of the Salters' Chemistry course e.g. in the units Plastics (recycling plastics) and Minerals (recycling glass, winning metals) but without the context-led development of the concept of the conservation of elements (see also Hill et al., 1989, pp. 77 & 122). Similarly, Holman (1991, p. 122) discusses the recycling of metals but without mentioning the concept *element conservation*.

27 The student book (Hill et al, 1989, p. 4) briefly addresses the *special* status of iron and rusting, when it says that "corrosion of iron is commonly called rusting", and it deals with how other metals such as tin or magnesium can be used to protect iron from rusting. In TNM4 word equations are given, both for the oxidation of magnesium and the corrosion of iron, but the latter equation does *not* mention the presence of *water*, which was an important key point of lesson M3. Thus, here the general case of oxidation appears to take full precedence over corrosion and rusting.

After a week it will be found that none of the nails in the first two tubes have rusted, but those in the third are covered with rust. Hence, both air and water are needed for rusting (Clynes & Williams 1960, p. 54).

In other words, the logic here is that the iron nails do *not* rust with just water or just air, but only when both water and air are present.

In Metals (1989) students are led to the conclusion that "air and water are necessary" by way of three consecutive questions they have to answer (SAG M3.1). Question 1 reads: "From the appearance of the nails in tubes A [no change] and C [some rust], do you think that water is needed for iron to rust?" The TNM3 gives as answer: "Water should emerge as being necessary for iron to rust". A more accurate answer would be, the presence of water is necessary but not sufficient. After all, in tube B [no change] water is present. Question 2 reads: "From the appearance of the nails in tubes B [no change] and C [some rust], do you think that air is needed for iron to rust?" TNM3 gives: "air should also be necessary for rusting". Again, a more accurate answer would be, that the presence of air is necessary but not sufficient. After all, in tube A [no change], air is present. Question 3 reads: "What are the conditions for rusting? TNM3 give as an answer that "air and water are necessary". The answers given to questions 1 and 2, though, do not seem to lead logically to this conclusion. This would take the *simultaneous* comparison of three tubes A, B and C, using all the available observations.

How the changes with iron in tubes A – D come about is another matter. Is it by way of a chemical reaction with air and water, or perhaps catalytically, involving salt? Again, students will not be able to tell from the evidence provided. For example, students have to take it on trust that the drying agent in tube A only reacts with air and is not a condition affecting, in whatever way, the nails even though it is in contact with them, as is the salt in tube D, which does affect them.

So, this seems to be a second example in this lesson of the tension between *context and process* mentioned above which shows itself as engendering a certain lack of evidential teaching, which will probably also affect the quality of the learning process of students.[28]

The striking resemblance of the 'rusting' experiments used by the developers of the unit Metals of Salters' Science (1989) and by Clynes and Williams (1960) in their textbook "General School Chemistry" almost thirty years earlier, seems to indicate that the structure of school chemistry not only determines the choice and sequence of chemical concepts and techniques, but also the choice of experiments used, and perhaps even the way in which they are depicted. This shows that standard experiments from traditional textbooks are used by developers of an alternative approach to school chemistry, without adapting the experiment specifically to their purposes, except for the added role of the salt. Further, it would be more in accordance with design criterion two, *relevance*, to replace systematic chemical terms by common names: "anhydrous calcium chloride" by *drying agent* and "paraffin oil" by *oil* (see 4.5.2).

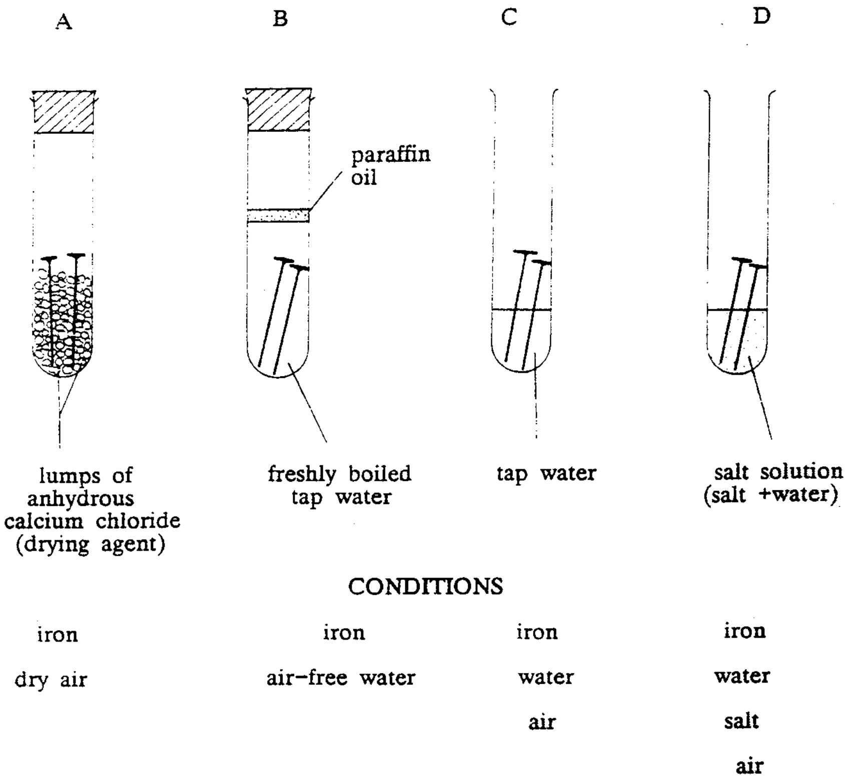
The use of systematic names and technical chemical terms, not only here but also in SAG M2.1, is probably also a consequence of importing standard experiments into the unit Metals.

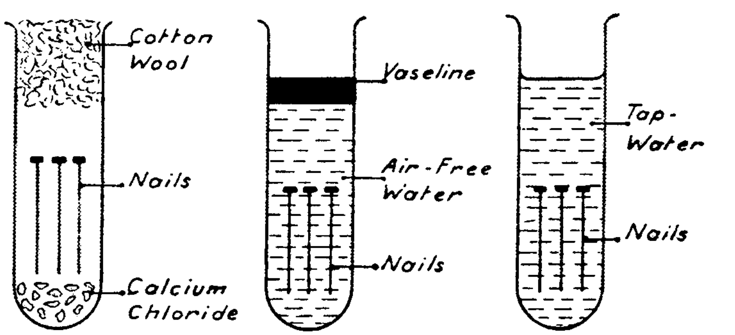
---

28 Garforth (G92b:17) points to a kind of trade-off between *context and process* when remarking on the place of the chemical industry in school chemistry: "It's always been there but we ... perhaps in the Salters' course *we made more of it*. Nuffield – *they rather played it down*, because they were so hung up on explanation ...". In other words, the Nuffield approach emphasized processes over relevance, whereas the Salters' Chemistry approach emphasized relevance over processes.

Figure 5.9 Experiments on the Rusting of Iron

Top figure: From *Salters' Science* (1989), UYSEG, Unit Metals, SAG M3.1, Side 1/2.
Bottom figure: From *General School Chemistry* (1956), Clynes & Williams, 5.10 Rusting and Burning, p. 53.





Conditions for Rust. The third tube acts as a control for the others, because no special precautions are taken.

SAG M3.1 ends with a question which addresses, in accordance with design criterion two, *relevance*, a chemical-societal context and, in a student-centered way, in accordance with design criterion four.

> Suppose you work in the marketing department of a company that makes cars. The company is trying to think of ways they can explain to the public why it is important to hose down the underneath of cars in bad winters. Produce a leaflet or poster which attracts attention and show why this hosing down process is so important.

Having learned, in the previous activity, the causes involved in rusting, students are offered here a chemical-societal context in which they can apply/transfer their newly won chemical knowledge.[29]

Summary

Lesson M3 starts with a chemical-societal context, corroded metals, followed up, after the introduction of the chemical concepts *element, reaction, and compound*, by another, more specific CTS context, the rusting of iron, in which students investigate the possible causes or factors affecting rusting. The lesson concludes with a chemical-societal context from daily life, the hosing down of cars. Thus, here we have a good example of a *sequence* of chemical-societal contexts, and of the introduction and application of chemical concepts in accordance with design criterion two, *relevance*. So, lesson M3 does have its origin fundamentally in everyday life contexts.

Secondly, do the chemical concepts introduced in lesson M3 arise naturally from or are needed for the study of the everyday contexts mentioned above, in accordance with design criterion three, *context-led development of concepts*? If we focus on the specific case of the rusting of iron, it is clear that the factors or *causes affecting rusting* arise naturally and are needed for students to make sense of chemical/societal phenomena of rusting. As for the basic chemical concepts involved in corrosion in general, the concept of chemical reaction seems to be crucial to make sense of corrosion being a socially unwanted chemical change of the surface of metals. The concept of an element as "the simplest possible substance" does not appear to be necessary in the context of corroded metals or rusting. The concepts of pure metals, pure substance, and compound, might not be needed either. A general concept of substance or material will do. Thus, a discussion in terms of metal *materials* (pure, mixed, or alloyed) and their chemical *changes* would probably be sufficient to deal with the contexts of corrosion and rusting in this lesson. On the other hand, the concept of an element as a principle of conservation of matter, although not developed, arises naturally from the context of recycling, if such a context were to be added.

5.2.4 Analysis of lesson M4

The synopsis of lesson M4: A CLOSER LOOK AT CORROSION AND BURNING reads:

> After looking at the results of the *rusting* experiments, students investigate the burning of magnesium and *compare* the *processes* of burning and corrosion. Ideas about elements and compounds are reinforced.

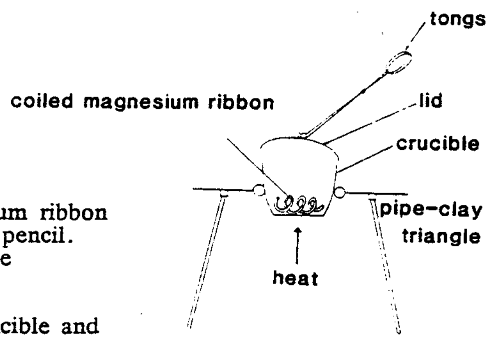
[29] Garforth (FG92a:15) remarks that "it was definitely intended" by the developers to solve the problem of application, or transfer, in this way.

The lesson starts with a teacher-student discussion from which should emerge the key points of the students' experiments with rusting iron nails (SAG M3.1). These will be summarized by the teacher as (LPM4): "Air and water are both needed for *rusting*. Salt makes *rusting* happen more quickly. Iron is used up during *rusting*. A new substance is formed when iron *rusts*". And TNM4 adds: "As *air* generally contains *moisture*, iron *objects* will therefore rust in air."

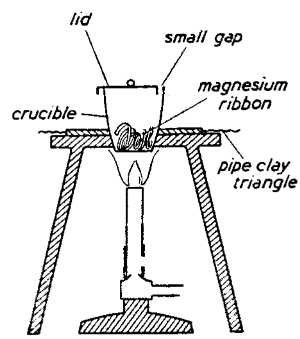
The *specific* chemical-societal (CTS) context *rusting*, stressed by the points above, is abandoned, as we will see, in the main part of lesson M4 and is replaced by the *general* pure chemistry (PC) context *oxidation*. The latter context is preceded and prepared by the context of burning, which can be treated either in a chemical-societal context such as the operations of the fire brigade or in the purely chemical context of oxidation. It is the latter context, illustrated by the burning of a piece of magnesium ribbon in a classic experiment, which is also used by Dingle and Simpson (1959, p. 51) in a book called *Basic Chemistry* intended "for the first two or three years before O. L. [O-level]". Again, as with the experiments on rusting (SAG M3.1), there is a striking resemblance between the traditional experiment, used by Dingle and Simpson, "To Discover if Metals gain in Weight when Heated" (ibid., p. 51) and the experiment in the unit Metals of Salters' Science (1989) used to study "possible changes in mass during burning and rusting" (TNM4), as a simple inspection of Figure 5.10 shows.

Figure 5.10 Experiments on Burning Magnesium

Left: From *Salters' Science* (1989), UYSEG, Unit Metals, SAG M4.1, Side 1/2
Right: From *Basic Chemistry* (1959), Dingle and Simpson, Experiment 31, p. 51.



1. Make a coil of magnesium ribbon by winding it around a pencil. Put the ribbon inside the crucible.
2. Place the lid on the crucible and weigh the crucible, lid and ribbon together.



Combustion of Magnesium.

The demonstrated experiment should illustrate, and in a spectacular way, the *process* of burning (see synopsis). Students are invited to observe what happens "without looking at the burning ribbon directly" (TNM4, their emphasis). This is of course good safety advice, but it has the unfortunate effect that the students are provided with experiences, mainly of the initial *state,* the "starting materials (reactants)", and of the final *state,* the "final materials (products)". These are easily and safely observable, as against aspects of the *process* in between, except for the fact that "the magnesium flares up" (TNM4) while burning in *air*. The purpose of the teacher demonstration of the burning of a piece of magnesium ribbon in air is to show that: "(i) magnesium *is used up* during burning; (ii) a new substance is formed when magnesium burns; and that (iii) *air* is needed for magnesium to burn." (TNM4).

In the small group discussion following the demonstration, groups of 4-5 students are invited to discuss "what they have seen in the rusting and burning experiments" (TNM4). Students are encouraged to come up with hypotheses on the process of burning and with ways of testing them.

A remark about the place of this activity seems to be in order here. At this point in the unit Metals, students have acquired some *experiences* with the *specific* chemical-societal case of the *rusting* of iron (SAG M3.1) and are now asked to compare these *direct* experiences with the limited and indirect experiences gained from the *demonstration* experiment of the phenomena of *burning* magnesium ribbon. Later in the lesson, the teacher may decide to let students perform the experiment of burning magnesium coil in a crucible (SAG M4.1). Students are encouraged to do the experiment themselves "rather than just observe the teacher demonstration" (TNM4). It seems to me, that the discussion in small groups could be more productive for students after having collected direct experiences with both the experiment on rusting of iron nails and the burning of magnesium coil in air.

In the subsequent teacher-student discussion, addressing the question: "How can we prove that iron and magnesium gain something from the air during rusting and burning" (LPM4), the teacher "may need to direct the discussion towards the consideration of possible changes in *mass* during burning and rusting" (TNM4). So, the comparison between "the *processes* of burning and rusting" (synopsis) focuses on just one similarity, namely that of changes in mass or weight, a similarity which is indeed of crucial importance for the *purely chemical* context of oxidation. The *differences* between the processes of rusting and burning, important for societal uses and applications of metals and (in this case) also fuels, hardly receive any attention.

The next activity consists of laboratory-based practical work (SAG M4.1) and/or a teacher demonstration which aims to provide students with evidence of "possible changes in mass: (i) as magnesium burns, (ii) as iron rusts" (LPM4). The key points are: "When a metal corrodes or burns it [sic] gains *mass*. Corrosion and burning involve reaction with *oxygen. When elements* react with *oxygen* compounds are formed. Reactions with *oxygen* are called *oxidation* reactions."

It should be noted that these key points imply that the concept of corrosion of metals is now *subsumed* under the general chemical concept of oxidation of all metals or even of all chemical elements. Earlier in lesson M3 the rusting of iron was subsumed under the general phenomenon of corrosion.[30] Students can only observe in these experiments

---

30 Garforth (FG92a:15) stresses the *gradual* development of a "generalised chemical concept of reaction, the generalised chemical concept of oxidation" starting with daily life phenomena such as the rusting of iron nails or the browning of apples.

that the starting material increases in weight and that there is a change in color and/or texture. They have no way of telling, though, that it is "something in the air" (LPM4), called oxygen, which reacts in a process called oxidation, with metals such as magnesium and iron to form compounds, called oxides. Hence, in the concluding third teacher-student discussion all this chemical knowledge must simply be transmitted to the students.

Corrosion, burning or oxidation

The teachers' notes accompanying the third teacher-student discussion contain much which is worth commenting upon (see Figure 5.11 in which I use bold numbers in parentheses to refer to points discussed in the text immediately below the figure; my comments follow the figure). The outline of this activity reads: "Discussion should allow the production of word equations to summarize the processes of corrosion and burning and should reinforce the ideas about elements and compounds from M3" (LPM4). This should lead to the key point: "Elements can combine to form compounds, but they cannot be made to *weigh* less" (LPM4).

Figure 5.11 Teachers' notes for teacher-student discussion three (Metals, 1989)

The reactions which have taken place can be summarized as <u>word equations</u> (underlining by developers). These also serve to reinforce the ideas covered in the previous lesson.

	magnesium	+	oxygen (1)	➛	magnesium oxide (1)
i.e.,	element		element (2)		compound
	iron	+	oxygen (1), (3)	➛	iron oxide (1)

Word equations summarize a process (4). They show the *starting* materials (the reactants) on one side of an equation and the *final* material(s), the products, on the other side. Sometimes more information is added to an equation by including state symbols as a subscript after the name of the substance.

State symbols are:	(s)	for solid
	(l)	for liquid
	(g)	for gas
	(aq)	for a solution of a soluble solid in water

e.g.	magnesium (s)	+	oxygen (g)	➛	magnesium oxide (s)

Generally speaking, an arrow (➛) is used when the equation is used to describe a <u>qualitative</u> reaction, whilst an equals sign (=) is used when the equation is being used to describe a reaction <u>quantitatively</u> (i.e. formulae are included, and the *equation* is *balanced* (5) in terms of reactants and products). These word equations show what happens when the *element is burned* (6), and *the reaction with oxygen* part (7) of the corrosion process. Reactions in which metals combine with oxygen are examples of OXIDATION reactions.

Comments

(**1**) In this lesson no evidence is presented to pupils for the part played in the process of corrosion or rusting by "something from the air", called oxygen. The role of *air* is introduced to students in lesson M3, and mentioned several times in lesson M4, up to and including SAG M4.1. At the end of M4, students are simply told about the existence, role and name of oxygen.

(**2**) There is no evidence presented for the claim that the metals mentioned (or the nonmetal oxygen) are elements. Students have to accept on authority, of text or teacher, the key point: "Elements can combine to form compounds, but cannot be made to weigh less"(LPM4).

(**3**) The role of water, crucial to rusting, is left out in this word equation (see also point 7). The developers illustrate here the point I made above about the implicit assumption of the concepts of rusting and corrosion under the general concept of oxidation. In brief, the specific and concrete CTS context *rusting* full*y* gives way to the general and abstract PC context *oxidation*.

(**4**) The (qualitative) word equations do "summarize processes", but by reducing the processes to the *states before and after* the actual chemical change. The chemical process itself is not represented in the word equation (see Chapter 2).

(**5**) The concepts associated with (quantitative) balanced equations such as formulae, state symbols, and equals signs do not seem to be needed at this stage for students to understand the processes of rusting/corrosion and burning (or even of oxidation).

(**6**) The phenomenon of burning seems to be extended or generalized from metals to *all* elements.

(**7**) In these word equations the complex processes of the corrosion of metals are simplified or reduced to the reactions of pure metals with just oxygen, thereby *making* corrosion processes *identical* to oxidation reactions.

Summary

In lesson M4 of the unit Metals (1989) the initial chemical-societal context of rusting of iron has almost completely given way to the classical purely chemical context of oxidation, covertly bridged by the ambiguous concept of burning. The lesson offers little by way of specific, local chemical-societal contexts. Thus, design criterion two, *relevance*, is not followed by the developers.

As for developers' adherence to design criterion three, *context-led development of concepts*, many of the chemical concepts introduced in M4 are related only globally and rather tenuously to the fundamental chemical-societal theme of corrosion. Therefore, the source of the justification for a number of the fundamental chemical concepts introduced, such as oxidation and balanced equations must lie elsewhere, perhaps in the perception the developers have of the structure of school chemistry, as commonly perceived or because of external constraints.

Except for the concepts of chemical change, the accompanying change in weight and word equation, most of the chemical concepts dealt with in lesson M4 do not arise naturally from, nor are they needed for, the study of the everyday situations such as the rusting of iron or the corrosion of metals. This leads to the conclusion that the lesson as a whole may not be needed.[31] The lesson lacks the sought for societal justification, and seems to be appealing largely to a chemical *conceptual-structural* justification (see section 5.2.8 for further discussion).

5.2.5 Analysis of lesson M5

The synopsis of lesson M5: DO ALL METALS CORRODE? reads:

> Students carry out a practical investigation to produce *an order of ease of corrosion* of metals. This leads into a consideration of *ways of preventing corrosion*.

This lesson begins, as did lesson M4, with an examination and recording of the results of the rusting experiment (SAG M3.1) performed by small groups of students. The rusting of iron is addressed here for the third time showing the importance of the unit theme *corrosion* in accordance with design criterion two, *relevance*. This time "each group should prepare a *written* report from their results" (LPM5) and "possibly *present* a report" (TNM5) to the class, which provides a good opportunity for students to practice valuable communication skills.[32]

As the synopsis indicates, lesson M5 focuses on a practical investigation by students into the differences in c*orrodibility* as a basis for their understanding of ways of *preventing corrosion*. The laboratory-based practical work (SAG M5.1) is preceded by a teacher-student discussion, in which the teacher reminds students of the display of corroded metals they saw in lesson M3, while pointing out that "differences in the *extent* of corrosion suggests that there might be *an order in ease of corrosion*" (TNM5). Subsequently, the teacher demonstrates (from a display of five metals) the reactions of sodium with air and *water*, which introduces students to the investigation of the "*corrodibility* of the remaining four metals [calcium, magnesium, iron and copper] by observing their action with *water"* (LPM5). So, students first witness that the freshly cut, shiny silvery surface of a piece of sodium "tarnishes as it reacts very quickly with the *air*" (TNM5). Secondly, in the spectacular reaction of a piece of sodium with *water*, they observe, that it "will melt forming a silver ball ... move rapidly across the surface of the water, fizzing as a gas (hydrogen) is produced ... may spark or burst into a yellow flame" (TNM5).

In the ensuing practical work students investigate the corrodibility of pieces of calcium, magnesium, iron and copper by observing the reaction of these metals with *water* (LPM5).

A few things should be noted at this point. First, the student investigation concerns the corrosion of metals in *water*, not in atmospheric air. Second, this lesson deals again

---

[31] I found confirmation for this claim in the trial unit Metals (1984), which does *not* contain a lesson dealing with burning or oxidation. Metals (1987), however, does contain such a lesson but as an optional enrichment (M3X). This lesson became lesson M4 of Metals (1989), that is, it was promoted to a core lesson, which means that "the specific content" (OGT, p. 13) of this lesson now had to be *examined*.

[32] Metals (1987, LPM4) describes these skills as "communicating in writing [and] communicating orally". As we saw, the results of the experiments have already been summarized by the teacher in M4.

with *pure* metals, not with metal *objects*. Furthermore, as noted already in the analysis of lesson M1, some of the metals investigated, e.g., sodium, most students will not have met in everyday life nor will they (need to) meet them after their school chemistry days.

Students observe the reaction of small clean pieces of calcium, magnesium, iron and copper with cold tap water by inverting a test tube, fully filled with water and the metal, in a beaker filled with tap water (SAG M5.1). They observe and collect the emerging gas which they test using "a lighted splint", learning thereby to identify the gas as hydrogen. With the help of four questions (SAG M5.1), students are led to the conclusion that the *order of reactivity* decreases from the most reactive metals: sodium, calcium and magnesium to the least reactive ones: iron and copper (the latter two metals show no visible reaction with cold tap water). Or, as the key point of the following teacher-student discussion reads: "The order of decreasing *corrodibility and reactivity with water* of the metals is sodium, calcium, magnesium, iron and copper. This order forms a *reactivity series* for the metals".

Corrodibility of metal objects or reactivity of metal elements

The key point of this lesson, namely, the question of *an order in ease of corrosion* of metals (synopsis), a societal unwanted change of the surface of solid metals exposed to atmospheric *air*, is tackled here by an investigation into the *order of reactivity* of five metals in their reaction with *water*. Thus, the chemical-societal context of *corroded metals* again gives way to a classical pure school chemistry context, this time leading to the concept of *the reactivity series* and the revisiting of the concept of oxidation. The corrosion of metals with water is conceived as the chemical reaction of metals with the element oxygen in the compound water: "so it appears that the oxygen in water prefers to react with sodium" (TNM5).

Furthermore, the developers implicitly assume that the *order of reactivity* of metals found in the latter PC context, in reactions of metals with water, is also valid for the CTS context of corrosion, in reactions of metal objects with atmospheric air, that is, that the order of corrodibility of metals is the *same* as the order of reactivity of metals.[33] In Figure 5.12, I have summarized a number of *differences* between the process of corrosion, taken as a societal unwanted change of the surface of solid metals exposed to atmospheric *air* (CTS context), and corrosion taken as a chemical reaction of pure metals with water (PC context)

In brief, metal objects are reduced to metal elements, corrosion in atmospheric air is reduced to the reaction of metal elements with the element oxygen, and corrodibility is identified with reactivity. These *context switches* are not presented explicitly, but are introduced covertly. Thus, this lesson presents another example of developers leaving a CTS context for a PC context and then returning to the CTS context without much justification or explanation (cp. analysis lessons M2, M4).

33 Metals (1984) also states, as the outcome of the pupils' experiment of some metals reacting with *water*, that "metallic elements can be placed in an *order of reactivity*", adding the argument that "since corrosion involves *oxidation*, the order of corrodibility *is the order of reactivity of the metals with oxygen*". There seems to be a covert switch, first from equating reactions of metals with water to reactions of metals with oxygen, and then with reactions of metal objects with atmospheric air (corrosion). Metals (1987) states as outcomes of the class practical: "*The Reactivity Series, *Corrosion involves the reaction with oxygen*, *Gain of oxygen is called oxidation, *Metals (elements) form compounds when they react with oxygen" (asterisk and italics in original).

Figure 5.12 Corrosion in a CTS context and in a PC context[a]

Statements in a CTS context	**Statements in a PC context**
Unwanted change of surface metal objects in atmospheric air.	Chemical reaction of metals with oxygen (air).
Solid metal objects can be elements, alloys, or composite materials.	Metals are elements, solid substances which cannot be made any simpler.
Air and water cause iron objects to rust (corrode); salt increases rate of rusting.	Corrosion and burning involve reaction with oxygen.
Metal objects change color, texture, and weight during corrosion.	Corrosion of metals in air (oxygen) is same as corrosion of metals in water (oxygen).
Degree of corrodibility: metal objects differ in the extent and ease of corrosion (*a kinetic concept*).	*Reactivity series: metals as elements differ in their reactivity towards water (oxygen), a thermodynamic concept.*
A corroded metal object is formed, a combination of the metal object and atmospheric air.	A new substance, a compound of element metal and element oxygen, an oxide, is formed.
A heterogeneous change of solid metal objects in atmospheric (moist) air or in natural (e.g. salt) water.	*A heterogeneous change of solid metals in oxygen or in (pure) water.*
Prevention of corrosion addresses air, water, and salt (*or other ingredients of atmospheric air*).	*Prevention addresses only oxygen, if at all.*
A complex set of processes in which solid metal objects undergo unwanted societal changes, including catalytic changes.	A simple combination reaction of a metal element and the element oxygen, forming a compound called metal oxide.
No gas is produced; ingredients of atmospheric air are used, including gases.	Metals reacting with water produce a gas called hydrogen ; oxygen from the water is used.
A slow process, visible at surface e.g. rusting.	Can be very quick and violent, e.g. reaction of potassium in water.
Focus on the corroded metal object, and on how to prevent the corrosion thereof.	Focus on identifying escaping gas, hardly at all on corroded metal.
Corrosion of metal objects differs from case to case, e.g. copper tarnishing involves carbon dioxide and water.	Involves always oxygen and a metal.
Since corrodibility degree is a kinetic concept, aluminium is not an exceptional metal.	*Reactivity series is based on standard reduction potentials. The behavior of aluminum is taken as an exception to this thermodynamic rule.*
Relates to surface, texture, and internal crystalline structure of solid, e.g. nickel.	*Relates to bulk of pure substance, element.*

[a] Some statements are taken literally or paraphrased from Metals (1989). Other statements, put in italics, are used implicitly in the treatment of the corrosion of metals there, or must be assumed as I have argued in the text.

In accordance with design criterion two, *relevance*, one would have expected that the "practical investigation to produce an order of ease in corrosion of metals" (synopsis) would have focused more on corrosion reactions proper such as the rusting of iron or the tarnishing of copper, that is, on the changes metals undergo when exposed to atmospheric air, e.g. students could have investigated the *order of corrodibility* of the set of corroded metals used in lesson M3.

In the last activity (SAG M5.2) called "Preventing Corrosion", students return to the CTS theme *corrosion* and learn to make sense of a number of methods for preventing corrosion of iron *objects*, such as painting, oiling, plating and alloying, that is, really for the preventing of *rusting*. They are asked to do this in terms of the causes of rusting they have learnt in lesson M3 (and reinforced at the start of M4 and M5), namely air, water and salt, and in terms of the *order of corrodibility* of metals. The method of alloying is introduced as follows: "Iron can be mixed with another element to form an alloy which *corrodes less easily*" (SAG M5.2). Apparently, for their understanding of ways of preventing corrosion or rather rusting, students do not need the concept of the order of reactivity of (pure) metals nor the concept of oxidation. These chemical concepts do not arise naturally from the study of everyday situations used, while the concept of the *order of corrodibility* of metal objects does.

As for the title of lesson M5: "DO ALL METALS CORRODE?", this question is addressed briefly in the last activity (SAG M5.2). There the technique of plating is introduced in which iron is coated with a thin layer of a metal "which does *not* rust" such as chromium. This implies that *not* all metals corrode.

Summary

Does lesson M5 have its origin and justification for study, fundamentally, in aspects of everyday life? The lesson begins by reminding students of the CTS contexts of rusting and corroded metals but quickly leaves these for a classical PC context of reactions of metals in water, a development which is hard to justify in terms of relevant CTS contexts. Lesson M5 does end with a CTS context, prevention of corrosion, in accordance with design criterion two, *relevance*, addressing the properties of metal objects students are familiar with in everyday life, or which they need to know. Thus, the lesson does not consistently develop the CTS contexts rusting and corroded metals along the lines of corrosion and corrodibility of metal objects.

Are the chemical concepts treated in lessons M5 needed for the study of everyday situations in accordance with design criterion three, *context-led development of concepts*? This appears not to be the case for the concept of the order of reactivity of metals nor for the concepts of oxidation, but it is the case for the concept of an *order of corrodibility* of metal objects and the techniques for preventing rusting.

5.2.6 Analysis of lessons M5X1 and M5X2

Lessons M5X1 and M5X2 are so-called *optional enrichment* lessons. These lessons:

> Provide possible extensions of some core lessons either by looking at *more background information* or by giving additional *examples of the development and application of concepts* introduced in the preceding core lesson. These lessons are *not* designed only *for the more able* students *nor* will the specific content of these lessons ... *be examined* on either written paper (OGT, p. 13).

I will return to the italicized points below when analyzing lessons M5X1 and M5X2 (see Appendix 5 for the full lesson plans of M5X1 and M5X2 and).

Lesson M5X1

The synopsis of lesson M5X1: HOW DO WE PREVENT RUSTING? reads:

> After examining the *ways in which a bicycle is protected from rusting*, students investigate the *effectiveness of commercial rust inhibitors*.

This first enrichment lesson offers two CTS contexts for the "application of concepts introduced in the preceding core lesson" (OGT, p. 13). The concepts applied are the process of rusting, the causes of rusting (water, air and salt) and the methods of preventing rusting (painting, oiling, plating and alloying). These concepts, as we saw, have been introduced and developed in lessons M3, M4 and M5. Two earlier applications of concepts learned by students concerned written work: the *making of a leaflet* on the hosing down of cars (SAG M3.1) and *completing a question sheet* on the prevention of corrosion (SAGM5.2). Lesson M5X1 takes this further by providing two CTS contexts in which students perform *practical* work.

Lesson M5 X1 begins with an everyday life context, namely, how to prevent the rusting (of parts) of *a bicycle*, whereas the sequel of the lesson is also devoted to a context in which chemical, technological and commercial aspects of a number of rust inhibitors are explored. The examination of a bicycle, to be carried out by students (SAG M5X1), is introduced as follows:

> You will be shown a bicycle whose frame, cranks, chain and gears are made of *steel*. If these are allowed to go rusty, *iron in the steel* will be *used up* in making the rust and the bicycle will wear out more quickly. Different parts of the bike have been prevented from rusting in different ways.

Students are then asked to "state how the parts are prevented from rusting and why the method stops the corrosion" (SAG M5X1), while using a table with the following headings: Part of bicycle, How is rusting prevented? and Why does this method stop the rusting? This examination brings home to students by way of practical work on a bicycle, an everyday life *object* or "machine" (LPM5X1) made of predominantly metal materials, that "rusting is prevented by excluding air and/or water" (LPM5X1). Thus, students meet here a very clear example of a familiar daily life metallic object, many parts of which are made of *alloy*s, especially of steel. In the context of preventing the rusting of metallic objects such as cars or bath taps through alloying students have been informed of the *fact* that "stainless steel is an alloy" (SAG M5.2). The developers add that "[d]uring lesson M6 you will be looking at the *properties* and *uses* of alloys".

As we have seen earlier, in lessons M1 and M2, students have met several other daily life metallic objects, such as sauce pans and drawing pins of which they learned to identify the *dominant* metal by way of simple chemical tests or analysis. As I argued there, the method of chemical analysis puts the emphasis on the concept of *pure* metals (pure substances), whereas in daily life, as is clear from examples such as a bicycle, the metallic parts are often alloys. Thus the concepts of mixtures and of alloys arise quite *naturally* from the study of everyday objects made of metal, more so than the concept of pure metals/substances. The former concepts should therefore, in accordance with design criterion three, *context-led development of concepts*, receive not only more emphasis but also earlier treatment in the unit Metals (see also discussion M6).[34]

It should be noted that the "*iron* in the steel" has to be present as the element iron, taken in the sense of a pure substance or "the simplest possible substance" (M3). After all, only the pure substance iron can be "used up in making the rust" (SAG M5X1.1).

The second part of this lesson consists of laboratory-based practical work for students set in a CTS context of "commercial rust inhibitors" (synopsis). The student activity, titled "DO 'RUST STOPPERS' WORK?" is introduced as follows (SAG M5X1.2):

> Many *makes* of rust stoppers are sold to *treat* rust on metal, usually in cars. In this experiment you are going to try to find which rust stopper works best.

In the experiment students file away a layer of tin off the sides of two tin cans and make three patches halfway each can.[35] Two of these patches are covered, each with a different rust stopper (seven commercial brands are mentioned), while one patch remains untreated. The cans so treated are put in a plastic bowl of salt water in such a way that the water covers half of each patch. Students then compare, each day for about a week, the treated and untreated patches, while using the unfiled parts of the tin cans as a control. In a presented table they write down "when each patch starts to rust" and "how rusty each patch is" (SAG M5X1.2).

Having completed their experiments, students are asked the following questions:

Q1. Which is your best rust stopper?

Q2. Which is your most expensive rust stopper?

Q3. Is this experiment a *fair comparison*? Could you improve upon it? Explain your answer.

Q4. Tin cans are made mostly from steel. Did the unfiled parts of the can go rusty?

Q5. Which parts of a car are protected from rusting by covering them with another metal?

Students can answer the first question on the basis of their observations which might include weighing the amount of (rubbed off) rust formed after a week (cp. lesson M4). The second question can lead into other economical and commercial aspects of rust prevention. For example, which rust stopper has the lowest price/performance ratio? And, whether 'rust stoppers' are really rust *stoppers*. If not, why are they called that way by their manufacturers, and not, for example, rust *inhibitors* as it says in the synopsis of

34 In the chapter Metals (section "In brief") of the student book (Hill et al., 1989, p. 7), the concept *alloy* is defined as follows: "An alloy is a mixture of two or more metals." It is added that "Alloys have different properties from any of the metals they contain."

35 The tin layer on the iron can is very thin. Thus, in contrast with the analytical context of lesson M2, the (implicit) focus is here clearly on the 'recessive' metal (tin), not on the dominant metal (iron).

lesson M5X1. The third question leads into "the usual issues about the use of identical tins, identical thickness of rust stopper layers" (TNM5X1). Students practice scientific *process* skills such as "controlling variables [and] using a control" (Metals, 1987) needed to make a fair comparison of the rust stoppers. The developers further point out that (TNM5X1):

> ... students should be encouraged to think about the instructions for the use of the rust stoppers. Some commercial brands are designed to be placed onto clean iron and steel surfaces (as in this experiment) but others have *a different mode of action* and are painted onto *surfaces which are already rusted*. A *comparison* of the effectiveness of rust stoppers can only be *fair* if the instructions for use are identical.

Students will learn more about this other way to 'stop' rusting, that is, to slow down or to inhibit rusting in the next lesson (M5X2). The last two questions require no comment, except that students need to (learn to) make careful observations to be able to answer them.

Summary

The context *prevention of rusting of a bicycle* is a good example of a CTS context, in which relevant chemical concepts (rusting, its causes and methods of prevention; alloys, i.e., steel) acquired by students in earlier CTS contexts are applied. The same can be said for the context *rust stoppers* for which the first context forms an excellent preparation. Apparently, students do not need other chemical concepts in order to understand the ways in which metal objects such as bicycles or cars are prevented from rusting. The *process* skills *controlling variables* and *using a control* are needed to make a fair comparison of rust stoppers.

This leads to the conclusion that design criterion two, *relevance*, and design criterion three, *context-led development of concepts* are adhered to consistently in this enrichment lesson.

Lesson M5X2

The synopsis of lesson M5X2: DO OTHER METALS STOP IRON FROM RUSTING? reads:

> The *effect of the presence of another metal on the rusting of an iron nail* is investigated. The results are then related to the *order of corrodibility* of the metals, and their *use in protecting iron*.

The lesson begins with a teacher-student discussion. The teacher (TNM5X2) is advised to:

> Remind the students of the need *to cover iron* and *steel* to prevent rusting. *Tell* the students that other metals (such as zinc, tin and chromium) are often used to coat iron, though plastic is a cheaper alternative. Perhaps there is another reason for using other metals in addition to simply *covering the iron*.

Actually, students have already answered some questions related to the technique of coating iron with zinc, tin or chromium (SAGM5.2). They have gained *experiences* with tin coating in M5X1.2, and have previously met a few examples of coating or plating in M1 (tin coating) and M2 (e.g. copper coating). The teacher could also come back to the investigation on rust 'stoppers' (SAG M5X1.2), especially on those brands that can be applied to already rusty surfaces. This kind of rust 'stoppers' might contain, if and when inspected by students, as an important ingredient some other metal, which could lead students to the idea of a different mode of (inter)action than simply *covering* the iron.[36] Students could find out this way that in some 'rust stoppers' it is the metal ingredient which slows down rusting. Some students might even note that these metals belong to the more reactive metals in the *order of corrodibility* they have met in lesson M5. Thus, the previous chemical knowledge and experiences could be used to elicit ideas from students about the effect of some other reactive metals such as magnesium and zinc on iron rusting.[37] And this activity would also prepare students for the practical investigation which addresses the effect of some other less reactive metals such as tin or chromium on iron rusting.

In the laboratory-based practical work SAG M5X2.1 (or teacher demonstration) with the title: DO OTHER METALS STOP IRON FROM RUSTING,[38] the students (or teacher) investigate the rusting of iron in a salt solution in the presence of a second metal. They set up five test tubes which contain "clean" iron nails in a salt solution with "tightly wrapped" strips of a second metal around them, namely zinc (1), tin (2), copper (3) and magnesium (4). The students are instructed to look at the their test samples each day for a week, and to record their "observations each time in the results table" which has as headings "appearances of iron" and "appearances of the other metal" (SAG M5X2). Students are then asked:

Q1. Which metals *speeded up* the rusting of iron?

Q2. Which metals *slowed down* the rusting of iron?

These two questions are answered as follows in the TNM5X2:

Copper and tin should speed up the rusting process. These metals are less reactive than iron.
Zinc and magnesium slow down rusting process. These metals are more reactive than iron.

At the start of lesson M6, the students' results are discussed and generalized. This leads to the "explanation of the differences in behavior of metals in terms of differences in *corrodibility*" (LPM6), that is, to a macroscopic explanation. Students learn the phenomenological generalization: "Metals above iron in the reactivity series slow down rusting; those below iron speed it up" (LPM6).[39]

As noted above in Figure 5.12, the thermodynamic PC concept of reactivity series should be replaced, in the context dealing with corrosion and rusting, by the kinetic CTS

---

36 The teacher could also use the argument mentioned in the student book (Hill et al., 1989, p. 4) to elicit ideas from students: "The lumps of magnesium are obviously not covering the whole of the ship (...) and so they must be protecting the iron in another way."

37 Maybe pupils could also be asked, at this stage, to make some suggestions about the *kind* of interaction between iron and the second metal, which must be different from simply covering the surface of the iron.

38 Lesson MX6.1 of Metals (1984) is simply titled: "What is the effect of other metals?" This title leaves open the nature of the effect (positive, negative, or neutral) which would be more in accordance with an *open-ended* type of investigation (OGT, p. 62).

39 Further explanations, in terms of the thermodynamic potential differences between metals or in terms of corpuscula (electrons, ions, and atoms), can be dealt with, if needed, in units of a further course which would build on the chemical knowledge acquired in lesson units such as Metals. For an example of corrosion phenomena in an experiential, electrochemical, *societal* context from which a corpuscular explanation *arises naturally*, see Acampo (1997).

concept *order of corrodibility* (see synopsis). The latter concept is developed from CTS contexts, is used in activities by students, and is all they need. The lesson ends by asking students the questions:

> Q3. A tin can is really an iron can coated with tin. In a damp atmosphere what would happen if some of the tin was scratched off one part of the can?
>
> Q4. Galvanized iron is coated with zinc. In a damp atmosphere what would happen if some of the zinc was scratched off one part of the iron?

By answering these two questions, students learn to apply their newly acquired corrosion 'law' to the chemical-societal contexts described in these questions. In the first case, that there is indeed another reason (besides simply covering the iron) for using the metal zinc. More reactive than iron, zinc *slows down* the rusting process. Secondly, other metals such as tin and chromium are, in fact, simply covering the iron surface and protecting thereby the iron for rusting. After all, when tin does *not* fully cover the iron, as in the case described in Q3, it will, being a less reactive metal than iron, actually *speed up* the rusting process.

Summary

Out of the investigation into the effect of the presence of another metal on the rusting of an iron object *arises naturally* the phenomenological generalization that *metals above iron in the order of corrodibility slow down rusting, while those metals below iron speed it up*. This generalization is all that students *need to know* to make sense of the chemical-societal corrosion phenomena related to the prevention and treatment of corrosion treated in the last three lessons of the unit Metals. Thus, also in this second enrichment lesson, design criterion two, *relevance*, and design criterion three, *context-led development of concepts* are adhered to consistently, except for the confusing reference to the PC concept reactivity series in the teacher student discussion.

Since lessons M5X1 and M5X2 are *optional enrichment* lessons, the specific lesson content is *not* to be examined (OGT, p. 13). It will therefore strongly depend on the teacher's views on school chemistry and on the constraints operating on her or him when teaching real children in a real classroom in a real school whether or not these optional lessons will be taught, and if so, in what form (section 5.4). This is much to be regretted, because, as we have seen above, these two lessons are good examples of *relevant, context-led development of concepts* and should therefore be really part of the *core* of the unit Metals, taken as a unit focused on the fundamental theme *corrosion*.

5.2.7 Analysis of lesson M6

The synopsis of lesson M6: WHAT ARE METAL ALLOYS? reads:

> (If the M5X lessons have been followed the results should be discussed at the start of this lesson). Solder is used to investigate *the effect of alloying on properties*. Students then use data on alloys to suggest appropriate alloys for particular *purposes*.

Lesson M6 begins with a teacher-student discussion, for which TNM6 suggest to:

> Introduce the word alloy: a *mixture* of two or more different metals or a metal to which carbon has been added. Mixing other metals or carbon with iron appears to *prevent rusting*, e.g. stainless steel (iron with chromium and nickel) cutlery does not *rust*.

This is the first time students are introduced to the *general* concept *alloy*. In lesson M5 they have been given a description of alloying specified to iron: "Iron can be mixed with another element to form an alloy which corrodes less easily. Stainless steel is an alloy." (SAG M5.2) In lesson M5X1 (if covered) students have investigated the prevention of rusting of bicycle parts made of steel (not specified which *kind* of steel). As we have seen in the analysis of lesson M2 (5.2.2), the introduction of the concept alloy was circumvented there by the introduction of the concept of *dominant* metal which was needed to make sense of the chemical identification of the *dominant*, *pure* metal in metallic objects such as paper-clips and staples.[40] Thus the essential role of other elements or ('recessive') metals for the properties of alloys is not discussed until the last lesson.

The introduction to SAG M6.1 reads: "Most of the metallic *materials* used today are *not pure metals but mixtures* of a metal with one or more other elements. These mixtures are called ALLOYS" (last emphasis in original). As I will argue, it would have been more in accordance with design criterion two, *relevance*, and design criterion three, *context-led development of concepts* to give the concepts of alloys an earlier and more central place in the unit Metals.

The next activity is a teacher demonstration showing "the bendability and brittleness of a paper-clip and a darning needle" made of *different* kinds of steel, that is, both iron based alloys. The key point of the demonstration is that "the *composition* of an *alloy* determines its *properties*" (LPM6). The presence of a small amount of carbon and/or other metals turns out to be crucial since it changes the properties of the object made of the alloy. For example, the alloy *mild steel* (iron and some carbon) is used to make a paper-clip which easily bends but is difficult to break. The alloy *stainless steel* (iron, chromium and nickel) is used to make a darning needle "which is difficult to bend but snaps cleanly if it does break" (TNM6). This is to be contrasted with lesson M2 where, in the context of the chemical identification of the dominant metal of a metallic objects, the effect of 'recessive' metals was neglected.

Lesson M6 continues with a second demonstration in which the teacher prepares the alloy solder by pouring molten tin (5 g) and molten lead (5 g) into a mould of sand. The casting of solder is compared with the castings of tin (10 g) and lead (10 g) in terms of two properties: their melting point and "the ease with which the samples are dented by a weight" (TNM6), a measure for their hardness. The key point of this activity is that "the melting point of a metal can be lowered by the presence of a second metal." (LPM6). Both teacher demonstrations stress the important chemical relationship that "the *composition* of an *alloy* determines its *properties*" (LPM6).

Let me note at this place, that it would have been more consistent with design criterion four, variety of teaching and learning activities, if the activities used so far would have been performed not by the teacher but by the *students*; and also in reverse order thereby

---

40 TNM2 refers to brass and solder, but students meet in these alloys only the dominant metals copper and lead. Looking back, one must also note that many of the iron objects students meet in the unit Metals, such as spoons (M1), paperclips (M2), and nails (M3, M5), are really made of one or another kind of steel.

increasing the active involvement of students. Thus, students *prepare* alloys, after which they *compare* the properties of differently composed alloys, followed by the formulation of the *definition* of alloys.

The last activity of this lesson consists in a homework suggestion for students (SAG M6.1) and concerns the completion of a question sheet, called "ALLOYS". The activity is introduced to students by three important statements. The first, as we already saw above, reads:

> Most of the *metallic materials* used today are *not pure metals but mixtures* of a metal with one or more other elements. These mixtures are called ALLOYS.

The concept of pure metals which students have met earlier (SAG M2.1) is not explicitly defined in the unit Metals. The implicit suggestion is that pure metals consist of one kind of element or maybe one kind of atom (see 5.2.2.). Another implicit reference to the concept of purity is made in TNM6 in the following answer to a question put to students about the production of iron:

> Iron produced in a modern furnace contains a very high proportion of *impurities*. This makes the iron brittle [breaks when struck with hammer].

What this quote brings out is that in a CTS context a distinction is made between apparently unwanted *impurities* as in the case of the 'iron' production in a modern blast furnace and wanted *'impurities'*, as in mixing iron with carbon forming steel. The distinction is made in relation to the *purpose or use* of the product formed. Steel is useful, brittle iron is not. The latter is impure iron, the former is 'pure' steel.[41] But, neither the steel alloy nor the 'iron' produced are pure metals. This seriously raises the question whether the concept of pure metal or pure substance *arises naturally* from societal or technological situations as the one discussed above.

The concept element has been defined as "the simplest possible substance" (LPM3). The concept of mixtures or alloys is defined both negatively, in terms of *not* being a pure metal, and positively as some kind of mixtures of pure metals. What *kind* of mixtures alloys are is not addressed. Are alloys homogeneous mixtures such as a solution of salt in water or heterogeneous mixtures such as wood or rocks or maybe something else? In view of the fact that many of the metallic materials used in daily life are mixtures, it would be worthwhile to explore with students the different characteristics of alloys, metal plated objects and the layers formed on corroded metals.[42] For example, is solder a homogeneous mixture, that is, a solution of one molten metal (tin) in another metal (lead) or maybe a compound with a particular composition? The second statement reads:

> The *elements in the mixture* and the *amount* of each element present affect the properties of the alloy so it is possible to make alloys which have *specific properties needed for a particular job*.

---

41 Another example is pure water. In a PC context this refers to a pure substance (compound or molecules) and in a CTS context to a potable mixture prepared according to societal specifications (De Vos, 1992).

42 In lesson M3, students have investigated these in the form of rubbed off corrosions of the metals iron, copper, and zinc; or they have met these layers unwittingly, as in lesson M5X2, where they had "to *clean* all the nails and strips of metals", that is, in order to perform their experiments with uncorroded metals.

If an element is taken in the sense used throughout the unit, that is, as the simplest possible substance, retaining, as it would in a 'classical' school chemistry mixture, all its properties, it is hard to see how the elements in the mixture could affect the specific properties of the alloy.[43] After all, as has been shown for example in the teacher demonstrations in this lesson "alloys have different properties from any of the metals they contain" (Hill et al, 1989, p. 7); they are made for that purpose. It is to be noted that the latter definition of alloys is practically identical with the definition of a compound, that is, a combination of elements involving a concomitant change of physical as well as chemical properties of the reacting elements.[44] The weight of metals is conserved, while other physical and/or chemical properties are changed when an alloy or compound is formed. The third statement reads:

> Alloys are usually made by mixing together the *correct amounts* of each of the elements. The metals are *mixed* in their molten (melted) states.

The criterion of mixing *correct amounts* of each of the elements when preparing an alloy is quite similar to the criterion of the fixed *composition* of compounds. Thus mixing molten lead and molten tin gives a 'mixture' or rather alloy which has many characteristics of a compound. In accordance with design criterion three, *context-led development of concepts* one would have expected that the concept of *composition* which emerges as a crucial concept in the contexts of the comparison and the preparation of alloys, would have been given a more central and also earlier place in the unit Metals.

In the last activity of lesson M6, a homework suggestion, students complete a question sheet addressing the relationship between the *properties* of an alloy and the *use* of an alloy in daily life. In other words, to find out "the specific properties needed for a particular job" (SAG M6.1). A similar relationship between the physical and chemical properties of a *metal* and the use of a *metal* in daily life has been addressed in lessons M1 and M2 . In general, the relationship between properties of materials and their use, here of metals and alloys, is an important and recurrent theme of the Salters' Chemistry course fully in accordance with design criterion two, *relevance*.

Students are given a list of eight alloys (SIS M6.1) with their composition and properties. They are asked (SAG M6.1) to decide which alloy they would choose to make airplane wings, kitchen sinks, high speed drills etc. The key point of this activity is to learn that "the *use* of an alloy depends on its *properties*" (LPM6).

Summary

In accordance with design criterion two, *relevance*, one would have expected that the concepts of mixture, alloy and composition would have been developed earlier and more systematically from the CTS contexts presented in the lessons of the unit Metals. Further, one would have expected that once these chemical concepts are introduced they would be

---

43 School chemistry textbooks traditionally state that the substances which make up a mixture *retain* all their properties. A recent textbook states that the properties of mixtures are "*similar* to the substances which make up the mixture". The contrary claim can be defended, namely, that mixtures and certainly alloys, do *not* as a rule have all the properties of their components. For example, iron does rust, stainless steel does not, or the mixture gunpowder is explosive, but its constituents saltpeter, carbon, and sulfur are not (De Vos & Verdonk, 1990).

44 Another school chemistry textbook (Ainly et al, 1987, p. 250) states, for example, that "[i]n some cases alloying produces marked chemical as well as physical changes".

systematically related to the daily life objects and contexts (e.g. bicycle, nails) met earlier in the unit Metals. Since the concept of pure metal does not arise naturally, it is not be needed here.

Lesson M6 introduces, in accordance with design criterion three, *context-led development of concepts,* both the important chemical relationship, the *composition* of an *alloy* determines its *properties*, and the important chemical-societal relationship, the *use* of an alloy depends on its *properties*. Similar relationships hold between a *metal*, its properties and its use (see M1, M2) which can be seen as a special cases of the relationships holding for alloys.

5.2.8 Chemical concepts developed as needed for context–based unit Metals

For the purpose of discussion, I will first summarize in Figure 5.13 the results of the consistency analysis of the content of lessons of the Salters' Science Unit, Metals (1989). While assuming a strong interpretation of the design criteria described in section 5.1.3, I will compare the written curriculum of Metals (1989), analyzed in sections 5.2.1 - 5.2.7 with the formal curriculum of Metals (1989) as presented in Figure 5.7. This will enable us to see to what extent the developers did adhere consistently to the adopted design criteria in the process of development of *lessons* of a unit of the such Salters' Science course such as Metals (1989).

Secondly, the extent to which the developers adhered de facto to the two *central* design criteria, *relevance* and *context-led development of concepts,* will lead us into a discussion of the first design criterion, *no preconceptions*. The focus of the discussion lies in particular on the role of first criterion, *no preconceptions* in relation to the way the developers used and / or perceived the conceptual structure of school chemistry.[45] In connection with this, I will also discuss to what extent the developers of the unit Metals(1989) escaped from Normal Chemistry Education, as it existed in England at the time.

The consistency analysis of the content of the eight lessons of the written curriculum Metals (1989) was performed while trying to answer the following two research questions related to design criterion two, *relevance*, and design criterion three, *context-led development of concept*.

- Does each *lesson* of the unit Metals have its *origin*, and hence its *justification* for study, *fundamentally*, in aspects of *everyday life*?
- Are all chemical concepts and explanations introduced in the lessons of the unit Metals *needed* for the study of these everyday situations?

Summary of analysis lessons of the unit Metals

In figure 5.13, a brief summary of the results of this analysis is given in terms of the contexts used in the lessons of Metals, the pure chemistry (PC) content and chemical-technological-societal (CTS) content developed from these contexts (see section 5.1.4).

45 The role of the fifth criterion, *flexible, teacher-mediated use*, will be discussed below (5.3.2), as will the role of the fourth design criterion, *variety of teaching and learning activities* (5.4.4).

The first column of Figure 5.13 lists the contexts, chosen by the developers for the lessons of Metals, either PC contexts e.g. chemical analysis or CTS contexts e.g. rusting.

The second column, *PC content needed and developed*, lists the chemical concepts, relationships and techniques used by the developers of Metals (1989), and needed according to my analysis, to make sense of the CTS theme of the unit, *corrosion*, and of the contexts used to introduce and explore this theme.

The third column, *PC content <u>not</u> needed, but developed*, lists those chemical concepts, relationships and techniques used by the developers of Metals (1989), and *not* needed according to my analysis, to make sense of the CTS theme of the unit, *corrosion*, through the contexts used to introduce and explore this theme.

Inspection of the third column shows that there are three main PC concepts which are developed and *not* needed, namely: *chemical analysis, oxidation and the reactivity series*. Some other PC concepts in this column, such as atoms, symbols and systematic chemical names, although introduced in the unit Metals are developed to a much lesser extent.

Thus, design criterion three, *context-led development of concepts*, has *not* been fulfilled in a *consistent* way. The PC content in the unit Metals is developed more than needed. In brief, PC content is *over*developed.

Figure 5.13 Summary analysis lessons Metals (1989), a unit of the written curriculum

Context Lessons	**PC content needed and developed**	**PC content not needed but developed**	**CTS content needed and developed**	**CTS content needed and not developed**
M1 lab survey; comparison metal/plastic; student survey; use of metals	about ten common metals and their names; physical properties	atoms; symbols (shorthand), names of most metals	metal items in the lab; use of common metals; economic properties; relation physical properties with use	familiar metal objects from surroundings; useful properties, e.g. spoons used for eating; alloys/mixtures
M2 chemical analysis, application in daily life	physical properties; chemical properties (differences); some metals more reactive	chemical analysis, tests, identification; pure metal; systematic chemical names		analytical route: composition alloys; relation chemical properties with use; kinetic reactivity
M3 investigation corroded metal samples; rusting	chemical reaction	pure metal; element as simplest substance; chemical compound; systematic names	corroded metals corrosion: chemical reaction surface metal; metal is used up; causes, rate of rusting	corroded metal objects from surroundings; recycling (element as conservation principle); alloys/mixtures

Figure 5.13 Summary analysis lessons Metals (1989), a unit of the written curriculum (continued)

Context Lessons	PC content needed and developed	PC content not needed but developed	CTS content needed and developed	CTS content needed and not developed
M4 corrosion burning; oxidation	chemical reaction; change in weight; word equation	burning,oxidation; states (initial/ final); role oxygen in rusting		chemical change/ reaction as a process; role water in rusting
M5 reactivity of metals in air/ aqueous solution; prevention corrosion	common metals: calcium, iron, copper, zinc, chromium; iron based alloy steel	reactivity series metals; oxidation reinforced; reactions of metals in aqueous solutions; some metals (sodium)	techniques for preventing rusting; causes rusting: air, water and salt are reinforced	place of iron in order of corrodibility metals
M5X1 investigation rusting bike; 'rust stoppers'	iron in steel alloy; controlling variables, using a control		causes rusting; preventing rusting; commercial aspects of produced materials	alloys/mixtures; element as principle of conservation of matter
M5X2 investigation effect of other metals on rate of rusting	common metals; controlling variables, using a control	reactivity series metals	order of corrodibility; more reactive metals than iron slow down rusting; less reactive metals speed it up	kinetic reactivity
M6 metal objects often alloys; steel alloys; preparation of solder	general concept alloy; macroscopic explanation differences in corrodibility metals		composition alloy determines properties; composition alloy determines use	alloys/mixtures; element as principle of conservation matter

The fourth column, *CTS content needed and developed*, summarizes CTS content needed, according to my analysis, to make sense of the corrosion theme which arises naturally out of the theme *corrosion* and its contexts. The fifth column, *CTS content needed and not developed*, summarizes additional CTS concepts which according to my analysis arises naturally out of the theme *corrosion* and its contexts, and which therefore seems to be needed to make sense of the latter: the composition of metal objects, the process of chemical change, and the order of corrodibility. These worthwhile CTS concepts or relationships could be expected to occupy a more central place in the unit Metals as reconstructed in the light of the results of the analysis performed in this section.[46] Thus, design criterion two, *relevance* and design criterion three, *context-led development of concepts* have not been fulfilled in a consistent way. The CTS content in the unit Metals is developed less than needed, or CTS content is *under*developed.

As we saw above, in the analysis of lessons M2 and M4, CTS contexts had to give way to PC content. Thus, the lesson analysis discloses in the unit Metals a *tension* between the PC content factually used and the CTS content actually needed conform design criteria two and three. The use of PC content in the development process clearly tends to dominate over the need to develop CTS content. CTS content being underdeveloped and PC content being overdeveloped, I conclude that the CTS/PC ratio of the written curriculum of the unit Metals (1989) has decreased by a fraction or two compared to the CTS/PC ratio of the formal curriculum of the unit Metals (1989), which is graphically illustrated in Figure 5.5 above. This conclusion remains the same whether we would choose as starting point for the CTS/PC ratio,**1/1**, categorizing the Salters' Science as a "Science along with STS Content" course, containing about 50% STS content and about 50% pure science content, or whether we would choose, with Campbell et. al (1994), as starting point for the CTS/PC ratio,**1/2**, categorizing the Salters' Science as a "Science through STS Content" course containing about 30% STS content and about 70% pure science content (see section 5.1.4). In both case there is a substantial decrease in CTS/PC ratio moving from the formal to the taught curriculum level of the unit Metals.

No Preconceptions and the Conceptual Structure of School Chemistry

As I have argued above, the presence and use of the excess PC content developed in the lessons of Metals (1989) cannot be justified in terms of contexts related to the theme *corrosion*. So, why are these PC concepts developed in the unit Metals? Why are they included as "being worthy of study" as it says, for example, in Metals (1984)? Do the developers give, either implicitly or explicitly, another justification? Perhaps in terms of the *conceptual* structure of school chemistry as they perceive it? If they do, to what extent can we say that the developers have escaped from the tradition of normal chemistry education (NCE) as described in Chapter 2?

[46] This additional CTS content can be seen as part of a proposal to *redesign* the unit Metals around the theme *corrosion*, to be consistent with the design criteria of the Salters' Chemistry course (cf. 5.1.5). This proposal for redesign evolves, as it were, 'naturally' from the consistency and reversed design analysis as undertaken in this section. In order to find out whether these suggestions are effective, the proposal must be developed in more detail and trialled in practice (see also section 5.1.4).

Comparison of successive units of Metals

At this point it is interesting to compare (Figure 5.14) the three units of Metals developed successively in the period from 1984 to 1989: the Salters' Chemistry trial unit (Metals, 1984), the Salters' Chemistry revised unit (Metals, 1987) and the Salters' Science Foundation unit (Metals, 1989). This comparison enables us to see whether the two earlier units of Metals (1984 and 1987) develop the same PC concepts and CTS concepts as the later unit (Metals, 1989).

We must also bear in mind that the successive units of Metals were developed under different external constraints. Thus, Metals (1989) had to comply with the rather strict requirements of the National Curriculum (DES, 1989), while Metals (1987) had to fulfill the National Criteria of Chemistry (1985) which "were not very prescriptive at all" (G92a:8). As for the trial unit Metals (1984), no specific external constraints operated on its development. However, the developers realized that a Year Three unit such as Metals "had to come out with some kind of basis for going on to O-level" (G92b:10). The developers added that "at that point *our* external constraints came in (…) we had to bear in mind what pupils who had gone through a *standard* chemistry course would in fact have been exposed to" (G92b:10).

Figure 5.14 Comparison of the main PC and CTS concepts developed in successive units of Metals

Metals (1984)	**Metals (1987)**	**Metals (1989)**
elements, symbols; Periodic Table	atoms, elements and symbols	atoms and symbols; elements
systematic chemical names	systematic chemical names	systematic chemical names
testing	chemical tests are better than physical tests; testing in solution	chemical analysis pure metal/substance
oxidation/burning: no lesson	oxidation/burning: optional lesson	oxidation/burning: core lesson
order of corrodibility/reactivity	reactivity series	reactivity series

Inspection of Figure 5.14 shows that, the same PC concepts which were developed in Metals (1989) were also developed in Metals (1984) and in Metals (1987), except for the concepts of oxidation and burning. The trial unit Metals (1984) did not contain a lesson devoted to the latter concepts, while in Metals (1987) they were addressed in an *optional* lesson, and in Metals (1989) in a *core* lesson, called: "A CLOSER LOOK AT CORROSION AND BURNING".

Metals (1987) has *three* optional lessons; two have a CTS emphasis and are taken over as such in Metals (1989). The other lesson, "A CLOSER LOOK AT CORROSION AND BURNING", has a strong PC emphasis, and has been promoted to a *core* lesson of Metals (1989). Thus, the arrangement of lessons in Metals (1987) seems to give more room for developing the fundamental theme *corrosion* than the arrangement of lessons in Metals (1989). For example, teachers could easily skip a PC lesson in Metals (1987), thereby making room for at least one of the optional CTS lessons.

Metals (1984), on the other hand, had seven core lessons and two optional lessons: "HOW CAN WE EXTRACT IRON?" and "WHAT IS THE EFFECT OF OTHER METALS?" Besides the latter lesson, which mentions explicitly the CTS concept *order of corrodibility* as a key teaching point, some of the core lessons of Metals (1984) seem to have a strong CTS emphasis too, for example, lesson five: "HOW CAN RUSTING BE PREVENTED?", a lesson which became optional as lesson M5X1 in Metals (1989). It appears, therefore, that the earlier a Metals unit has been developed, the more it has been possible for the developers to address CTS content in the lessons of the unit related to the CTS theme *corrosion*. In brief, CTS content decreases, while PC content increases in the consecutive units of Metals in the period from 1984 to 1989.

The comparison also shows that even in the early period which was relatively free of external constraints, the developers felt the need to introduce traditional PC concepts such as chemical analysis and the reactivity series which are, as we have seen, only tenuously related to the theme *corrosion*. This leads to the conclusion that these PC concepts have been introduced, not just under the influence of external constraints, but also under the influence of an 'internal' constraint, namely, the conceptual structure of school chemistry as used and/or perceived by the developers. When no prescriptive external constraints apply, the developers' perception of the conceptual structure of school chemistry often seems to function as a kind of internal constraint (see also Chapter 4). This *conceptual-structural* mechanism then determines to a large extent the introduction of PC content in the unit Metals, that is, chemical content which is not really needed for students to make sense of the corrosion contexts chosen. At the same time, some of the CTS content needed to make sense of the corrosion *contexts* remains underdeveloped, or is deleted.

Thus, the main result of the consistency analysis of lessons of the unit Metals (1989) performed in sections 5.2.1 – 5.2.7, namely, the incomplete and inconsistent operationalization of design criterion two, *relevance* and design criterion three, *context-led development of concepts*, might very well be attributed to the largely implicit role of the conceptual structure of school chemistry on the process of developing a new, relevant school chemistry course.

No Preconceptions

It is remarkable, certainly in view of design criterion one, *no preconceptions*, that the PC content in Metals is *over*developed and CTS content *under*developed. In brief, that PC content came to dominate the CTS content. Could it be that the developers have not been able to fully rid themselves of their preconceptions with regard to the structure of school chemistry?

Before we try to answer this question, it is important to remember that the developers came to make a distinction between two kinds of preconceptions.[47] As mentioned above (5.1.3), the developers came to stress a distinction between, on the one hand, the attempt *not* to have or use preconceptions with regard to the *coverage* of chemical concepts, and on the other hand, the need to have and use their preconceived ideas with regard to the r*elationships* between chemical concepts. John Lazonby put it as follows:

[47] The following paragraphs have been written while taking into account the critical comments which David Waddington, John Lazonby, and Peter Nicolson have made on earlier versions of Chapter 4 (W97) and Chapter 5 (W2001) of this thesis.

> We had no intention of escaping from relationships between concepts, that is, we did not want to go against the order of concepts (personal communication, Lazonby, 1997).

But, as argued in Chapter 2, relationships between chemical concepts can refer either to:

– the *sequence* of chemical concepts, as used in teaching and teaching materials;
– the *logical* relationships between concepts, which together comprise the structure of school chemistry.

In the quotations used, the developers sometimes seem to refer to the sequence of chemical concepts as in “certain concepts require a *prior* understanding of other concepts” (personal communication, Waddington & Lazonby, 1997). In other quotations they seem to refer to the logical relationships between concepts, as in “not go against the order of concepts” (ibid.). The distinction between sequence and logic of concepts is clearly made and used in the following quotation taken from the Salters’ Chemistry Overall Guide to Teachers (1988):

> In some cases the *logical* development of concepts does dictate a teaching *sequence* (OGT, p. 22).

With this distinction in mind, we should ask two things. One, how did the developers use their preconceptions with regard to the sequence of chemical concepts current in school chemistry courses? Two, how did developers use their preconceptions with regard to the logical development of chemical concepts?

From the very start of the Salters’ Chemistry Project it is clear: the developers did not *want* to use their preconceived ideas about the traditional sequence of concepts (see Chapter 2). They were strongly against a “science first” (Holman, 1987) approach and sequence and very much in favor of an “applications first” (ibid.) approach. Having chosen a radically new starting point (design criterion two), the development of chemical concepts from daily life contexts and from applications (design criterion three) was bound to lead to a different sequence of chemical concepts in the units of the course.

Thus, in order to construct a new chemistry course *relevant for all* pupils, the developers intended, needed, and got a different sequence of concepts: context-led, ‘drip-feed’, and spiral. They conjectured that “[t]his spiral development may be more effective at establishing and reinforcing ideas, than the traditional, linear approach” (Holman, 1987, p. 437). At the same time, they realized that any sequence of concepts ‘discovered’ during the development of the Salters’ Chemistry units had to be based on, or at least be compatible with, the *logical* development of concepts. During the development process, the order of concepts, both sequential and logical, was monitored at a central control point (Chapter 4). The result made sense to the developers since it provided the necessary *coherence* to the course. At the end of the development of the Salters’ Chemistry course, at a second editorial stage, the *conceptual coherence* of the course was strengthened again, and also made accessible to teachers planning to use the course in the Overall Guide to Teachers (1988, pp. 22-29). Therefore, as the developers have emphasized themselves, they both intended and needed to use the *logical relationships between concepts*. As a consequence, they used and largely retained “the structure of chemistry as we all perceived it” (L92).

Conceptual structure of Dominant School Chemistry

The analysis above leads us back to the *logical* conceptual structure of *dominant* school chemistry as described in Chapter 2, in particular to the explicit and implicit relationships between chemical concepts this structure contains. In the following I will discuss in what way the developers of the unit Metals implicitly used, or explicitly appealed to, several of the these relationships that are part of the currently dominant school chemistry curriculum. I will thereby try to answer the two questions:

- To what extent did the developers used use the relationships contained in dominant school chemistry, represented in England at that time by the core chemistry syllabus?
- To what extent did the developers escaped escape, not only from the coverage and sequence of concepts, but also from the relationships between concepts present in Dominant School Chemistry?

Dominant School Chemistry, compared with the *coherent* conceptual structure of school chemistry, turned out to have quite an implicit, incomplete, and incoherent structure. As we saw (Chapter 2), it can be characterized by the following relationships:

– explicit demarcation from physics, common sense, and implicit demarcation from technology and society;
– implicit, incomplete, and incoherent relations between the concepts of chemical reaction, chemical, pure substance, and chemical element;
– reaction conditions often implicit, isolated, incomplete, and incoherent;
corpuscular theory dominates (e.g. symbolic notation, balancing equations), while the relationship of descriptive chemistry with theoretical chemistry lacks coherence.

The core chemistry syllabus (1979), mentioned in Chapter 4, is taken here as a representation of *dominant school chemistry* in England in the 1970s. It is from this core syllabus that the developers tried to escape while articulating and operationalizing a set of five design criteria in units such as the unit Metals (1989) analyzed in this chapter.

1. Demarcation

Design criterion two, *relevance*, entails a wish to escape from the demarcation or isolation of school chemistry by bringing in five relevant aspects: social, economic, technological, environmental, and industrial aspects (Metals, 1989). This intention is realized through the number of CTS contexts actually used in the Salters' Chemistry course, and in the standard PC content and CTS content actually developed from those contexts.

The traditional demarcation of physics as a school subject from chemistry as a school subject is not *explicitly* addressed in the design criteria or in the text of the unit Metals (1989). The unit does, however, implicitly introduce in lesson M1, the distinction between physical and chemical properties by starting with a set of some standard physical properties, to be followed (in lesson M2) by a set of chemical properties (tests, reactions) as is customary in traditional school chemistry textbooks. Lesson M2 mentions as *grounds* for this distinction, that "*physical* properties do not always differ sufficiently from metal to metal to allow *one metal to be distinguished from another"*. This leads to the suggestion that "a more precise *identification* can be made through study of their *chemical* reactions" (TNM2). Since it can be argued that the distinction between physical and chemical properties loses its meaning in a CTS context, its introduction in lessons M1 & M2 might have been made on other grounds. A probable reason is the wish to introduce some simple qualitative tests needed for chemical analysis. Such chemical methods are needed to distinguish common metal objects by assuming they contain one dominant, pure metal. In brief, the distinction between physical and chemical properties is mainly introduced to underpin the PC concept of chemical analysis, and is only weakly justified in relation to the CTS theme *corrosion*.

It is to be noted that the most obvious *chemical* property of solid metallic or alloyed objects is not mentioned in the *analytical* context of lesson M2, namely, the corrodibility of different metal objects on attack by air; this in spite of the thematic and central role this chemical property takes on in the unit Metals. The chemical properties which *are* used in lesson M2 are certain chemical reactions, not of solid metals (of metal atoms at a surface), but of metals (ions) in dilute (aqueous) acid *solution* reacting with a sodium hydroxide *solution*. These reactions are important for purely chemical reasons, that is, to make possible a simple identification of the (dominant) metals present as elements in either metal objects or as metal ions in solution. They are not of primary importance in a chemical-societal context as are the corrosion processes of metal objects. Thus, analytical objectives seem to replace the attention given earlier, in lesson M1, to societal purpose or use of metals. It is for the purpose of chemical analysis that specific chemical reactions/tests are used. By contrasting physical properties/tests with chemical properties/tests the developers seem also to appeal implicitly to the demarcation of school chemistry from school physics.

2. Relationships between the concepts of chemical reaction, chemical substance and chemical element

The introduction of a simplified method of chemical analysis involves a complex *analytical route* from texture/surface to a sample in solution, to pure substance, to a closed group, to precise identification (5.2.2). The concept of chemical analysis is really a cluster of related chemical concepts, the most important of which are chemical or pure substance, chemical reaction, and chemical element. Thus by introducing chemical analysis, the developers appeal implicitly to the latter concepts, including some of their relationships. The concepts of chemical reaction, chemical compound, and chemical element ("simplest possible substance"), receive systematic and explicit attention in lesson M3. The concepts of pure metal and substance, and the concept of element, as a principle of conservation of matter, remain implicit, as do the *logical* relationships which pertain between the concepts of chemical reaction, pure substance, and chemical element. As argued in Chapter 3, the concepts chemical reaction and pure substance presuppose each other; while the concept of chemical element requires both these basic concepts. Thus, the context of the identification of common metal objects, taken as consisting of dominant metals, leads to the introduction of a simplified method of chemical analysis which in turn involves a partly implicit use of a number of basic chemical concepts and their relationships present in dominant school chemistry.

The introduction of the concept oxidation is also meant to "reinforce ideas about elements and compounds from M3" (LP M4). Again the developers appeal implicitly to some of the relationships between the concepts of chemical element, compound (pure substance), and chemical reaction. For example, in the context of oxidation reactions, students learn that a metal "gains mass" (LP M4). When a metal burns or corrodes, it forms a new substance or a compound. On the other hand, as we have seen in lesson M3, when a metal corrodes "some metal is used up". Further, metals being elements "cannot be made to weigh less" (LP M4). Thus, metals seem to weigh more, less, or the same during corrosion. This paradox can only be resolved by observing the distinction between elements/metal in the sense of non-decomposable pure substances and elements/metal in the sense of a principle of conservation of matter. In de the latter sense metals are conserved; in the former sense metals are used up during corrosion while the resulting compound weighs more than the metal initially present. Again, the concepts of pure substance and elements are not addressed explicitly, nor are the relationships between chemical reaction (oxidation, burning) and pure substances (chemical compounds, oxides), and chemical elements (oxygen).

Thus, by introducing the concept oxidation in the context of corrosion of common metals, a daily life context in which the role of air would have sufficed, the developers of Metals (1987, 1989) appear not to have escaped from (i) covering this classical topic of school chemistry; (ii) the chemical concepts involved, and (iii) the partly implicit and/or inconsistent relationships as characteristic for Dominant School Chemistry (Chapter 2).

3. Reaction conditions

As we saw in Chapter 3, school chemistry textbooks address the reaction conditions in an isolated, incomplete, implicit, and incoherent way. As I will argue below, the same applies to the Salters' Chemistry Course. The argument is based on a document analysis of the formal, written curriculum (OGT and SLB), and on the results from the analysis of the unit Metals (1989) and of relevant parts of some Salters' Chemistry units such as Minerals (1987).

The first reaction condition, element conservation, is not dealt with in the unit Metals (5.2.2), or in other units of the Salters' Science course, such as Mining and Minerals (1990 – an adaptation of Minerals, 1987.) As in Metals (1989), the concept *element* is treated as "a substance which cannot be split into simpler substances" (LP MM1). It is not treated as a principle of conservation: not in the context of extracting iron from its ores as in the blast furnace (MM6), not in the context of extracting aluminum from bauxite (MM7), nor even in the contexts of the recycling of glass, plastics and metals (Hill et al, 1989, pp. 76, 120). As argued above, while extracting or recycling metals, the metals (conserved) in the ores or scrap metals reappear as *elements* in the sense of simple substances. In the preparation of alloys such as bronze or solder (M6), the reverse is the case: reacting metals (elements) disappear as simplest substances to form alloys with different, useful properties, while the metals taken as elements, in the sense of a principle of conservation of matter, are preserved.

The second reaction condition, the decrease of Gibbs energy during a chemical reaction, as well as the third reaction condition, kinetic activity, are not addressed explicitly in England before upper secondary level, that is, not before A-level. For example, this condition is addressed in Salters' Advanced Chemistry, under "Chemical Ideas" (1994, p. 6), in terms of the total entropy change (which must be positive in order for a chemical reaction to proceed). On the other hand, the developers of Metals (1989) appeal to the second reaction condition *implicitly* when they introduce the reactivity series, because that concept is derived from thermodynamic data, namely, from standard electrode potentials. This is done explicitly in, for example, the Salters' Advanced Chemistry course Chemical Ideas (1994, p.164), where it says: "with the most positive potential at the bottom, the series is called the electrochemical series", while giving a series of metals (Mg, Zn, Cu, Ag) that coincides with the reactivity series introduced in

Metals (1989).[48] Thus, the concept of *reactivity* used in the reactivity series is a thermodynamic concept, not a kinetic one. It is only against this *thermodynamic* background that the behavior of such metals as aluminum or tin, and also in everyday life contexts, must be seen as exceptions to the thermodynamic rule.

As Ainly et al. (1987, p. 168) explain in their textbook for the new 16+ examinations, when dealing with the reactivity series of metals: “the positioning of aluminum is not straightforward as the metal is covered with a layer of aluminum oxide which is very resistant to attack”. They continue, “observations of reactions of aluminum would lead you to think that it ought to be placed lower in the series” (ibid., p. 168). So, the reactivity series does not portray an order of actual or kinetic reactivity, and therefore, it cannot, without further explanation or assumptions, be equated with the actual order of corrodibility, which is a kinetic as well as a chemical-societal concept.

By introducing the concept of the *reactivity series* in the context of corrosion of common metal objects (a daily life context in which a kinetic concept of corrodibility would have been appropriate in accordance with the design criteria), the developers do not appear to have escaped from the thermodynamic concept of *reactivity* as formulated in the second, thermodynamic reaction condition.

Finally, there is a zero condition for most reactions (except for decompositions) which seems almost too obvious to deserve separate mention, namely, that chemical reactants should be in *contact* with each other. This condition is easily fulfilled for reactants in aqueous solutions or for reacting gases, but can be quite difficult to realize for solid reactants. In lesson M6, there is an implicit reference to the condition of contact, where it says (SAG M5 X2.1) to “wrap the end of the strip of zinc [or tin, copper, magnesium] *tightly* round the middle of another [iron] nail”. It is also an important condition for reactions which occur at solid/gas or solid/liquid interfaces, such as corrosion, and for understanding the prevention of corrosion by *covering* the solid metal surface with paint, grease, or another metal.

To sum up: The zero condition of contact between reactants, the first reaction condition of conservation of elements (metals), and the third kinetic reaction condition are all needed or can be justified in the contexts of corrosion and the recycling of metals, but the second, the thermodynamic reaction condition, *cannot be justified* because is not needed to make sense of the corrosion phenomena studied at this stage. In so far as PC concepts are not needed to make sense of chosen daily life contexts of corrosion, but are still developed either explicitly or appealed to implicitly (concepts such as the reactivity series, chemical analysis, and oxidation in Metals, 1989), one can say that the developers *do not escape* from these chemical concepts and the relationships they entail. The developers operate, as it were, under an *internal constraint* consisting of the relationships between chemical concepts as they perceive them, that is, by the conceptual structure of school chemistry to which they are accustomed. It is apparently very difficult to escape from this *internal constraint*.

---

48 Hill et al. (1989, p.171) state that there is a “similarity between the electrochemical series and the reactivity series”, while describing the former in terms of cell voltages.

4. Role of corpuscular theory

As we saw above in lesson M1 of Metals (1989), it is explicitly stated that the symbols for metals refer to "one atom of the metal" (TNM1). In lesson M4, in the context of balancing equations, there is a reference to formulae, that is, chemical formulae in terms of number and kind of atoms. But apart from these two allusions, Metals (1989) does not refer or develop corpuscular concepts, nor does it develop, therefore, the relationship between macroscopic and corpuscular concepts. Rather, in these lessons there is strong emphasis on empirical, macro relationships:

(i) relationship between the physical or chemical properties of metals/alloys and their uses (M1, M2);
(ii) the causes or factors which influence rusting (M3, M4, M5);
(iii) the trend of decreasing corrodibility (reactivity) within the series of metals (M5);
(iv) the generalisation that metals above iron in the reactivity series slow down rusting, metals below iron in the reactivity series speed up rusting (M6);
(v) the composition of an alloy determines its properties (M6); the 'identity' or elemental composition of a metal determines its properties (M2).

Thus in the sense described above, the developers of Metals (1989) escape almost completely from the traditional dominance of corpuscular theory in school chemistry by *not* introducing, in the chemical-societal context of corrosion, either corpuscular concepts or the relationship between macroscopic and corpuscular concepts.

Concluding discussion

I agree with the developers, that it is *not* possible for teachers or developers "to *forget* all they [know] about how an understanding of certain concepts *require* a *prior* understanding of other concepts" (W97). As I argued in Chapter 3, teachers and developers of school chemistry curricula should be fully aware of the chemical concepts and the *particular temporal* relationships between them which are implicit in current textbooks or in the teaching materials that they have *chosen* to develop or use for teaching school chemistry. Furthermore, teachers and developers of school chemistry curricula should also be fully aware of the *logical relationships* that hold between the chemical concepts used in school chemistry curricula. Finally, it is important for teachers and developers to realize that several *temporal or teaching sequences* are compatible with the same logical conceptual structure of school chemistry. Thus, teachers as well as developers need to have detailed knowledge of the *coherent conceptual structure of school chemistry* in order to use this knowledge consciously and selectively, especially for the design of new school chemistry curricula that deviate radically from traditional school chemistry. The vision or design criteria of the new school chemistry curricula will determine the choice of chemical concepts and the *temporal and logical* relationships between them needed to realize these aims.

Waddington remarks that "in a couple of instances *slightly different relationships between concepts* did emerge" (W97) during the development of the units for the Salters' Chemistry course. For example,

> A macromolecular model for polymers which was used to 'explain' some physical properties *prior* to pupils meeting atomic structure and theories of bonding; and it was realized that the calculation of reacting quantities could be justified and done without introducing the *mole* concept.

In the first example, the physical properties of polymers are explained, not as in traditional courses by recourse to atomic theories, but by a *newly* introduced low level macromolecular model of polymers (another example is the deletion of the concept of the *Periodic Table* mentioned in Chapter 4). In the second example mentioned here, the decision is made *not* to use the traditional chemical concept, the *Mole*, usually present in school chemistry courses. Hence, sometimes the development of logical relationships between chemical concepts is not needed to make sense of the selected contexts, *just as* it is not necessary for the development of some chemical concepts. The examples the developers give here bear out what is argued above, namely, that it is the chosen CTS emphasis, theme, and contexts which will determine not only which concepts, but also which *temporal and logical* relationships between chemical concepts, are justifiably needed in teaching, and which concepts and logical relationships are not needed to make sense of the selected daily life contexts. In view of the analysis (Chapter 2) into the structure of school chemistry, this is not unexpected. Basic chemical concepts, for example the concept of *chemical reaction*, entail logical relationships with other chemical concepts, namely the concept of a pure or chemical substance and the concept of a chemical element. To sum up, in a few cases the intention of the developers to have no preconceptions with regard to the coverage of concepts was extended to the logical relationships these concepts have to each other.

When we take a strong interpretation of the Salters' design criteria, this means that only those *concepts and relationships* should be used which are needed for the chosen contexts, that is, concepts and relationships which arise naturally from the study of everyday situations, consistent with design criterion two, *relevance,* and with design criterion three, *context-led development of concepts*. In view of this discussion, the latter design criterion must be taken to refer to both the *context-led development of chemical concepts* and the *context-led development of relationships between chemical concepts*. In brief, design criterion one, *no preconceptions*, should extend to coverage, sequence, and logical structure.

Developers' adherence to design criterion one, *no preconceptions,* did clearly result in their escape from the traditional *linear sequence*. Their escape from the traditional coverage of concepts and relationships, whether they intended to, as with concepts, or whether they did not intend to, as with relationships, was less complete. Of course, this must be attributed to the force of external constraints working on the developers, but only partly, as we saw. A most important cause lies in the *internal* constraint the developers chose to follow. As Waddington put it :

> There is a much more powerful reason if you find that we have not escaped from your web [i.e. my curriculum framework] – ourselves and our own history (W97).

This statement appears to confirm remarkably well, Garforth's conjecture which she made just before the start of the Salters' Chemistry Project:

> Equally it may be that by our own schooling, subsequent training, and teaching we cannot see anything different adequately filling the space called chemistry at this level (Garforth, 1983, p. 29).

Reflection on the unit Metals: the developmental process

In section 5.1.1, I argued that the unit Metals can be seen as a representative unit within the set of Salters' Science units, as designed by the developers following a number of selected design criteria. This does not exclude, of course, that a consistency analysis of other Salters' Science units would not reveal a smaller degree of slippage. Nevertheless, I think the analysis points to an important phenomenon of which, especially in the *process of design and development,* a project must take serious account.[49] As noted above (Figure 5.14), the phenomenon of slippage can occur even when external constraints are weak. It is a curriculum phenomenon which must be attributed for an important part to an internal constraint, here called the *NCE-reflex*.

5.3 The interpreted and taught curriculum of the unit Metals

In this section I describe and analyze the process of transformation of a unit of the formal curriculum, the Salters' Science unit Metals (1989). The changes made to the unit of the formal curriculum by the Department of Science of the school I visited in Yorkshire, England led to the unit Metals (1992), a unit of the *interpreted* curriculum, based on the Salters' unit Metals (1989).

Metals (1992) was used in the science classroom in the form of a study guide or student booklet by the chemistry teacher, also heading the Department of Science at the time, and became the point of departure of the taught curriculum.

The analysis will focus on the design criteria *relevance*, *context-led development of concepts* and *flexible teacher-mediated use*. The aim is to find out to what extent a teacher, congenial to the Salters' philosophy, is able to teach the interpreted curriculum in accordance with these Salters' design criteria, to students in one particular class and school.

I will begin by giving the reasons for my choice of this chemistry teacher and school (5.3.1). Secondly, I will describe and analyze the interpreted curriculum of the unit Metals (1989), *as interpreted* by the science teachers of this particular school, by analyzing the lessons of Metals (1992), a student booklet based on the Salters' Science Foundation Unit Metals (1989), but adapted to the goals of the science staff at the time. For that purpose I will also use the interview I held with the chemistry teacher who agreed to participate in the classroom based research (5.3.2).

Thirdly, I will analyze and discuss the actual lessons of the unit Metals (1992) as *taught* by the participating chemistry teacher, that is, the taught curriculum of this chemical unit of the Salters' science course. This time, I will look into the process of transformation of the interpreted curriculum into the taught curriculum of the unit Metals (1992), on the basis of audio tapes of the teacher-student discussions, classroom observation and teacher interviews (5.3.3).

Fourthly, I will summarize and discuss the results of the analysis in section 5.3.4.

---

49 Another example occurred in the Dutch "Techniek 15+" Project (De Beurs et al., 2003, p. 27) aimed at the development of units providing upper secondary students (aged 15-18) with learning experiences of the 'cycle' of technological design. In the initial phase of the project some of the developers used more science content than students would need for the design of the artifact in question.

5.3.1 Choice of teacher and school

In section 4.1.2, I explained the rationale for choosing Salters' Chemistry as an object of study, and in section 5.1.1 for performing a qualitative case study based on the classroom-based research of a chemical unit of the Salters' Science course, Metals (1989). I will now give my reasons for the choice of chemistry teacher and school participating in this study.

In 1992, Lida de Gier performed, as part of her teacher training, a small classroom based research study on the teaching of chemical units of the Salters' Science / Chemistry course. Her pilot study (De Gier, 1992), for which I acted as supervisor, prepared the way for my own more extended case study research of the unit Metals (1992) at the same school.

The participating chemistry teacher had been involved for some time in innovation projects, in particular, with regard to the elementary chemistry course for Year Three. What is relevant, too, the school had acted as a Salters' Project School in the years 1985 – 1987, trialling units of the Salters' Chemistry course. Prior to the De Gier's pilot study the school had hosted the research project of Christie Borgford (see further section 5.4.4). Hence, the chemistry teacher agreeing to participate in my research study was not only willing, but also accustomed to having an educational researcher in his classroom. He could thus be expected to act naturally in his classroom teaching during the research period, hardly being disturbed by the research setting.

Furthermore, since the teacher was familiar with the Salters' approach to chemistry teaching, he could be expected to teach the adapted unit Metals (1992) in accordance with the Salters' educational philosophy as characterized by the Salters' design criteria described in Chapter 4. Thus, this teacher would probably emphasize as much as possible relevant contexts and the CTS concepts needed to make sense of them. A chemistry teacher with a neutral or reluctant attitude to the Salters' approach, on the other hand, could be expected to teach Salters' units with a focus more on traditional PC concepts, adding on some CTS content only if thought expedient. In other words, the former kind of teacher will probably make an attempt to break away or escape from NCE, while the latter kind of teacher would have no such motive. As such the former kind of teacher would be the more relevant to observe in the classroom, the findings would probably say more about the conditions for a successful escape of the teacher.

Since the Salters' Science courses aim to provide science education to students across the full ability range, it was appropriate that the research would take place in a comprehensive school. Finally, on a more practical note, the school was located in Northern England, within commuting distance of the University of York, the venue I wanted to use to interview the developers and study relevant teaching materials produced by the University of York Science Education Group (UYSEG). Both the teacher, acting also as Head of Science, and the Head of the School were informed beforehand on the precise nature and duration of my research project, while anonymity of the collected data was assured to all participants involved: students, teachers, and school.

5.3.2 Interpreted curriculum

The changes made to the unit of the formal curriculum, Metals (1989) by the Department of Science of the school led to the student booklet, Metals (1992), a unit of the *interpreted* curriculum. The latter unit was one of the chemical units of a new science course which used at its starting point twelve units from the original twenty-one Salters' Science Foundation Units (1989). The new science course was developed "in order to make the change to balanced science up to GCSE level" (Hill, 1991, p. 4) as it was put by one of the science teachers of the school, and as required by the National Curriculum (1989). The resulting course was taught for a period of two years, from 1989–1991, by the science staff of a comprehensive 13 – 18 upper secondary school situated in North England.

In order to promote "self-motivated learning" (ibid., p. 5), students were given so-called study guides (student booklets) based on the Salters' Science Foundation Units "with some *additions* by our staff to guide them from one activity to another" (ibid., p. 4). The two upper bands of pupils "are told that they were going to *work like real scientists*" (ibid., p. 4) while using these study guides[50]. The pupils did form groups of three and were divided into four laboratories with four members of staff and the appropriate apparatus. Since everyone and everything had to rotate in this system, this new and radical approach to teaching science using Salters' Science units received in the school in question the nickname the "Circus".

Prior to the "Circus" (1989–1991), the *chemistry* teachers of the school had taken initiatives to become a trial school for the Salters' Chemistry GCSE course (1985-1987). In fact, the positive response from science staff and pupils to this trialled chemistry course led to the idea of using Salters' Science Foundation Units for the teaching of the Circus approach. As the teacher said in the interview, "the Salters' philosophy of guiding each unit with relevant and important questions, with *realistic* experiments and with varied teaching styles" (T92) was taken over. The changes the teachers made to the unit Metals (1989) were to encourage and support self-study by students using the student booklet Metals (1992), a compilation of Student Activity Guides (SAG) and Student Information Sheets (SIS), largely taken over from Metals (1989). Teacher demonstrations of Metals (1989), though, were *replaced* by student activities, mostly by laboratory-based practical work in Metals (1992).

As in section 5.2, in the analysis of the lessons of Metals (1989), I will try to answer here too, in the analysis of the lessons of the unit Metals (1992), the two questions stemming from design criterion two, *relevance*, and design criterion three, *context-led development of concepts*.

– Does each lesson of Metals (1992) have its *origin* and *justification* for study, *fundamentally*, in aspects of *everyday life*?

– Are all chemical concepts and explanations treated in the lessons of Metals (1992) *needed* for the study of these everyday situations?

---

[50] The lower band of pupils, the less able pupils, followed special courses such as Working with Science (1978).

The student booklet Metals (1992) contains the same number and sequence of lessons as the unit Metals (1989), while largely the same order of activities is followed. There are some changes in the student booklet Metals (1992), either additions to or deletions from the formal curriculum unit Metals (1989). I will use in this section for Metals (1992) the same codes for the lessons and activities as in section 5.2 for Metals (1989) - the context of the discussion will make clear to which unit I refer. The lessons of the unit Metals (1992) are introduced as follows:

> In this unit you are going to think about metals: how *important* they are, the link between kinds of metals and their *uses* and the problems of *corrosion*. Remember when you think you have achieved a *skill* to have your work checked by the member of staff and the box initialed (Metals 1992, p. 1).

The first part of this quote follows the contextual theme of Metals (1989) on the importance, use and corrosion of metals (see Figure 5.6). This theme is already set by the cover of the student booklet which depicts the industrial process the winning of iron starting from ore to the production of metal objects used in daily life such as nails and hammers. The second part of this quote refers to the emphasis on scientific skills (and processes) required from students working "*like real scientists*" in the Circus, an emphasis well tuned to the National Curriculum (1989), mandatory for schools from 1990 onwards. The following *skills* are explicitly mentioned in the lessons of Metals (1992) for students to have checked by a member of staff: *drawing conclusions* (M2), *making accurate observations* (M3) and *using apparatus safely* (M4).

In terms of Roberts (1982) one could say that the science staff of the school was putting a SCIENTIFIC SKILL DEVELOPMENT emphasis or interpretation ('science as process' approach) on the original EVERYDAY APPLICATIONS and SCIENCE/TECHNOLOGY DECISIONS emphases of the Salters' Science Foundation Units (see Figure 3.4). Thus, right from the inception of the student booklet, Metals (1992), there seems to be a dual emphasis, on the one hand, on daily life contexts and, on the other hand, on scientific skills or processes. On the basis of two years experience with the Circus approach Hill (1991, p. 5) remarks that "the mixture of Salters' Science and self-motivated learning is a happy and productive one". The question here is to what extent this claim is supported by the research reported on below.

Before answering this question, I will first describe and analyze, for each lesson of Metals (1992), the addition or deletion of CTS contexts used, and of PC content and CTS content developed from the selected contexts in comparison to the formal curriculum unit, Metals (1989), as analyzed in section 5.2.

Changes in lesson M1

Activity M1.2 of Metals (1992), "Hunt the Metals", a word search puzzle, contains an additional assignment, namely: "Write down the 16 metals you find in this table [puzzle] in your notes and after each one write its chemical symbol" (Metals, 1992, p. 4). This assignment directs the attention of the students to the relationship between the metals (and their names) and their symbols, that is, to a PC relationship. The activity M.1,"Symbols for Metals", contains an extra assignment with regard to the list of seventy symbols for metals:

> The metals which are asterisked are those which you will meet most often in this unit. For each one of those write down a common everyday use (ibid., p. 7).

This time the focus is on the relation between common metals and their use, a CTS relationship.
Deleted from lesson M1 of Metals (1989) are: the laboratory survey in which students list things which they think are metals and the ensuing teacher-student discussion, the optional student activity, and the teacher-student discussion on metals and properties familiar to pupils.

The addition of the first two assignments does not change the balance between PC content and CTS content in Metals (1992) but the deletions of the aforementioned activities does, namely, in the direction of using more PC content and less CTS content (see also Fig. 5.15 below).

Changes in Lesson M2

Again, there are two additions, this time to lesson M2 of Metals (1989). First, at the end of the laboratory-based practical work (M2.1) students are asked to:

> Construct a table from your experimental results which can be used as an information sheet for the Special Investigation below (ibid., p. 9).

The *active* construction of such a table should help students to act as scientists in *drawing conclusions* from the practical work about the identification of metals in common objects.

Secondly, the special investigation at the end of the lesson contains the extra assignment:

> Try not only new drawing pins but also ask the member of staff for a solution of nitric acid in which *worn* drawing pins (emphasis theirs) have been dissolved" (ibid., p. 9).

As the teacher later explained in the interview, the purpose of this additional activity is to show that in both cases, whatever the appearance of the pins, iron can be identified as the dominant metal since "the coating does not show up at all" (T92). Thus, one of the choices involved in the analytical route going from sample to dominant metal is explicitly addressed here (see section 5.2.2). The added experiment justifies the neglect of any 'recessive' metals present, and clarifies thereby the CTS concept of dominant metal. The addition of these two assignments hardly changes the balance between PC content and CTS content in lesson two of Metals (1992).

Changes in Lesson M3

This lesson contains two major additions, that is two *new* activities, labeled M3A and M3B. The first activity, "What happens when metals corrode?", is a practical activity. The second activity, "Elements, Compounds, and Corrosion", deals with the *theory* of oxidation in relation to the corrosion of metals, especially iron. It is a text added for students to read as an alternative to the teacher-student discussion which was part of lesson M3 of Metals (1989).

In accordance with the self-motivated learning approach of the Circus the teacher demonstration of Metals (1989) is *replaced* by the student activity M3A in the form of laboratory-based practical work. Students receive the following instructions:

> You will need to collect a sample of each of the corroded metals and some emery cloth.
> *Look carefully* at the corroded metal and enter your observations in a table like the one below.
> Rub the surface with emery cloth and collect anything that comes from the metal on some clean white paper.
> *Look carefully* at the material coming from the surface and at the surface you have rubbed. Your results should again be entered into your table (Metals, 1992, p. 10; emphasis theirs)

There follows a table with the headings: "Name of metal, Color of corroded metal, Can the corrosion be rubbed off?, Color of substance rubbed off, Color of metal after cleaning, Is the metal used up when it corrodes?, headings taken over from lesson M3 of Metals (1989).

Transforming the teacher demonstration of Metals (1989) into this student activity also offers the teacher the possibility to test students' skill at *making accurate observations*. No questions are asked here to direct students to the theoretical purpose of the experiment, understanding the chemical concepts of reaction, element and compound as stated in the original teacher demonstration (TNM3, see section 5.2.3).

It is the newly added activity M3B which deals with these chemical concepts (reaction, element and compound) and which also introduces some additional chemical concepts and terms. For example, after having pointed out that some elements such as gold are not reactive, the text continues:

> Other metals do react with the atmosphere and COMBINE with the oxygen and water (and sometimes carbon dioxide) to form COMPOUNDS. These compounds are usually the METAL OXIDE but may be a HYDROXIDE (due to water) or a basic CARBONATE (due to the carbon dioxide). We could write a simple CHEMICAL EQUATION:
> metal + oxygen —> metal oxide (ibid., p. 11, emphasis theirs).

As argued above (section 5.2, see also Figure 5.12), in a chemical-societal context it is sufficient to explain the phenomenon of corrosion by referring only to the action of the atmosphere. So, the chemical concepts emphasized above are not really needed, not even the concept oxygen.

Further on the text of the student booklet, Metals (1992), offers a simple qualitative answer to the question, "Why the rusting of iron is a problem unlike the tarnishing of silver or the oxide coat on aluminum" (p. 11).[51]

> When most metals tarnish or corrode they do so at the *surface* of the metal and form a layer of metal oxide which prevents any further reaction between the metal and the air. In the case of iron the metal oxide *expands* when it forms and this causes the surface to *flake off* and so exposes more iron to react and so on.

Note that this explanation could work just as well without using the technical term oxide, using instead a term as the combination of a metal with the atmosphere. Activity M3B further contains representations of double bonds in oxygen gas molecules, of lattices of metals and metal oxides, concepts equally unnecessary for students to make sense of corrosion phenomena at this stage. On the other hand, it is pointed out there that "mixtures with copper such as brass" (ibid., p.11) also corrode, so not just pure metals, and that this is important in daily life.

Activity M3B thus explicitly addresses the role of oxygen (which is not mentioned in

---

[51] As the teacher later explained, "they [the teachers] felt that they really needed to explain why it is a problem that iron corrodes and that other metals such as aluminium do not cause a problem" (T92). I take it they meant why the rusting of iron is such an important *chemical-societal* problem.

lesson M3 of Metals, 1989) and offers students additional PC content not needed to make sense of corrosion. On the other hand, by explaining that the rusting of iron forms a special chemical-societal problem, activity M3B also addresses the CTS aspect of corrosion. The last activity, M3.1, "What happens when iron rusts", has been taken over unchanged from Metals (1989).

Together these additions tend to reinforce the tension, already present in Metals (1989), between PC content and CTS content, while the balance between PC content and CTS content is tipped in the direction of the former.

Changes in Lesson M4

Again the teacher demonstration from Metals (1989) is replaced by a student practical. The activity M4.1, "A Closer Look at Corrosion and Burning", is preceded by two instructions.

> First hold the <u>shortest</u> length of a magnesium ribbon [2.5 cm length] in the Bunsen flame using tongs and wearing eye protection. Don't look at it *directly* but of course notice what happens.
> Before you do anything else find out the *mass* of the crucible and the lid by themselves and make a note of it. You will need it later (Metals (1992, p. 14; (emphasis theirs).

As pointed out in section 5.2.4, the intense flaring up of magnesium will hinder the accurate observation of the *process* of oxidation. The second instruction focuses the attention of students on the change in mass involved, that is, on the crucial aspect within the context of oxidation. Other aspects relevant to corrosion and burning are thereby excluded (see also Figure 5.12).

To replace the teacher-student discussions of Metals (1989), activity M4.1 is followed by four extra questions after the seven questions taken over from Metals (1989). These are:

Q8. "What is meant by the word 'OXIDATION'?" (ibid., p. 15, emphasis theirs). Thus, after having met the terms oxygen and oxide in activity M3B, students are now invited to reflect on the concept of oxidation.

Q9. "What is the link between burning and oxidation?" (ibid., p. 15). The focus being on oxidation, the process of burning is taken as a special case of the former. The comparison between the processes of burning and corrosion is not addressed.

Q10. "If two elements join to form a compound, what can you say about the mass of the compound?" (ibid., p. 15). The focus is on the increase in quantity of mass, possibly also on the conservation of mass, during chemical reactions. Students are given the assignment:

> Work out the mass of the magnesium used. Work out the mass of the oxygen it combined with. Plot your results on the master graph in Room 103 (ibid., p. 15).

Q11. "What do you notice about the results which everyone else have already plotted?" (p. 15).

As the teacher explained in the interview, the students, working like real scientists at the time of the Circus, were supposed to find out that "everybody's points were on a straight line" (T92). The 'master graph' would illustrate another important mass relationship which holds for chemical reactions, namely, that the reactants combine in fixed proportions by mass. It adds another PC relationship (Proust's Law) and thereby removes further from sight the relationship between corrosion and burning, the title and intended context of the original lesson in Metals (1989). Lesson M4 of Metals (1992) bears no title, the title of Metals (1989), "A Closer Look at Corrosion and Burning", is not being taken over, nor is the experimental study of the changes in mass as iron rusts. By adding Proust's Law the balance between PC content and CTS content shifts to the former, and away from the latter.

Changes in Lesson M5

This lesson of Metals (1992) begins with activity M5, "Corrosion rate". This is a practical for students that replaces the teacher demonstration of Metals (1989) on the reactions of calcium, sodium, iron, copper, and magnesium with air and with water. The practical is introduced to students as follows:

> Ask the member of staff for the display of five metals which you are going to investigate. You should not only have a sample of each of the five metals but also a sample of each of them which have been left open to the *atmosphere* for some time (p. 16).

Thus, students first compare freshly cut, clean samples of these *solid* samples of metals with corroded ones, and try to answer the questions: "Which of the metals seems to have changed the most and which the least?" (Q1, p. 16) and "What can you say about the *rate* at which metals *corrode*? (Q2, p.16).

This activity gives an idea of the differences in *corrodibility* of solid pieces of metals when exposed to the *atmosphere*. It is followed by experiments of freshly cut pieces of sodium first with air and then with water performed by students who are wearing eye protection and taking great care. They answer the following questions:

Q3. What happens to the sodium [exposed to air] over a period of 10 minutes?

Q4. What happens to the sodium placed onto the surface of 100 mL of water?

Students are told in the booklet that, "It [sodium] is being oxidized". This is followed by the questions, "Where is the oxygen coming from? and What must this leave behind? (Hint: What two elements combine to make water?)". Note that in the reactions of metals such as sodium with water the oxygen comes from the water, and not from a gas in the atmosphere, as with corrosion in a CTS context (See again Figure 5.12). Activity M5.1, "Do all metals corrode", and activity M5.2, "Preventing corrosion", are taken over unchanged from Metals (1989).

In spite of both the promising title, and the beginning of activity M5 in a CTS context (the corrosion of five solid metals exposed to the atmosphere), the focus of the lesson shifts quickly to the reactions of these metals *in water and the order of reactivity*, thus giving little emphasis to the order of corrodibility of metal in the air. Again, concepts related to oxidation are reinforced. As in lesson M5 of Metals (1989), the CTS context corrosion is used to develop mostly PC concepts. The CTS context is really addressed in activity M5.2 , "Preventing corrosion", tipping the balance between PC content and CTS content again in the direction of PC content.

Changes in Lesson M5X1

The second investigation of lesson M5X1 of Metals (1989), "Do 'rust stoppers' work?", has been left out. The first activity, on how rusting is prevented, is here introduced to students as follows: *Consider* a bicycle whose frame, cranks, chain and gears are made of steel (ibid., p. 22), whereas Metals(1989) had as an introductory line, "You will be *shown* a bicycle, etc."

Thus, the second CTS context of this optional lesson has been deleted, and the first CTS context seems to be introduced (*pace* the Circus approach) more as a thought experiment than as a hands-on one. Deleting the context 'rust stoppers' also deletes the CTS concept 'commercial aspects of produced materials'. Again, PC content prevails over CTS content.

Changes in lesson M5X2

Activity M5X2.1, "Do other metals stop iron from rusting", is taken over from Metals (1989). At the end of the lesson is added the remark (Metals, 1992, p. 24):

> You should be coming to the conclusion that not all metals react as well or as quickly as each other. We can put them into a sort of "league table" with the most reactive first. The following list is known as *the reactivity series* for metals: K, Na, Ca, Mg, Al, Zn, Fe, Pb, Sn, Cu.

The metals listed above in *the reactivity series* coincide with the set of asterisked metals mentioned in lesson M2 of Metals (1992), that is, metals students "meet most often in this unit" (ibid., p. 7), put here in an order of decreasing reactivity from left to right. Lesson M5 has established this order, empirically, namely for Na, Ca, Mg; Fe and Cu. Lesson M5X2 teaches students that Sn and Cu are less reactive than Fe, and that Zn and Mg are more reactive than Fe. The metals K, Al, and Pb are *not* empirically addressed in the unit Metals, nor are comparisons made between Zn and Mg or between Sn and Cu.

Students are subsequently asked, "Can you name them all without looking back?" This question gives the impression that the reproduction of an important PC relationship such as the reactivity series is considered as more important than the acquisition by students of all the evidence on which it is based. Furthermore, the emphasis on the reactivity series, rather than on the order of corrodibility, detracts from the CTS aim of the unit Metals, that is, to make sense of corrosion phenomena in daily life such as the prevention of corrosion and the specific problem of rusting. Thus a PC concept suppresses a CTS concept, as a consequence of which the balance between them shifts towards more PC content.

Changes in Lesson M6

The first teacher demonstration, on the comparison of the bendability and brittleness of a paper-clip and a darning needle, is deleted, as is the second teacher demonstration on the preparation of solder. Both experiments would have shown empirically that the different properties of alloys depend on their composition, an important relationship relevant to the use of metals. The lesson is limited to activity M6.1, a homework assignment taken over from Metals (1989). Pupils complete a question sheet on the use and properties of alloys. The key point here is that the *use* of an alloy depends on its properties, and that "it is possible to make alloys which have properties needed for a particular job" (ibid., p. 25).

The deletion of the teacher-student discussions of lesson M6 of Metals (1989) leads to a serious neglect of important CTS concepts: the prevention of rust, the explanation of differences of metals in terms of difference in corrodibility, and the definition of an alloy. Deleting the teacher-student discussions and the teacher demonstrations and the CTS concepts arising from them, definitely tips the balance in this lesson in the direction of PC content over CTS content, if we compare Metals (1992) with Metals (1989).

Summary and discussion

The changes made to the formal curriculum unit Metals (1989) by the science staff of the school which led to the student booklet, Metals (1992), the *interpreted* curriculum, are summarized in Figure 5.15 below.

The first column shows the contexts deleted from the lessons, in casu, M1, M5X1, and M6. The second column mentions PC content added but *not* needed. The third column mentions additional CTS content needed and developed in Metals (1992) such as corrosion rate (M5) and the explanation of the problem of rusting (M4). Finally, the deletion of CTS contexts implies that some CTS content although needed for the theme *corrosion*, is *not* developed as indicated in the fourth column.

From the lessons analysis of Metals (1992), summarized in Figure 5.15, it is clear that not each lesson of Metals (1992) has its *origin* and *justification* for study, *fundamentally*, in aspects of *everyday life*. See especially lessons M1, M5X1 and M6 where CTS contexts, present in the unit Metals (1989), have been deleted. Inspection of Figure 5.15, the second column, also learns that not all chemical concepts and explanations treated in the lessons of Metals (1992) are *needed* for the study of the everyday situations used in the unit Metals (1992).

To conclude the analysis of the lessons of Metals (1992), the interpreted curriculum contains a somewhat different configuration of CTS contexts, PC content and scientific skills, and CTS content than the formal curriculum, Metals (1989). The curriculum emphasis appears to have been shifted in almost each lesson to more PC content and skills and to less CTS content. Thus, the CTS / PC ratio of the interpreted curriculum, Metals (1992), seems to be substantially smaller, from what it was for the formal curriculum unit Metals (1989), as analyzed in section 5.2 (Fig. 5.5). To put it in Roberts' terms, there appears to have been added a SOLID FOUNDATION emphasis by the science staff of the school to the original unit Metals (1989) besides the SCIENTIFIC SKILL DEVELOPMENT emphasis mentioned above (Figure 3.5).

The unit Metals (1992) presents a good example of how design criterion four, *flexible teacher-mediated use*, is interpreted and operationalized by science teachers planning to use Salters' Science Foundation units with their students in a "self motivated learning" approach (Hill, 1991, p. 5). The unit Metals (1989) is adapted to the conceptions of the teachers involved, while at the same time, as Hill (1991, p. 5) says, "it clearly fits the National Curriculum".

The students are to work at their own pace, in groups of three, doing the experiments and other activities as explained in their booklets while learning chemical concepts and skills with the teacher in a new, supporting role. Because teachers "needed to be experts in practicals that the pupils themselves were designing" (Hill, 1991, p. 5) they did not always know the 'right' answer. Students clearly expressed "enthusiasm for the new regime, working very hard to explore possible solutions in open discussion" (p. 5), trying to "work like real scientists" (p. 4).

In the student booklet, Metals (1992) there is no explicit reference to teacher-student or group discussions. The analysis in section 5.3.3. will show whether they took place or not.

Figure 5.15 Metals (1992): The Interpreted curriculum of Metals (1989)

Lessons Metals (1992)	**Contexts deleted from Metals (1989)**	**PC content added, but not needed**	**CTS content added and needed**	**CTS content deleted though needed**
M1	lab. survey of things made of metal; survey of common metals and properties	relation 16 metals – symbols ('chemical shorthand')	relation common metals with everyday use	
M2			dominant metal in drawing pins	
M3		oxidation / chemical equation; systematic names; double bonds / lattices	mixtures (brass) corrode; explanation of problem of rusting	
M4		constant proportion by mass (Proust's law)		
M5			corrosion rate	
M5X1	'Rust Stoppers'			commercial aspects of produced materials
M5X2		reactivity series		order of corrodibility
M6	properties steel alloys; preparation of solder			prevention of rust; composition alloy determines properties order of corrodibility

5.3.3 The taught curriculum

The lessons of the unit Metals (1989), *as interpreted* and taught by a particular teacher to a particular group of students at a school in England on the basis of Metals (1992) became the object of my classroom-based research performed in the months October and November 1992.

As we saw above, Metals (1992) is an interpretation of Metals (1989) to the desiderata of the Circus approach (Figure 5.15) and the requirements he National Curriculum (1989) in England. The resulting student booklet (Metals, 1992) has been used by the teacher for the teaching of his Year Nine science class within the constraints of the revised National Curriculum (1992).

The question I try to answer here is: to what extent would a teacher, congenial to the Salters' Science approach, teach a chemical unit of the interpreted curriculum, Metals (1992), in accordance with design criterion two, *relevance* and design criterion three, *context led development of concepts*.

Background teacher

As a pupil the teacher was taught Nuffield O-level biology, chemistry and physics.

> They were the great new course of that time. They were very much based on experiments and drawing the ideas out of the experiments. Whereas other groups did more traditional courses, the *top* group in science did Nuffield. We were given experimental sheets, did the experiments and then had to try to explain it with the chemistry teacher (T92).

Doing lots of experiments, not having to learn a lot of facts, and getting good grades: this was what the teacher enjoyed in the Nuffield course at the time (1970s). His A-level course was more traditional with lectures, note taking and "a fair amount of practicals" (T92). At university he studied chemistry majoring in inorganic chemistry with a special interest in the topic transition metals; his minor subjects were mathematics and geology. As a teacher trainee in science education, he was tutored by a chemistry teacher and did his teaching practice mainly with chemistry groups, including *teaching* Nuffield Chemistry.

> Funny enough, in one teaching practice I used Nuffield. Perhaps because I was comfortable with it ... someone else had taught me, so I know this (T92).

He also gained teaching experience with traditional chemistry courses and received subsidiary qualifications for teaching integrated science and physics courses.

In his first school he taught "a traditional 16+ syllabus (O/CSE), a forerunner of GCSE" (T92), made his own teaching scheme for both the O-level and CSE chemistry courses and also one for CSE physics, and taught an integrated humanity course (11 – 13). For A-level he taught a traditional syllabus, simplified the textbook used, lectured, and gave notes to his students. After about two years (in the mid '80s) he left to join the science staff of his current school, expressing a wish "to be a proper science teacher" (T92). Together he and a colleague devised their own Third Year Chemistry course: students would perform experiments presented to them on overhead sheets. Some years later he supported an initiative of two of his fellow chemistry teachers to trial the Salters' Chemistry GCSE course; as a result, he became enthusiastic about the Salters' approach to teaching chemistry.

The positive experiences of chemistry teachers and students with Salters' Chemistry as a trial school led science teachers of the school to the decision to offer, from 1987 onwards, their KS4 students (14 – 16) the Salters' Science GCSE course; as we saw above, it also led to the short reign (1989 – 1991) of the Circus.[52] Salters' Science was preferred over Suffolk Science, another alternative course considered, because the

---

[52] The Circus probably stopped because of the constraints the National Curriculum came to impose on the teaching of science. As Hill (1991) remarked, "while heading towards external examinations [in Year Five] we [the staff] will now work in groups which are larger – they are *class-sized*".

science staff felt that the latter course was less appropriate for the middle and high ability band of the school population. Another course, Science at Work, was already offered, from 1985 onwards, to the lower band of students. The science teachers felt that this course – because of the reading level and reduced conceptual loading compared to other courses, including (later) Salters' Chemistry – clearly motivated students of lower ability and also seemed to work for them in terms of results.

At the time, the teacher was in his thirties and was Head of Science. He was teaching: (i) Salters' Science Foundation units to Year Nine (KS3), using the student booklets such as Metals (1992). Thus, although the *practice* of teaching a 'supported self study' approach had disappeared by 1991, the 'Circus' booklets remained available and were used for teaching science from 1992 on, in Year Nine to 13 – 14 year old students;
(ii) Salters' Science Double and Single Award using Salters' Science units (1990, 1992) to the middle and upper band of Year Four and Five (KS4) and Science at Work to the lower band; (iii) Salters' Advanced Chemistry to his A-level students.

Methods and set-up used in the education experiment

The classroom-based research for Metals (1992) entailed, first and foremost, the tape recording of all the lessons of the unit, that is, of all teacher-led explanations and also of a few student discussions. Secondly, I made additional notes of what happened in the classroom, what the teacher put on the blackboard and some of the reactions of students (cf. 5.4.3). Thirdly, I interviewed the teacher about the way he had chosen to teach Metals (1992), and about his background as a chemistry teacher relevant to the way he adapted and taught the observed and analyzed unit Metals (1992).

As is customary in England, the science class observed contained a number (4) of laboratory tables provided with gas and water taps. Students, seated on stools, work at these tables, either individually, in pairs or in groups. Since the case study focused on the performance of the teacher, a tape recorder was placed at the teacher's bench with two microphones at each side. Most of the teacher-student discourse in the lessons of Metals (1992) could be recorded this way; some student group discussions were recorded by placing a small tape recorder on a lab table among a group of students. It was decided not to use an extra microphone on the teacher. Both teacher and researcher felt this might disturb the regular teaching-learning processes. The researcher was situated at the left side of the teachers' bench in order to make observations in the classroom. In between short 'plenary' sessions, students worked most of the time at their lab tables with the teacher assisting them. Quite soon the researcher felt free to walk around in the classroom in order to make additional observations with regard to the teaching-learning process.

The quotes used below come, unless otherwise indicated, from audiotapes made of the lessons of Metals (1992). If it is not clear from the context, the teacher is referred to as T. Students are referred to as S1, S2, etc., the numbers starting afresh for each excerpt of the tape. For details of the lessons of the unit Metals (1989), see sections 5.2.1 to 5.2.7, and Appendix 5.

Lesson M1

The teacher briefly introduces the theme of the unit Metals (1992) as follows:

> In my opinion one of the most important units ... some of the most important materials around us, and at home ... numerous articles e.g. cars ... are made of metals.

Beyond this introduction, the chemical-societal theme is not further explored in this lesson. The survey of things made of metal is deleted, as we saw above. Also, the teacher does not ask students "to make a list of metals they know and note what they look like", as in Metals (1989).

Thus, the lesson begins almost immediately with laboratory-based practical work (M1.1) in which students "first find out what makes them [metals] different, special, beautiful". Metal and plastic spoons are compared, and students do six tests, the results of which are recorded on a summary chart they copied from the booklet Metals (1992). The latter is done by putting in a "tick or a cross as instructed". Most students have no problem with the activity in this form. One student does not understand the term "dense", so the teacher explains it to him.

The lesson continues with a teacher-student discussion on the relationship of symbols to (names of) metals. The teacher asks the students what the symbols Al, Au, Fe, Cu, mentioned in M1.3, stand for. Most students can answer this. He further asks: "what is the third most expensive metal"?, pointing to the Data Table in Metals (1992, p. 6). A student answers, "Sn". Teacher: "What?" Students then says, "Tin". Another student is not familiar with lead (daily life!). The teacher subsequently refers students to the list of seventy symbols for metals in their booklet (p. 7). Students complete the word search, "Hunt the Metals". They seem to enjoy this activity and are able to find most of the names of the sixteen metals hidden in the puzzle. The last activity, M1.3 "How do metals differ from one another", explores the relationship between the physical properties of metals (listed by symbol) and their use; this is given as homework, as suggested in Metals (1989).

With the surveys about metals as widely used materials and the teacher-student discussions deleted, most teaching time is spent on the laboratory-based practical work and on the symbols representing metals. The teacher revealed to the researcher afterwards, "The next lesson about drawing pins, that is more like chemistry, the lesson about spoons is not chemistry" (T92).

Only the teacher-student discussion on the relationship between symbols and metals ('shorthand') is added prior to the extra assignment on finding the symbols for 16 metals. However, the extra assignment on the "common everyday use" of the term metals which pupils will meet most often in the unit (and in their daily life?) is not done. As we saw, the symbols of metals are not really needed – their names are sufficient – to make sense of metals in everyday life, while the CTS relationship of metals to their use *is* needed. Thus, lesson M1 is not taught fully in accordance with design criterion two, *relevance*, and design criterion three, *content-led development of concepts*.

On the whole chemical concepts and skills receive more emphasis than chemical-societal concepts, as can be concluded from the choices made by the teacher for the activities of lesson M1. During the lesson the teacher frequently informs, instructs, prompts, and corrects students.

Lesson M2

Like lesson M1, this lesson starts with laboratory-based practical work (M2.1) without first having an introductory teacher-student discussion on why "it is worthwhile to investigate whether chemical tests might give additional information" (TNM2 of Metals, 1989; see section 5.2.2). The teacher gives only a short explanation of the purpose of the activity, "Which metal is used to make a drawing pin?", after which he instructs, coaches, and monitors students working in small groups or pairs. He then gives the "Tip: With the copper and the lead I would keep them for a bit longer than iron [in dilute nitric acid], since it seems to take longer to react." The reaction of a metal solution with sodium hydroxide solution gives rise to the following dialogue:

T: What is that?
S1: A solid.
T: No, what is a posh word ... what do you call a solid inside a liquid?
S1: A muddle?
T: A precipitate!
S1: A what?
T: A precipitate (while referring to the student booklet, p. 9).

So, here we have an example of the explanation by the teacher of a systematic, chemical term mentioned in the activity M2.1, a term which students do not need in order to make sense of the chemical phenomena of this lesson.

After the practical, the additional assignment "Construct a table from your experimental results" is introduced by the teacher: "I will give one suggestion for a table". He does this while writing on the blackboard three columns with the headings "Metal", "Color of Precipitate", and "Conclusion: Metal made from" (note that metal should be taken as "metal *object*" both times). The teacher continues: "In the next stage (the special investigation) you are gonna do the same experiment all over again using a drawing pin, a paper-clip, and solder." He further explains that "very few things are named metals", although they are made of them.

One student is familiar with the fact that solder is used for welding. The teacher elaborates on this by saying that "it is a very soft metal [*sic*] used to stick bits of metal together". This is one of the few times that a CTS context spontaneously emerges in the lessons taught. Most of the lesson time is devoted to chemical analysis proper. Finally, the teacher points students to the last (added) line of the special investigation, "Write down clearly your results and your conclusions for this investigation" (p. 9). He instructs students that "your results are the colors produced" and "your conclusions are metals made from ....made from iron". The tests comparing new drawing pins with worn drawing pins, the other addition to this lesson, are not executed. The lesson does not end with a teacher-student discussion on the use of metals related to their chemical properties, as it has in Metals (1989). Therefore, the idea of dominant metal is not elucidated.

Thus, not only the format of the table is given by the teacher, but also the general results and conclusions of the experiment, except for the specifics of color and metal present (pace the Circus approach). Chemical concepts/terms and routinized (analytical) skills dominate over the chemical-societal context of the use of metals in relation to their chemical properties. Thus, in lesson M2, the teacher put more emphasis on PC content (precipitate, chemical analysis), and less on CTS content (relationship of metals and their use).

Lesson M3

Students start by performing the activity M3A (5.3.2). They remove the corrosion of the metals iron, copper, magnesium, and aluminium by rubbing the samples with an emery cloth. In an introductory teacher-student discussion the students are asked: "Why do you use plastics sometimes instead of metals?', while the teacher refers to question 9 of activity M1.3 (p. 6), "For what uses have plastics replaced metals? Why do you think this has happened?" Some students answer that "the disadvantage of metals is that they rust". The discussion ends with the conclusion that iron rusts, but other metals corrode.

During the practical M3A students form divergent ideas about the process of corrosion. Some students think it is possible to glue the rubbed off corrosion back on. Others think "It comes out of the iron". Some think that the metal "reacted with water". Their answers to the question: "Is the metal used up when it corrodes?" also points to different ideas as to what happens during corrosion. Several students say "No", it is not used up for all four metals. Some say that iron, copper and aluminum are used up, but not magnesium. Thus, the evidence collected by students in this activity gives rise to various interpretations which make it difficult for them to arrive at the conclusions about chemical reaction, compound, and, especially, chemical element (mentioned in TNM3, Metals, 1989).

In a teacher-student discussion following practical M3A, the teacher asks the question, "Can anybody say what happened to all the metals?" Firstly, he helps students with summarizing their observations: (i) before rubbing they looked dull; after, they are shiny; (ii) most corrosion has come off iron. Secondly, he asks: "Why does it corrode ... what happens when it corrodes?" Since no answer is immediately forthcoming, the teacher gives the students "a clue, it is a chemical reaction. What is it reacting with?" One girl answers "oxygen". The day before students were given as homework to study M3B, a text in which the corrosion of iron and aluminum is explained in some detail. The teacher now discusses the key points with the class, for example, that in the case of aluminum a layer of aluminum oxide is formed. The same girl is asked to make a drawing of this phenomenon on the blackboard. The teacher explains the concepts of chemical reaction and compound but not the concept of chemical element. Another student then remarks that "the oxygen can't get to the aluminum", and when asked about the case of iron he answers, "it keeps on going". This leads to the following exchange between the teacher and this student.

T: Why?
S1: It crumbles.
T: What happens, it flakes off ... makes it thinner, and reacts again.
T: What happens in a car when that happens?
S1: Holes.
T: So, rusting is a problem. Think ... things that are made of iron or steel such as bridges, cars, washing machines, etc., things in the house, they all got steel somewhere. Steel is mostly iron. So it is very important to find out to stop rusting from occurring.

Thus, at this point in lesson 3 of Metals (1992), the teacher returns and addresses more fully the CTS theme *corrosion* by explaining the chemical and *societal* problem of the rusting of iron. The teacher then continues this discussion by remarking, "If you want to know how to stop something you got to know what *caused* it", and asking, "What is causing rusting?" Students offer the following suggestions: damp, oxygen, water, carbon dioxide, gases, air. The past activity M3.1, "What happens when iron rusts", works well; most students enjoy setting up the experiment and checking their predictions on the rusting of iron nails in the following days.

With regard to the question why it is important to hose down the underneath of cars in bad winters (Q5, p. 13), the students are told that they "do not need to do a poster" to answer it. Producing a leaflet or poster would have engaged students more fully with the central CTS theme of the unit, corrosion of metals, but instead the question is answered in a teacher-student discussion. One student thinks it is done "to get salt away". The teacher adds that there is another method to protect steel or iron, namely "to seal it with rubber (underseal)". At the end of the lesson the teacher gives as homework, "Make a list of items made of metals. Try to suggest which metal they could be made from." This is an assignment similar to the survey at the beginning of lesson M1 of Metals (1989), but not executed in the classroom. Thus, in this lesson the students explore, for the first time in some detail, some important CTS contexts about common metal objects in their surroundings, about preventing a car from rusting, and about the societal problem of rusting. Thus, lesson M3 is taught fully in accordance with design criterion two, *relevance*, and largely in accordance with design criterion three, *context led development of concepts*.

Lesson M4

As in Metals (1989), in a teacher-student discussion the results of the students' experiments with rusting nails (M3.1), including questions 1 – 5, are discussed. There is some confusion over the results since they are not the same for all students. The teacher explains that this can happen because "it is very difficult to get rid of the *air*" from the water. For other students, the rubber bungs did not close their test tubes airtight, letting in air and with it water (moisture). The key point, that both air and water are needed for rusting, is made by the teacher while the key points on the forming of a new substance when iron rusts and using up iron are not (cp. LPM4, Appendix 5).

In line with Metals (1989) but contrary to Metals (1992), the next activity is a teacher demonstration in which magnesium and iron are burned in air. The teacher concludes that "magnesium reacts very quickly while iron does not seem to react at all ... it just gets hot". This is followed by a teacher-student discussion:

T: I got a question for you: what is the magnesium reacting with?
S1, S2: Heat, air.
T: What is in the air?
S3: Carbon dioxide, *oxygen*.
T: *We* got the idea.

The teacher then writes on the blackboard the word equations:

magnesium and oxygen —-> magnesium oxide

Then the teacher adds the symbols for the elements, making a chemical equation:

$Mg + O_2 \longrightarrow ?$

The teacher explains the formula of oxygen by saying "oxygen goes round in pairs", and asks:

T: What is *formula* of magnesium oxide?
S: MgO_2 [a correct addition, mathematically]
T: Nearly just, it is MgO. Because you have to put numbers in front to make it a proper *chemical equation*.

Teaching pupils the general chemical term formula and its specification for magnesium oxide is another example of introducing PC content not needed to make sense of the chemical phenomena at this stage.

Subsequently, the teacher first gives a detailed demonstration of the experiment of the burning of magnesium ribbon in a crucible, before he allows students to perform on the experiment (M4.1) themselves. As in previous lessons the teacher frequently informs, instructs, prompts, and corrects students what to do, and how to describe what they see. The focus of this activity should be on corrosion and burning but is in fact on *oxidation*, as is already clear from the brief teacher-student discussion reported above.

The last teacher-student discussion also puts the emphasis on the concept of oxidation by emphasizing the gain in mass. The (added) question, "What is meant by the word 'OXIDATION'?" (Q8, p. 15), leads to the following teacher-student dialogue:

S: Gaining oxygen.
T: What is the opposite of it?
S1: Losing oxygen
S2: Deoxidation.
T: Good try but it isn't. I will tell you later.
....
T: What is *reduction*?
S3: Take away of air, loosing oxygen
T: Removal of oxygen

Teaching pupils the general term 'reduction', over and above the term 'oxidation', is another example of a chemical concept not needed at this stage in order for students to make sense of corrosion phenomena.

Some of the conceptual difficulties students have in this lesson are revealed by their answers to the (added) question, "What is the link between burning and oxidation?" (Q9, p. 15).

S1: In burning you get rid of oxygen.
T: This is quite important. What did magnesium do?
S2: It glows, it burns.
S3: It is a chemical reaction.
T: Coal, paper, wood react with oxygen. When something burns, it is oxidized.

The teacher skips the last two added questions (Q10 and Q 11).

To sum up, the emphasis of lesson M4 of Metals (1992), as taught in the classroom, is largely on the transmission of basic chemical concepts, namely, the concepts of oxidation, reduction, formulae, and chemical equation. The CTS context of corrosion disappears completely in the background, and the processes of burning and corrosion are not really compared as announced in the synopsis of the lesson in Metals (1989). Students learn scientific processes mostly in the form of routine procedures and skills, and a discussion of their ideas with regard to chemical phenomena and how to test them is not encouraged. Thus, in lesson M4, the teacher puts the greatest emphasis on PC content, and almost no emphasis on CTS content, which is not in accordance with design criterion two, *relevance*, and design criterion three, *context-led development of concepts*.

Lesson M5

The students start with the added practical M5, CORROSION RATE, except for the reactions of sodium with air and water which are demonstrated, the teacher says, "because sodium is quite dangerous". As for the remainder of the practical, the teacher begins by explaining the set-up.

T: We do it a bit differently. Take one of these [samples of *corroded* calcium, iron, copper, magnesium] and describe it ... color, then swot it in your groups and then do questions one and two [Metals, 1992, p. 16]. Don't touch calcium, it is a bit dangerous. I move it around because I don't want it spilling.
T: You have to describe its color [reacting to the student who writes up the *length* of a rusted nail]. Look at title of practical: CORROSION RATE. Which one looks least shiny, is the most corroded? Which one is the least corroded?
S's: Sir, what do they, calcium and copper, originally look like?
T: Well, it's a metal, so it *should* be shiny and silvery.
S2: What color is calcium?
T: It *should* be silvery, shiny. Which metal has changed the most?
S's: Magnesium, iron, calcium, copper [in no clear order].
T: What I have done here ... I put some *fresh samples* of magnesium, iron, copper. Which of these metals seems to have changed the most?
S's: Iron or magnesium.
T: Perhaps magnesium changed the most, it totally lost its shininess whereas with copper and iron there still seems to be some shininess there. Calcium has corroded, changed the most.
S's: The same, exactly the *same* [with calcium]!!
T: Why this fresh calcium looks almost the same as the one which have been out for weeks? A bit of a problem with calcium, only visible with fresh metal, and it [the metal] is hard so I can't cut it.
S3: It [calcium] corrodes straight away.
T: The most corroded metal corrodes the quickest and is the least shiny [demonstrates sodium].
S's: It corrodes more [some say] ... less [others say].
T: Does it, sodium corrodes faster?
S's: It corrodes faster [some say] ... slower [others say] ... magnesium faster.
T: It seems to me and a few other people that sodium corrodes the fastest; then calcium and magnesium, then iron and copper. We can't say exactly now ... further experiments [needed] to find out more precise order.

Thus the students are led, as far as their observations permit, to a decreasing *corrodibility* order of the five metals exposed to the *atmosphere*. The fresh samples are introduced by the teacher halfway through the practical and not at the start as intended in Metals (1992, p. 16); see also 5.3.2. This change is inspired by the skeptical response of the students ("the same, exactly the same"), and it enables students to answer questions they themselves come to pose.

In activity M5.1 question 4 is skipped, and students investigate the reactions of the metals (except for sodium) with *water*. The observations and the questions following the experiments lead students to the order of metals reacting with water: sodium, calcium, magnesium, iron, and copper, with "the most reactive metal at the top of the list and the least reactive metal at the bottom" (p. 18).

T: What can we try to do to sort these [latter] two out?
S1: ... air, hot water
T: Another suggestion happens to be acid. Why acid?
S2: It corrodes metals.

The fact that iron corrodes so much to form the chemical-societal problem of rusting, as explained in lesson M3, is not invoked by the teacher to distinguish iron from copper. Furthermore, it is to be noted that it is tacitly assumed, by unit and teacher alike, that the reactivity order found for metals reacting with water is the *same* as the corrodibility order of the metals reacting with the atmosphere.

Finally, teacher-student discussions following question 5 (Which of the two elements hydrogen or sodium seems to like oxygen the most?) show some of the conceptual difficulties students appear to have with regard to the last practical.

T: Where do you think the oxygen ends up with? Stays with the hydrogen [the other element of which water is made] or goes to the sodium? (cp. Q5, p. 18)
S1: It goes away from the sodium, it comes out the water.
T: What?
S1: ... the hydrogen.
T: The hydrogen?
S1: No, the oxygen
T: Have you worked out which gas popped?
S2: fizz gas.
T: You have a choice of two.
S2: hydrogen?
T: hydrogen or oxygen
S2: [no answer]
T: You are thinking about that ... so it must be hydrogen.

The last teacher-student discussion reveals some interesting reasoning by students:

T: Where does hydrogen comes from?
S's: Sodium, air, metals, water.
T: Water. Why?
S3: Because splint doesn't pop when you light it!
T: Because when you light splint [and held it at top of test tube], it explodes. If air had hydrogen in it, and I did this, you would have exploded!

So, the teacher makes explicit this student's assumption that the hydrogen comes either from water or from air. Activity M5.2, PREVENTING CORROSION, is an activity in which students return to the CTS context rusting and is given as homework, as in Metals (1989).

Although the lesson starts with students trying to find empirically a corrodibility order in five metals reacting with the atmosphere or air, the lesson ends by equating the corrodibility order of metals *tacitly* with the reactivity order found for metals reacting with water. At the same time students have conceptual difficulties with the role of water (and its components) in the corrosion of metals. The latter could have been avoided by following the CTS definition of corrosion as the unwanted change of the surface of metals by the action of the atmosphere. The important CTS activity about preventing corrosion of iron, really rusting – now that students are supposed to know its causes – is given as homework, as in Metals (1989).

Thus, lesson M5 clearly shows the *tension* between traditional PC content (reactivity order, oxidation) and new CTS content (corrodibility order and methods of preventing rusting).

Lesson M5X1

In a teacher-student discussion students *consider* how rusting is prevented on various parts of a bicycle (M5X1.1) and why the method stops the rusting. For example, for handlebars students mention the methods of painting and plating, which "stops air, water getting through", and for rims of wheels they suggest "aluminum, paraffin wax, made of harder metal [and] paint it with aluminum". The teacher explains that moving parts are greased or oiled. A student asks, "what about the rims, they are moving" to which the teacher responds, "yes, but they are not in contact".

This is a good example of a CTS context, for which the teacher could also "have brought a bicycle in the class" (T92). This would have made the activity more experiential for students, of course. Other than that, design criterion two and three are followed in the activities of this lesson.

Lesson M5X2

The students start right away, without an introductory teacher-student discussion on "the need to cover iron and steel to prevent rusting" (Metals, 1989), with the laboratory-based practical work (M5X2.1), an investigation into the effect that other metals (zinc, tin, copper and magnesium) have on the rusting of iron. The results of their experiments are discussed in the ensuing teacher-student discussion. Three test tubes show a brown/orange color on the iron nail (one tube contains a nail and only salt solution), while two tubes show a white color on the other metal (zinc, magnesium), according to the teacher "the best results I ever got" (T92). The latter results are taken as slowing down rusting, while tin and copper apparently speed up rusting. The last two questions (Q3 and Q4), also addressed by the teacher in class, deal with these chemical effects in daily life. Dented tin cans speed up rusting while iron coated with zinc slows it down. This activity teaches students important CTS relationships about the speeding up and slowing down of the rusting of iron on the basis of evidence they gathered themselves, relationships which are subsequently used to explain chemical-societal manifestations of these phenomena. The conclusion: "not all metals react as well or as quickly as each other" (1992, p. 24), is not addressed by the teacher here, nor are the metals looked into in this unit placed in a "league table" as suggested by the addition put in Metals (1992). Therefore, with this extra PC content being skipped, the lesson M5X2 is taught fully in accordance with design criteria two and three.

Lesson M6

The teacher starts by explaining the concept alloys. With teacher demonstrations 1 and 2 being deleted (5.3.2), the lesson is limited to students working on the completion of a question sheet called ALLOYS (M6.1), with question 1 given as homework.

Instead of students discussing their "ideas with other members of the class" (Metals, 1992, p. 25) the teacher helps students with question 2: "Think about the following statements to see if you can explain them. For Q2 (a), "In making steel the amount of carbon added to the iron is very carefully controlled", he gives the answer, "If too much carbon is added to the metal it becomes brittle (weak) and it changes the properties" [quoted directly from one student's revision book]. And Q2 (b), "When iron is produced in a low temperature furnace, it can be beaten into shape. Iron produced in a modern blast furnace breaks when struck with a hammer.", is answered by this student as follows: "Heat will weaken the iron so if too much heat is added the iron will break." The student apparently substitutes heat for carbon in the answer provided by the teacher above. (Actually the iron becomes brittle because of the high amount of impurities formed under these conditions.) This shows that these difficult, although relevant CTS questions, cannot be answered by students on their own if they are not sufficiently prepared for them by text and/or teacher.

With teacher demonstrations 1 and 2 being deleted, the lesson is really restricted to answering the question sheet addressing the CTS relationship between the properties and use of alloys, while the students do not learn much about the other important CTS relationship between the composition of alloys such as steel and their properties such as their strength. Thus, lesson M6 is not fully taught in accordance with design criteria two and three.

5.3.4 Summary and discussion

From the analysis of the lessons of Metals (1992), as provided by the teacher to his students and summarized in Figure 5.16, it is clear that about half of the lessons do not have their *origin* and *justification* for study, *fundamentally*, in aspects of *everyday life*. CTS content is best realized in lessons M3, M5X1, and M5X2, and to some extent in lesson M5.

Inspection of Figure 5.16 below, the second column, also learns that quite a number of chemical concepts and explanations treated in the lessons of Metals (1992) are not *needed* for the study of the everyday situations used in the unit Metals (1992).

Comparing the taught curriculum (Figure 5.16) with the interpreted curriculum (Figure 5.15) of Metals (1992) can tell us whether or not the CTS/PC content ratio has changed. As we saw, the deletion of CTS contexts from the interpreted curriculum has not been undone in the taught curriculum except for the survey of things made of metal addressed in lesson M3. Some of the PC concepts (double bonds, Proust's law), added onto the interpreted curriculum, were not addressed in the classroom. The teacher adds two new concepts, though, reduction and formulae, while the concept of chemical shorthand and some systematic names are given more explicit treatment. Some of the CTS concepts added to the interpreted curriculum are not taught in the classroom; the deletion of teacher-student discussions also means that some CTS content is not taught. Thus, when we compare the taught curriculum with the interpreted curriculum of Metals (1992), the CTS/PC content ratio has decreased again substantially (Figure 5.5.).

The main emphasis is on the PC concepts (analysis, oxidation, and reactivity series) which tends to overshadow the CTS theme of corrosion and prevention of rusting. The analysis of the taught curriculum of Metals (1992) further showed that pupils' learning of chemical concepts and skills were more strongly teacher-directed, compared to the "self-motivated learning" students of the 'Circus', a finding which seems to go against design criterion five, *variety of teaching and learning activities* (but see below).

Discussion

The changes made by the teacher during the actual teaching are a further illustration of the operation of design criterion four, *flexible teacher-mediated use* (cp. 5.3.2). His introduction of new chemical terms, such as reduction, not needed by the students to make sense of the phenomena, seems to violate design criterion one, *no preconceptions*.

Although the Circus, largely a process approach, was no longer followed in 1992, the teacher reinstated only some teacher-student and group discussions that were originally present in Metals (1989). This is to be regretted, in particular for the opportunities lost thereby to develop CTS content out of chemical-societal activities or contexts. Because CTS content is of a different nature than PC content, it needs careful contextual introduction and activities, such as discussions and poster making, in order to get the relevant CTS curriculum emphasis across to students; for example, the fact that familiar metal objects from students' surroundings are usually mixtures or alloys.

CTS content is best realized in lessons M3, M5X1, and M5X2, in other lessons of the unit the emphasis on PC content either overshadows or competes with that on CTS content. As the teacher remarked, a CTS activity is sometimes done, because "it is always handy to have that to fill in a bit of time" (T92). Sometimes the teacher added PC content such as the concepts formulae and reduction. Students spend most of their time on laboratory-based practical work for which the teacher gives elaborate instructions, guidance and corrections. He did this mainly, he said, because he had to deal in this case with "a slightly lower to middle ability group" (T92), not accustomed to deal with a set of varied activities on their own. Thus the level of the class also determines the variety of activities used by the teacher.

Students seemed to experience a number of conceptual difficulties with what goes on during corrosion, rusting and oxidation, for example with the role of water and its components, hydrogen and oxygen. The teacher mentioned in the interview three other examples, which confirm this impression.

The first one concerns the role of water and air during corrosion and rusting. Students "sometimes fail to realize that there is air surrounding all the time ... just the water is seen as important, a piece of iron or steel is damp, they can see the water" (T92). This confirms that the focus of teaching should be primarily directed on the role of air and water during corrosion, taken as a CTS phenomenon, and in accordance with design criteria two and three. As argued above, grasping the role of oxygen is not needed by students in that context.

Secondly, students have problems with the reactivity series. As the teacher remarks, students "having seen orange copper gone green and silvery magnesium gone gray cannot appreciate that magnesium corrodes as much or perhaps more than copper" (T92). Visual inspection alone might indeed not be sufficient here. Furthermore, students, familiar with aluminum window frames and bicycle parts, have difficulty with "the realization that aluminum initially corrodes, forms a thin layer, and then corrodes no more" (T92). A consistently treatment in the lessons of *only* the order of corrodibility of metals in air could maybe help here.

Thirdly, students do not easily grasp that alloys are mixtures of metals. In activity M6.1 ALLOYS they often choose aluminum as the metal to make airplanes wings, and not "Duralumin", the alloy whose composition (Al, Cu, Mg, Mn) and properties (low density, stronger, and more corrosion resistant than aluminum) are *given* on their information sheet.

The emphasis on practicals strongly guided by instructions, with insufficient conceptual development combined by the lack of emphasis on CTS content shows that there is a real danger that this can lead to, predominantly, the reproduction of chemical techniques and facts, especially with students of low to middle ability. This comes close to our characterization in Chapter 2 of dominant school chemistry in terms of students learning propositions and algorithms.

Reflection on Metals: the teaching process

The conclusions I draw for the teaching process of Metals, based on one teacher teaching one unit, can not be considered as representative, as were the conclusions I draw for the developmental process of the teaching units. The population of teachers using Salters' Science units has a much greater variation width than the set of Salters' Science units, as designed by the developers following a number of selected design criteria. Nevertheless, I think that the phenomenon of slippage in the *process of interpreting and teaching* a unit is important enough to draw attention to. Furthermore, it is a well known phenomenon mentioned in the research literature (Goodlad, 1997; Van den Akker, 1988), especially with regard to the teaching process. There will certainly have been teachers who escaped to a larger extent, who therefore showed less slippage. Still other teachers may have shown more slippage.

Figure 5.16 The Taught Curriculum of Metals (1992)

Lessons	**Contexts not taught**	**PC content not needed, but not taught**[a]	**CTS content needed, and taught**	**CTS content needed, but not taught**
M1	lab. survey of things made of metal; survey of common metals and properties	relation symbols to metals; metals/name to symbols		relation common metals with everyday use
M2		precipitate		relation use of metals to chemical properties; dominant metal in drawing pins
M3		oxygen, aluminum oxide	explanation of problem of rusting; prevention rusting; things made of metal	
M4		reduction, oxidation; equation; formula oxygen, magnesium oxide		
M5		hydrogen oxide hydrogen, oxygen	corrosion rate/order of corrodibility; prevention rusting	
M5X1	'Rust Stoppers'		methods of prevention rusting	commercial aspects of produced materials
M5X2	properties steel alloys; preparation of solder		order of rusting iron: more reactive metals slow it down; less reactive speed it up	
M6				composition alloy determines properties

[a] PC content deleted: double bonds, Proust Law.

5.4 The experienced curriculum of the unit Metals

The consistency analysis in terms of the CTS / PC ratio, performed so far, has addressed the various curriculum levels at which the unit Metals (1989) is *offered* to either teachers or students. The formal curriculum unit of Metals (1989), as provided by developers to teachers, was analyzed in section 5.2. The interpreted curriculum and taught curriculum of Metals (1992), as offered by a teacher to his students, were analyzed in section 5.3. In both cases it was found that the CTS / PC ratio decreased in the transformation of the formal curriculum level to the interpreted, and then to the taught curriculum which was accompanied, as we saw, by an increasing tension in the material used in the unit between context and content.

The claims about the quality of the provided curriculum made above are based on my own research, more specifically, on the consistency analysis performed in this chapter on the chemical unit Metals (1989, 1992), taken as a representative unit of the Salters' Science approach. As we will see below, the claims about the quality of the experienced curriculum are to some extent based on my own research, but mostly on the (sometimes extensive) research on the Salters' Science approach performed by others.

It would be interesting to describe, analyze and discuss the relationship between the quality of the provided curriculum as characterized in this chapter and the quality of the Salters' Science curriculum as experienced by students, even though the latter was not the primary focus of my research. On the other hand, the pedagogical structure, part of the theoretical curriculum framework I use in this thesis (see Chapter1), contains as subcategories not only the aims and teaching approach but also the learning approach as used by developers. Furthermore, comments of IF and DF members (see Chapter 2) pertain not only to the formal and taught curriculum of school chemistry but also to the curriculum as experienced and learned by students.

This makes it relevant to look into students' experiences with regard to the content and activities provided in the unit Metals (1992). In other words, what can be said about the experienced curriculum of the unit Metals (1992) is based on my own research while putting it in the context of other relevant research into the Salters' Science curriculum.

In this section, I will address, therefore, the question how the students *receive* the interpreted and taught curriculum: What do students experience and learn when the unit is taught to them by the teacher using the booklet Metals (1992)? More specifically, are students motivated by the kind of contexts and activities provided by the interpreted and taught curriculum? Do they acquire, apply and use the intended content of the unit Metals (1992), as entailed by these contexts and activities, and as interpreted by the teacher?

At the end of the lessons of Metals (1992) the students in the classroom were asked by the researcher to fill in a questionnaire, the results of which are discussed below (5.4.1). Secondly, I refer to some excerpts of teacher-student discussions I audiotaped, showing students' learning experiences with regard to activities of the unit Metals and also to some excerpts of audiotaped student-student discussions in the classroom (5.4.2).

Thirdly, written comments of students on trial editions of Year Three units such as Metals (1984), collected by the developers, are summarized and discussed below (5.4.3). Fourthly, I will discuss the results of a number of other research studies on the Salters' Chemistry or Science courses, especially with regard to students' learning experiences and results (5.4.4). This will make it possible to put into perspective my answer to the question whether and to what extent the chemical unit Metals (1989), a part of the formal curriculum of Salters' Science, has been realized as intended in a particular class of students by a particular teacher of a particular school. Finally, I will draw together the findings from my own research (primary sources) and other relevant research (secondary sources) in order to discuss the relationship between the quality of the Salters' curriculum provided by developers and teacher (Metals, 1992) and the quality of the curriculum as received and experienced by students (5.4.5).

5.4.1 Student questionnaire

The purpose of my questionnaire was, as I formulated it in my notes at the time: "To find out if *newness* of Salters' Chemistry is visible". Thus, the questionnaire was designed to probe mainly the perception and knowledge of students with regard to the new CTS emphasis, earlier called, "Chemistry along with CTS Content" (5.1.4). Thus, the questionnaire was not specifically designed to probe students' learning of PC content nor of *all* CTS content contained in the unit Metals (1992). In the discussion of relevant findings of other research studies below we will see also that the probe used in a research project depends on the research question asked (5.4.4).

The questionnaire consisting of ten questions was introduced to the student (S) as follows:

a) If you fill in this questionnaire you would really help me with my research on the unit Metals.
b) Please work with your usual groups, talk about the questions a bit and then write down what you think is a proper answer (emphasis in original).

The questionnaire was administered by the researcher to a group of sixteen Third Year students, in November 1992, that is, immediately after they had followed the lessons of the unit Metals (1992). Twelve students filled in the questionnaire, two did not, and two were absent.

The questions 1, 2, 5, and 6 below addressed students' *perceptions* of the lessons of the unit Metals in terms of keywords such as enjoy, (dis)like, useful, and choose. The questions 3, 4, 7, 8, 9 and 10, on the other hand, asked students to *use* the CTS knowledge they had acquired in the unit Metals.

The latter questions were designed with the idea that students would be able to transfer relevant knowledge to other CTS contexts if and when they would have acquired or learned that CTS knowledge in a relevant context to begin with. That is, relevant contexts would not only motivate the process of learning CTS concepts, but this process of relevant learning would also facilitate the application or use of the learned CTS concepts in other relevant contexts.

So the general idea of the questionnaire is: do students experience the new CTS emphasis and learn, apply and use some relevant CTS content when taught the unit Metals (1992)?

Analysis of the results and discussion

QUESTION 1: Mention one or two things that you enjoyed doing in the unit Metals.

A great majority of students (9) said they enjoyed the practical work, that is the *experiments*, in the unit the most. The experiments on rust (M 3.1) and on corrosion (M

5.1) were mentioned twice. One student (S5) wrote: "I enjoyed burning metals and putting them in water...", referring to M 4.1. Two other students enjoyed the crossword part of one activity (M 5.2) and the word search, "Hunt the Metals" (M 1.2) the most. One student said he enjoyed "nothing" (S11).

On the whole, students enjoyed doing the experiments, in particular the ones which where set within a relevant context such as rust and corrosion. Providing relevant contexts in line with design criterion two, *relevance*, appears to motivate students the most.

QUESTION 2: Mention also one or two things which you found *useful to know* about metals.

Most students (8) found that it is useful to know something about (prevention of) rusting and corrosion, for example:

> I found out useful things such as air and water is needed to rust. (S4)
> Some things I found useful was what metal rusts the fastest and which metal are easy to use. (S3)

The CTS relationship between properties of metals and their use, hinted at by S3, is hardly visible in other students responses. A number of students (4) found it useful to know the "chemical symbols of the metals" (S7).

Thus, it seems largely the developing and teaching of *relevant* contexts such as rusting, in line with design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, which leads to knowledge found useful by most students.

QUESTION 3: Your friend and you have found a very rusty bike. Now you want to fix it up. So you can sell it afterwards for a good price. What are you gonna do about the different rusty parts of the bicycle?

Many students (7) write up that they are going to sand paper the rust away from the rusty parts and then paint / grease / oil / chrome plate the clean parts, for example:

> Sand paintwork down clean and grease some parts and respray. S3
> Get some sand paper and oil and grease to get the rusty parts working. S9

A number of students (4) would just "paint it" (S11), but do not mention they would sand paper the rusty parts first. One student's idea is to "get new parts" (S4).

Apparently, many students use the skill of rubbing corroded metals with sand paper acquired in activity M 3A as well as *transfer* their acquired knowledge of methods of preventing rust to a new daily life situation. Thus, developing and teaching relevant contexts on the prevention of rusting, in line with design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, leads many students to transfer their knowledge, that is, applying, in a similar context, their acquired knowledge and skill, showing thereby their understanding.

QUESTION 4: Your mom says that you must not buy *dented* food cans. Why not?

All students report that the can will rust. Most students (7) add something to the effect that the rust might get to the food and "damage" (S3) or "ruin" (S11) it, for example:

> Because rust gets in the groove and might affect food. S4

Again, as in their answers to Question 3, many students *show* in their reply to Question 4 a *transfer* of relevant chemical knowledge. Therefore, design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, effectively guide the developing and teaching process.

QUESTION 5: Name a few things which you did not like to do in the unit Metals.

Students say they do not like homework (4), writing text-related activities (3), and cleaning test tubes (2). Some students (3) say they did not like most of it. As one of them (S10) said: " I am not bothered with metals".

From this response, and the response to Question 1, it can be concluded that most students dislike some rather obvious things such as homework but that, on the whole, they do seem to like the practical work, mostly the relevant experiments and some of the other activities.

QUESTION 6: Will you choose science after your GCSE exam? And which science then?

Five students answer that they will not choose science, for example;

> No, what I want to do, I don't need science. (S 11)

Two students qualify their answer as follows:

> I would not choose science for a job but I would learn more depending on the job I get. (S6, S8)

The remaining students either choose medical science (S1, S2), general science (S7, S12), biology (S3), science for working with computer (S9), or simply say "yes, I will" (S5).

Thus, about half of these students see themselves as taking up some *science* subject after their GCSE exam. Only one student says she will choose a separate science subject, namely biology, and *none* of these students mentions *chemistry* as an option. Having been offered the unit Metals as part of their *science* classes, it seems understandable that Year Three students do not yet perceive particular science topics, e.g., Metals, as belonging to a separate subject or science.[53]

QUESTION 7: Give an example of something you do outside school where you could use the knowledge you learnt about metals.

Some students (4) mention fixing their (motor) bike or its engine. Others (2) mention things other people do: car design, engineer and builders. The other half of the students

---

53 See De Gier (1992) for a similar observation. Pupils, at this stage and age, when being offered a course on (broad and balanced) science do not perceive chemistry or even chemistry teachers but only science and science teachers.

either do not give examples, or do not know, for example, a student (S4) says, "it depends on the metal".

Thus, it seems rather difficult for students to imagine a *new* situation in which they can apply their acquired knowledge about metals. However, students can apply their knowledge to a new situation given or described to them as the responses to Questions 3 and 4 showed.

QUESTION 8: Here is a list of different occupations. Maybe you will choose one of them later in your life. In which occupation is knowledge about metals important? Please give a tick (÷) and explain why you think so. A table of occupations gives: grocer, banker, car mechanic, computer programmer, housewife / man, cook, chemist, engineer, fireman / woman, police officer.

Students 'ticked' most often the occupations car mechanic (7) and engineer (7). Some explained their choice, e.g., an engineer "deals with different metals" (S5). Other occupations were mentioned once: a housewife is "cleaning metal" (S5), a fireman should know "what metal burns fast" (S3), a chemist "experiment with metals" (S12), for a computer programmer it is important to know the "right metal for circuit board" (S9), and for a cook to know "right metal for pans" (S9); grocer, banker and police officer are not ticked at all.

About half of the students answer that they either do or do not like some of these occupations, apparently focusing on the second introductory sentence of question 8. Thus, on the whole they do not answer the intended question about the relevance of metals in common occupations. It seems not clear to most of them that metals can be important in many more occupations besides the rather obvious ones they mentioned, car mechanic and engineer. Even with occupations clearly presented to them, it might still be difficult for students to imagine what role metals play in that occupation. For these students things made of metals seem to be much more visible in crafts and engineering than in chemistry as a science which seems consistent with the CTS approach taken by developers of Metals (1989).

QUESTION 9: Do you know of any other occupation in which a knowledge of metals is useful?

As can be expected by now only a few students come up with suggestions (see discussion Question 7 and 8). They mention plumber (1), architect (2), builder (2) and helicopter pilot (1).

QUESTION 10: Do you know of any other activities in your own life in which a knowledge of metals is useful?

Again, students give only a few suggestions which refer either to their present or future life or to things other people do such as "cleaning a car" (S10), "metal craft" (S11), "working with metals" (S12), "in science" (S10).

Summary and discussion

We will now use the findings of the questionnaire to answer the question to what extent the chemical unit Metals (1989), a part of the formal curriculum of Salters' Science, has been realized as intended in a particular class of students by a particular teacher of a particular school.

The findings show that the teaching of the CTS unit Metals (1992) to a group of 13 – 14 year old pupils can be an effective way to *motivate* the majority of these pupils. Many students also appear to acquire some useful chemical knowledge which they are able to apply to daily life situations, if clearly presented to them and similar to those they have met before. It appears much more difficult, though, for students to transfer their knowledge to unfamiliar situations or occupations, while to imagine new situations for application appears most difficult.

The responses to the questionnaire further show that students are motivated by some specific CTS contexts, from which they have learned some fundamental CTS concepts such as the causes of rusting / corrosion and their prevention, and which they can apply to similar contexts presented to them. The relevance of metals in daily life is recognized by them to some extent. On the other hand, students' responses do not clearly show to what extent students appreciate or have learned PC content, mainly because my questionnaire did not set out to do so (see 5.4.4).

To sum up, relevant contexts do not only motivate the process of learning CTS concepts, but this process of relevant learning also does facilitate the application or use of the learned CTS concepts to a set of similar relevant contexts. One could call this *the principle of local transfer through relevant learning*. The global or general idea of transfer, on the other hand, implies the possibility of a transfer of acquired general chemical concepts to all situations, relevant or not.

In the interview I held with Garforth (G92a:15), she acknowledged that the latter, general idea of transfer underlay the development and units of Salters' Chemistry. She put this in terms of familiar and unfamiliar materials, not as I did in terms of the kind of contexts used:

> It was definitely intended (..) that *we would introduce things,* that were normally introduced in unfamiliar materials, *using familiar materials*, so it was certainly the idea that the chemical concepts, the concepts which came out of and the generalizations which came out of our experiments on rusting and browning apples would be upgraded - would gradually become the kind of generalized chemical concept of reaction, the generalized chemical concept of oxidation in both those two cases (my italics).

It is to be noted that this global idea of transfer implies a focus on the learning of general chemical concepts and generalizations with a primary emphasis of learning PC concepts in and through familiar daily life situations or contexts. The principle of local transfer through relevant learning, on the other hand, focuses primarily on the learning of CTS concepts and of only those PC concepts needed to make sense of the familiar contexts. Thus the tension between CTS context and PC content, referred to many times above, manifests itself also in two different ideas of transfer of knowledge: of local and global transfer.

About half of the students say they will take up science, general or applied, after their GCSE exam, not specifically mentioning chemistry, though.[54] Students do not seem to

[54] Out of a class of eight A-level pupils, following Salters' Advanced Chemistry at a grammar school I was visiting in October 1991, seven students said they were considering to study some kind of *engineering* at university. A few students were more specific, mentioning: civil (1), physics (1) or chemical engineering (1).

perceive the topic metals as belonging to chemistry taken as a separate science, but rather as a topic having to do with science in general, which includes for them craft or engineering. This perception appears consistent with the intended CTS emphasis in the unit Metals. In line with this, students appreciate, for example, in the contexts of corrosion and burning, the general role of air rather than the specific role of oxygen. The new curriculum emphasis of the unit leads for the greater part of this group of students to an interest in a form of relevant science.

Therefore, on the basis of these responses, it is possible to say that the formal Salters' Science curriculum, as operationalized in the unit Metals (1989, and interpreted and taught through the unit Metals (1992) has been realized with the majority of these students *as far as* the motivation by CTS contexts and the learning of some CTS concepts are concerned. This is a remarkable conclusion, to which we will come back in section 5.4.5, after reviewing other relevant research.

5.4.2 Students' classroom experiences with Metals (1992)

It became clear from classroom observation that most students enjoyed the following activities: M1.2 "Hunt the Metals" (a word search), and the experiments M3.1 "What happens when iron rusts?", M5.1 "Do all metals corrode?" and M5X2.1 "Do other metals stop iron from rusting?. They did not like so much activity M 6.1, "Alloys", which is a question sheet with some text introducing the questions. As noted above (5.4.1), students do not seem to *dislike* any of the practical activities of the unit Metals, a perception largely supported by classroom observation. Thus, students liked about half of the activities contained in the unit Metals, while not disliking the other half (M1.0, M1.2, M2.1, M3A, M4.1, M5X1.1, and M6.1).

On the whole, the teaching approach followed by the teacher using Metals (1992) appears to motivate the students in doing the practical activities and helps them also to make sense of the latter, at least of the CTS content. The context-and activity-led approach is facilitated by the arrangement of four laboratory tables surrounded by stools, a facility common in science class rooms in English schools.

Thus, the audiotapes of the classroom discussions of students working through the activities of Metals (1992), partly reported on and discussed in section 5.3.2, and the observations of students' activities by the researcher in the classroom, largely confirm what students *said* they enjoyed as activities in the questionnaire.

On the other hand, the recorded classroom discourse also showed (5.3.2) that students have difficulty understanding, or are confused by the following PC concepts: density (M1), precipitate (M2), chemical reaction, compound, and element (M3), role of oxygen (M4), and reactivity series (M5). According to the teacher (T92) students had also difficulty understanding the concept of alloys, and the role of air, aside from water, in rusting.

Besides the CTS concepts rusting and corrosion and their prevention, emerging as relevant and useful concepts from the student questionnaire (5.4.1), we have seen that students in the classroom were active and successful in constructing the concept of the order of corrodibility of metals (5.3.2). In the lessons some students also came up with things from their daily life relating to metals, sometimes spontaneously, for example the use of solder in welding.

Thus CTS contexts appear not only to motivate students to undertake practical work, they also appear to help students with understanding the CTS concepts involved, apparently more so than with the PC concepts introduced. This conclusion concurs with the tentative conclusion reached above (5.4.1), while adding that CTS concepts appear to be more appreciated and understood than PC concepts.

5.4.3 Students' perceptions of Year Three trial units

The following brief summary of student feedback is based on Garforth's remarks as made in the interviews.[55] For practical reasons the next phase of the Salters' Chemistry Project, the design and trial of the GCSE exam course, used only feedback from teachers (sections 4.4.4 and 4.5.3).

The perceptions from a large group of students from ca. 200 schools, which volunteered as Project schools for the trial of Salters' Chemistry units Year Three (e.g. Metals, Trial Edition 9/84), are that students found the Year Three trial units worthy of study. Students said they enjoyed these units very much because they felt they were using things they understood or knew about. As one pupil expressed it: "This is the best thing I have ever done since I came to school" (G/W 91:18).

Teachers trialling the units said about their students that they were not only very *motivated*, that is, liked and enjoyed the units, but also showed improved practical as well as thinking skills and had learned at least the basic concepts. Some teachers, though surprised by the increased motivation and activity of their students, remarked that students "haven't reached the level of understanding that we would expect at the end of the third year" (G92b).

The latter remark points to a problem these teachers, but not so much their students, may have with a "Chemistry along with CTS content" course. These teachers seem concerned whether the new course would prepare their students adequately for the next level of school chemistry; that is, whether the Salters' Chemistry approach would offer all their students the expected or required level of PC content, i.e. chemical concepts and skills. The finding mentioned above (5.4.2), that students experience difficulties with learning a number of PC concepts, would be a major concern for these teachers. Many students do not seem to share this concern.

Student responses to the questionnaire on the relevance of the topic metals in daily life (5.4.1), students' classroom experiences with the unit Metals (5.4.2), and students' perceptions of the Salters' Chemistry trial units, all seem to point in the same direction. For the majority of students, the CTS emphasis of Salters' Chemistry, such as is present in the unit on Metals, apparently motivates students to acquire and apply relevant chemical knowledge. This makes such a CTS unit a worthwhile experience for them.

[55] A full analysis of all the student perceptions available is not made here, but would deserve special study.

5.4.4 Review of relevant research on Salters' Chemistry / Science units

In this section, I will summarize and discuss the results of a number of studies into *the effects* of the context- and activity-based Salters' Chemistry/Science courses, in particular on students. This is done only to the extent that as these results are relevant for answering the question raised above, namely, to what extent a representative part of the formal curriculum of Salters' Science, like the chemical unit Metals (1989), has been realized with students in the classroom when taught by a teacher.

I start with the results of the study of Nicolson (1991), following this with a summary and discussion of the results of De Gier (1992), Borgford (1992), and Ramsden (1992, 1994, 1997). As noted above, it depends on the specific research question asked in these studies, and the methods or probes chosen there, as to the kind of results obtained.

Nicolson's study

In this discussion I will follow the summary of Nicolson (1991) as given in Campbell et al. (1994). Nicolson (1991) looks at the success of the GCSE Salters' Chemistry course, first examined in 1988, as measured by:

> … the number of users, and their satisfaction with the course after several years of use [and] … the number of students who choose to continue the study of science after completing their GCSE course (Campbell et al., 1994, pp. 440-441).

With balanced science becoming mandatory in the years before 1990, chemistry teachers, from 207 schools, entered an increasing number of their students for the Salters' Chemistry GCSE exam: 10,558 in 1988; 11,968 in 1989; and 12,177 in 1990. This overall increase of 1619 students (about 15 %) is an indication of the satisfaction teachers felt about the Salters' Chemistry course as "a solution to some of *their* current problems, as *they* perceive them" (ibid., p. 421; italics in original). The problems as perceived by the developers, and shared by the teachers taking up the GCSE Salters' Chemistry course, are:

– to provide a chemistry course which would be more accessible to students by making "links with the lives and interests of young people" (ibid., p. 418);
– to provide a sound basis for, preferably, an increasing number of students to pursue chemistry at a higher level of schooling.

Nicolson also compared (for a sample of 76 schools) the number of Salters' Chemistry students choosing A-level chemistry in 1988 with the number of students choosing A-level chemistry after completing a non-Salters' chemistry course in 1987. He found that the number of students choosing to continue chemistry after their GSCE Salters' Chemistry examination increased from 813 to 1118 students, which amounts to 37.5%. This increase shows that the second problem mentioned above has at least partly been solved. But as Campbell et al. (1994, p. 441) justly remark: "Increases in student *numbers* tell us nothing about the intervening process, or about the experiences of the teachers and the students *during* the course." Thus, whether the increasing student numbers have a sound basis to pursue chemistry at A-level remains a subject for further investigation.

Further, it is to be noted that the number of students choosing A-level chemistry, though considerably increased, constitutes still a minority of about 30 % of the total number of students (10,558) entered for the GCSE Salters' Chemistry examination in 1988.[56] Thus, the majority of students taking the Salters' Chemistry course do *not* choose to continue to study chemistry at A-level. This is quite a significant finding, since it makes the solution of the first problem, of providing an accessible and interesting chemistry course for *all* GCSE students, all the more important and necessary, even if the second problem is solved.

It is difficult to know, to what extent the overall increase of 15% in the number of students entered for the GCSE Salters' Chemistry exam could be attributed to the taking up of a chemistry course which would be more *accessible* to students, by making "links with the lives and interests of young people". How many students took up the course for this reason, and how many students took it because they wanted to continue to study chemistry at A-level? It is likely that the increase indicates that the first problem has at least been addressed, though it is very difficult to say to what extent this more tenacious problem has been solved, based on these numbers.[57]

In brief, the Salters' Chemistry course appears to enhance the interest in chemistry for a minority of students choosing to continue their chemistry study, and perhaps also to a small extent for the majority of students who, though they do not choose A-level chemistry, nevertheless need it as future citizens. As noted above, numbers alone cannot reveal just *what* it is in the Salters' Chemistry approach that works or does not work for either group. Case study research, based on structured feedback obtained by questionnaires and interviews from students and teachers, is needed to record and analyze the experiences of the teachers and the students during the course, preferably in combination with classroom-based research through observing, recording, and analyzing classroom discourse of students and teachers.

De Gier's pilot study

In a case study preceding and preparing for the more extended case study on Metals (1989) reported on in this thesis, De Gier (1992) probed a sample of 22 students using as data collection techniques: student questionnaires and observation and recording of classroom discourse of students, while trying to answer the following questions:

> How do students *experience* the science lessons?
> How do students seem to develop concepts? (ibid., p.1; italics in original)

The first question is very similar to the one I used (section 5.4.1) as a leading question for probing pupils' experiences with Metals (1989). The second question, unlike the questions in my questionnaire, focuses on students' learning of PC concepts.

In May 1992, De Gier investigated a couple of lessons of three other Salters' Science

---

56 This is assuming that the 207 schools entering Salters' candidates for the GCSE examination in 1988 would produce about the triple number of students choosing chemistry as the sample of 76 schools, which produced 1118.

57 Another indication is given by the examination results of the students who have been taught the Salters' Chemistry course from 1986–1988: about 75 % of these students passed, in 1988, with grades A – D (OGT, p. 6). This result is similar to that found for students following traditional chemistry courses (Borgford, 1992).

Year 10 units: Making Use of Oil (MUO), Mining and Minerals (MM), Seeing Inside the Body (SB); and some lessons of one Year 10 Salters' Chemistry unit, Keeping Clean (KC).

With regard to the first question and based on her analysis of students' responses to the questionnaires she administered in the classroom, de Gier arrives at the general conclusion:

> So, students enjoy the lessons and the lessons do start from where they are and have an impact on their daily lives (ibid., p. 25).

More specifically, "most students think of *concrete, contextual examples* for what they found *most striking, or most important*" (p. 25; italics hers).

These conclusions concur with the ones I reached (section 5.4.1) for Metals (1989), including the effectiveness of some specific contextual examples or CTS activities for the acquisition and transfer of relevant knowledge, such as the practical HOW CAN AN OIL SPILL BE CLEANED UP? (MUO) and HOW CAN WE MAKE A SOAP (KC).

With regard to her second question and on the basis of the analysis of her observations and recorded student-student discussions, De Gier first notes a specific misunderstanding on the meaning of the term "state at room temperature" (p. 26), in connection with the concept of flammability. This misunderstanding hinders students in their execution of the practical, INVESTIGATING SOME PRODUCTS OF CRUDE OIL (MUO). Secondly, in group work on BUILDING MODELS OF HYDROCARBON MOLECULES (MUO), "there was a *tendency to go for easy, concrete explanations only*" (p. 26; italics De Gier).

Thus, she concludes that there are "*still problems with concept development for the students*" (p. 26; italics hers). This concurs with my conclusion in section 5.4.2 on the conceptual difficulties students have with some PC concepts of Metals (1992).

Borgford's study

In a case study, Borgford (1992) describes and analyzes a pilot implementation of a unit of the Salters' Science course, Transporting Chemicals (1990), at a U.S. high school in January-February 1992. In my summary here I will focus on the effects found on motivation and learning of about 100 students (14-15 year olds) in four traditional U.S. chemistry classes. The participating chemistry teacher had over twenty years experience: "he agreed to try something *new* and was intrigued by the *potential* for this approach" (ibid., p. 17).

After students "had completed 18 weeks of introductory chemistry" (p. 15), for five weeks classes were taught the unit Transporting Chemicals (TC) by the teacher and Borgford herself. The research methods used were a student questionnaire, a teacher interview, and classroom observation by the researcher, who also acted as teacher. Thus, in this research design, students experience the teaching of an *applications-first* Salters' Science course unit right *after* they have been taught (and internally examined/graded) an introductory *science-first* course for one semester. These students can therefore make a *direct* comparison, unlike the students experiencing the unit Metals (1992) or the students in the other studies reviewed.

After a unit test covering the work on the unit TC, students were asked to respond to a questionnaire (returned by 83 of 92 students present) consisting of twelve questions, six of which concerned students' experiences. Their responses to question seven and eight are particularly relevant here. With regard to question seven: "What part(s) of this unit, *Transporting Chemicals*, was (were) most interesting to you?", Borgford reports that students expressed most *interest* in the role-play activity about the site of a chemical plant (31), followed by the laboratory activities (16), the activity about hazard warning signs and how to transport chemicals (13), and finding patterns in the periodic table (8). Some students (7) liked all activities, some (3) liked none, some (3) gave no response. Borgford concludes (p. 22):

> The greatest interest was generated by those activities in which students were able to move around, discuss their work with others, use their own ideas and consider *the real world use of the chemicals*.

In response to question eight: "What parts, if any, did you not like – and why, in the unit TC", students responded that they did *not* like: conducting the role play (3), laboratory activities (14); learning about the nature of chemical transport (6); learning about the periodic table (9); work with formulae and equations (7), managing labs: keeping track, uncertain goals (4). A large number of students said they liked all parts (20); some gave no response (10); some (3) said they liked none, it was too easy; some did not like going to the library; one did not like the test.

Borgford remarks that "the number who liked learning about the actual nature of chemical transporting is twice the number who disliked this aspect" (p. 22) and, also, that only three students "specifically cited the role play as one they did not like, while 31 found it to be the most interesting" (p. 23). Both these activities, performed as they are in a CTS context, are much appreciated by the average student. Further, she notes that it is surprising that so few students gave *writing formulas* as an answer to Question 8, "a traditionally unpopular type of drill exercise" (p. 22), maybe because this PC concept is set in "a context like that of transporting and using chemicals" (p. 23). By relating students' responses to students' grades, she notes that the high achieving students, those who earned "A" grades (17), do appreciate all type of activities *equally* well, but "have mixed reactions to the effectiveness of learning through the Salters' approach" (p. 26). For example, one "A" student seems confused with the setting of PC content in a CTS context.

> The last lab had too much uncertainty involved. It was too inconsistent such as the differences between baking soda and club soda, but they were used for the same chemical (ibid., p. 26).

Thus, the appreciation by the average student of the use of CTS contexts for learning chemistry seems more positive than that of high achieving or above average students.

It is important to realize that, because of the research design used, students' responses might have been influenced to some extent by their expectations of what high school chemistry teaching should be about, since they had first been taught an introductory *science-first* course.

On the internal assessment of the unit TC, students performed at least as well on test items that require *understanding and application*, as they had earlier on the test of the introductory chemistry course, with "more traditional items requiring comprehension and recall" (p. 30). The items, used for the internal as well as external assessment of Salters' units such as TC, emphasize "the same higher order thinking skills that form the course" (p.13; p. 35).

The cooperating teacher's perception of the effect of the Salters' Science approach to teaching, using the unit Transporting Chemicals, on students motivation and learning, is on the whole favorable:

> I think most of the kids got a better understanding of *what* they were studying and *why* they were studying it. Kids could relate to some of the products and were really wondering – real inquisitive as to why they put sodium carbonate in Calgon or why this other chemical was in something else. They were genuinely interested in what was going on. *It (the chemical) has to serve a function* (ibid., p. 19).

However, the teacher expressed as a serious concern about whether the unit TC contained enough:

> *Hard college prep type chemistry* [such as] the gas laws ... grams to moles and these kinds of things – formula writing, equation writing, predicting products (ibid., p. 18),

Thus, the teacher is here referring to what I called PC content, preparatory school chemistry which he apparently thought appropriate for high achieving, science prone students.

Discussion

In her study, Borgford (1992) describes the Salters' design criterion two, *relevance*, as follows:

> Perhaps the most significant aspect of the Salters' approach [is] the introduction of basic chemical ideas through *situations in the everyday world* that are of interest to young people" (ibid., p. 9).

She also gives a formulation of design criterion three, *context-led development of concepts*:

> The Salters' approach departs from the traditional, then in two ways: Ideas are introduced in *any sequence* as they clarify chemical phenomena from everyday life and ideas that are *not needed are not introduced, even if they normally are part of a traditional sequence* (ibid., p. 9).

Both formulations imply, what I called (sections 4.1.3 & 5.1.3), a *strong* interpretation of these two central Salters' design criteria. For Borgford in her studies into the use and perceptions of the Salters' Science courses, design criteria two and three (above), together with design criteria four and five: *variety of teaching and learning activity* and *flexibility*, characterize the Salters' approach to science teaching.[58]

The perceptions of students and teacher, and her own classroom observations led Borgford to a conclusion remarkably similar (she notes) to the one she reached in her previous study that involved a number of schools in England in the consequences of adopting the Salters' Science course on science departments of schools, teachers, and their students.

> It seems clear from this and previous research that *general* student motivation *and achievement* is *enhanced* by the variety of activities and the general approach represented by such programs as Salters' for the *"average" or non-science-oriented students* (ibid., p. 28).

Using Roberts' (1988) concept of curriculum emphases, Borgford characterizes the Salters' Science approach as follows:

---

[58] Borgford's interview with Francesca Garforth and David Waddington (G/W91) also mentions what I have called the first design criterion, *no preconceptions*, as referred to in Chapter 4.

> *A unique hybrid* of Everyday Coping, Solid Foundation, Science Skill Development, and Science, Technology, and Decisions (ibid., p. 28).

In other words, it was unique in the sense that it was a mix of an *applications-first* approach with the curriculum emphases Everyday Coping & Science, Technology, and Decisions, initially the main emphases of the course, and of a *science-first* approach with the curriculum emphases Solid Foundation and Science Skill Development, which became more prominent later. In Borgford's view, it is the use of chemical applications which leads to: "*fundamental* understanding which lays the *foundation* for further treatment in another *context* later on in the course" (ibid., p. 32).

The "unique hybrid" of the Salters' Science curriculum is, I think, to a large extent the result of the fact that the Salters' Science courses had to meet, more and more, the constraints set first by the GCSE exam, and later on by the successive versions of the National Curriculum (UK).

The GCSE exam brought in the emphasis on Solid Foundation as did the National Curriculum, the latter adding more emphasis on Science Skill Development as well. The latter development led to the so-called "investigative approach" demanding about 30% curriculum time.

It is to be noted that Borgford does not mention in her study on the unit Transporting Chemicals, any examples of an important consequence of the adjustment to external constraints of the Salters' Science course, that is, the introduction of more pure chemical concepts in Salters' Science units than *needed* to make sense of the contextual theme, which I found in the case of the unit Metals (see sections 5.2 and 5.3). In other words, she does not perceive a tension between the CTS contexts used and the PC concepts developed in TC or other Salters' Science units.

> Even with such broad treatment of science and its effects, *student understanding of traditional academic science ideas is a primary goal of the Salters' course.* It could be interpreted that such a course can serve the needs *both* of science education for the citizen and science education for the future scientist, in other words – Science for All (ibid., p. 36)

I see here a change in Borgford's characterization of the unit Transporting Chemicals, taken as an example of a Salters' Science unit. Initially, the unit Transporting Chemicals is characterized by her as an *applications-first* Salters' Science course unit, in which:

> Ideas that are *not needed* are *not introduced*, even if they normally are part of a *traditional sequence"* (p. 9).

Later on, the Salters' Science course is characterized, as we saw, as a mix of an *applications-first and a science-first* course, in which:

> Some would not *immediately* recognize the traditional science subject matter goals" (p. 36).

In Chapter 6, I will come back to this point in connection with some recent views of UYSEG developers on context-based approaches to the teaching of science (Bennett & Holman, 2002 and Millar, 2002).

Ramsden's studies

Finally, I will discuss the results of three studies performed by Ramsden (1992, 1994, 1997), in so far as they are relevant for my research into the experienced curriculum of Metals (1989).

Ramsden's study of 1992

The first study (Ramsden, 1992) concerns "*pupils' reactions* to context- and activity-based science" (ibid., p. 65), as offered by the Salters' Science Foundation full course trial units (1989). The study uses a sample of 124 pupils (59 female [F], 65 male [M]), that is, large enough to determine statistical significant differences in mean responses to the questionnaire (described below). It concerns a population similar to my qualitative research study (5.1-5.3), namely Year 9 pupils (aged 13 – 14, mixed ability, both sexes) being taught similar units in 1989-1990. Therefore, it seems appropriate to compare Ramsden's conclusions with the ones I have reached for the small sample (16) of pupils learning Metals (1992), as summarized above (5.4.1).

Science teachers from six schools, who had used at least eight Salters' Science Foundation units (including the unit Metals) without major alterations, were asked by Ramsden to administer to their students at the end of the school year, a questionnaire consisting of two parts. The first part listed six statements to which students were invited to respond on a five point scale (5: strongly agree; 1: strongly disagree). This generated 800 responses (356 [F], 444 [M]) which were processed statistically, in order to make comparisons *within* the sample in terms of mean responses to each of the statements below, differentiated for girls and boys.

1. I enjoyed this unit.
2. I enjoyed the practical work in this topic.
3. I enjoyed the non-practical work in this topic.
4. I felt the ideas in this unit helped me to understand more about some everyday events and problems.
5. I felt some of the things I learned in this unit would be useful in later life.
6. I felt this unit made me more interested in science (Ramsden, 1992, p. 67).

The second part of the questionnaire invited pupils to elaborate briefly and freely on their responses to these six statements. This generated 122 responses, this time qualitative data, placed by Ramsden into four broad groups: practical activities (50), non-practical activities (10), everyday future relevance (69), and other comments of interest (6).

She arrives at the following conclusions. The first conclusion, with regard to a possible differentiation for girls and boys, is that science appears to appeal equally well to girls and boys as a result of their experience with the Salters' Science Foundation units, though practical activities were "enjoyed significantly more than non-practical activities" by boys (ibid., p. 69).

Secondly, by far the largest number of students (69) commented positively on the "present and future usefulness" (p. 70) of what they had learned in the units. One student (M) really appreciated: "Finding out about things you need to know in our modern world to be able to be a better citizen" (p. 70), while another student (F) remarked: "I like finding out what goes on in everyday world" (p. 70). In my case study on Metals (1989), I was able to specify students' appreciation of "usefulness" by giving some concrete contexts students found relevant and useful, such as knowledge about corrosion, and rusting and its prevention (see also De Gier, 1992).

Thirdly, Ramsden (1992) reports that "one particularly noticeable feature of the responses made was the marked difference" (p. 69) in mean values for overall enjoyment of the units and increased interest in science. More specifically, "pupils' enjoyment of a unit did not necessarily correlate with a corresponding increased interest in science" (p. 69). It might be the case, she remarks, that "there is a mismatch in pupils' minds between the activities they were carrying out and their perception of what was appropriate for science lessons" (pp. 70, 71). Ramsden then draws the conclusion, albeit tentatively, that:

> Pupils appear to enjoy this type of approach but do not feel it constitutes 'science' (p. 71).

In other words, "If it's enjoyable, is it science?" (p. 65), as the title of her paper reads. This is, I think, a very interesting hypothesis[59] with which Ramsden can account for pupils responses:

> The things we did were *not* just what *scientists* need to know, they *help* in later life (p. 70).
> [The activities were] *not* just like *science* – they are *enjoyable and useful* for us (p. 70).

The hypothesis also seems to explain her second conclusion about students' high appreciation of the everyday future relevance of the course, and might even explain the first conclusion on the equal enjoyment of the course by girls and boys. As concluded above (5.4.1), students perceive and experience that, in particular, the CTS contexts and activities (such as the CTS contexts in the unit Metals, 1992) are "enjoyable and useful" for them, and they perceive and experience that they are able to use the acquired relevant chemical concepts in similar everyday life situations.

Ramsden's Study of 1994

The main purpose of the second study (Ramsden, 1994, p. 9) is to explore:

> "... teachers' perceptions of some of the effects of the Salters' Science GCSE course on their 15 and 16 year old pupils by interviewing teachers involved with the teaching of the course in their schools."

Ramsden used "semi-structured in-depth interviews" (ibid., p. 9) with eleven teachers at six *project* schools involved in the trial of the Salters' Science exam course, "providing systematic feedback on the materials as they used them" (p. 9). The basis of the interview, preceded by some questions about teachers' backgrounds, was formed by six general questions (Q7 – Q12) on students' responses to the course. The intent was to probe "initial answers more deeply with specific follow-up questions on particular activities mentioned by the teachers".

Q7 In general, which aspects of the course do you feel students particularly enjoy, and why?
Q8 In general, which aspects of the course do you feel students are not particularly happy with, and why?
Q9 What changes, if any, have you noticed in terms of students' involvement of lessons?
Q10 What changes, if any, have you noticed in terms of students' general attitude to science?
Q11 What changes, if any, have you noticed in terms of students' learning?
Q12 In your view, what has been the most noticeable effect on your students of adopting Salters' Science?

With regard to Question 7, there was a "consensus of opinion about the *motivating* effects of the use of everyday starting points and applications" (p. 10), which is supported by the results of Ramsden (1992) on students' high appreciation of the everyday future relevance of the course. Secondly, "the study also offers some support in very broad

---

[59] See also Aikenhead (1994, p. 178) who calls this "an intriguing result".

terms for the *motivating* effects of the use of a wide *variety* of learning strategies in science lessons" (p. 14). With regard to Question 8, teachers' comments were mainly on "the practical aspects of problems associated with a heavily *worksheet-based* course" (p. 12). With regard to Questions 9 and 10, four teachers perceived a specific improvement in pupils' involvement. For example:

> They are in general much more enthusiastic about the subject. It's not difficult to persuade them to opt for science (...). I suddenly thought for the last two years, no one has said to me, '*Why are we doing that, sir?*' – and that happened quite a lot in the past. (Teacher L, School 5)

The majority of teachers, though, said that "they felt it was actually very difficult to make very definite comparisons and judgements" (p. 12). With regard to Questions 11 and 12, teachers experienced a similar problem. Although specifically asked to name any activities "which they felt made a particular piece of science *easier or more difficult for pupils to understand*" (p. 12):

> None of the teachers was able, at this point, to give *an example of an activity* which they felt had either contributed to an improvement in pupils' *understanding* of a particular topic or enabled students to *use* their scientific knowledge to inform discussions on issues of concern. (Ramsden, 1994, p. 12)

This is not only the case, Ramsden notes, for teachers who are relatively new to the materials, but also most striking for the Heads of Science (4) who were responsible for the introduction of Salters' courses in their schools, and for the teachers (3) who had used Salters' Chemistry prior to Salters' Science. What she concludes from the data, is, that: "*the general classroom atmosphere* is of paramount importance to teachers" (p. 13). More particularly, that:

> "... the teachers carry with them an in-built assumption that a classroom atmosphere with 'a real buzz in it', where pupils appear to be engaging readily and with interest in the tasks set, enhances learning and improves pupils' more general views of the subject (p. 13).

My case study on Metals (1989) showed that students in the classroom are "engaging readily and with interest" in the CTS contexts and activities of the lessons of the unit Metals such as the ones on rusting, and corrosion and its prevention. They were able to use or apply the acquired relevant chemical knowledge in similar assignments. These findings, as may be expected from a case study, add some interesting detail to the general conclusion above.

Ramsden's study of 1997

Many teachers take a sympathetic view to the Salters' Science approach, where "scientific concepts are encountered on a *'need-to-know'* basis, as they arise in particular contexts" (Ramsden 1997, p. 697). Some of them, though, such as the American teacher quoted above in Borgford's study, are rather concerned about how well a context-based science course prepares their (more able) students for external examinations (see also section 5.4.3).

Unlike traditional, linear courses where ideas "are generally treated *in depth* as they are encountered" (ibid., p. 698), for context-based courses "it would be difficult to cover all aspects of these ideas in this single context, and they would need to be *revisited* at other points and *in more depth* for understanding to develop further" (p. 698).

In order to investigate the effectiveness of this so-called "'drip-feed' approach to concept development" (p. 698), Ramsden performs a comparative study in which she analyzes the differential effects of the context-based Salters' Science course and conceptually structured traditional GCSE courses on pupils' understanding of pure chemical concepts. In the quantitative part of this study she administers first a set of structured diagnostic questions on four key chemical ideas to a *matched* sample of 84 (2 x 42) students, that is, a sample from each group with a similar "distribution of predicted grades" (p. 702) to enable statistical comparison. With regard to the key chemical ideas, Ramsden states that:

> The four key chemical ideas form part of the *majority* of high school chemistry courses and are *central* to a pupil's understanding of chemistry at 16+. They are also ideas which are necessary for embarking on *further* study." (p. 698).

The diagnostic test consisted of ten questions: two questions per key chemical idea except for the key idea Periodic Table which had four questions. The key chemical ideas were:

- *elements, compounds and mixtures*: microscopic representations of matter (Q1); properties of matter (Q7)
- *conservation of mass in chemical reactions*: precipitation (Q2); as a means of predicting reacting quantities (Q6)
- *chemical change*: formation of new substances in a chemical reaction (Q4, Q5)
- *Periodic Table*: trends down a group (Q3); similarities within a group; as a means of predicting properties of compounds, as a means of predicting formulae (Q8, Q9, and Q12)

The students probed were of upper or middle ability, likely to go on to take A-level, as judged by their predicted GCSE grades, and were drawn from four schools following the Salters' GCSE course and four schools following traditional GCSE courses. The test was given to these 15–16 year old pupils about a month before their GCSE exam. They had about one lesson (40-50 minutes) to complete the test, which they were invited to consider as a kind of revision. Pupils were asked to give short answers to the questions and also to provide an *explanation* for each answer. Pupils' responses were marked (two points maximum per question) and processed statistically.

Ramsden's general finding is (p. 705):

> The average mark for all Salters' pupils completing the questionnaire was 9.22, compared with 9.48 for non-Salters' pupils. [adding that] ... this difference was statistically insignificant.

This is good news, she remarks, since it shows that Salters' pupils do not perform significantly different from non-Salters' pupils with regard to these PC concepts. There is also bad news mixed in, Ramsden notes, since the analysis of the responses also shows that *all* pupils, whether Salters' or non-Salters', have a poor grasp of some key ideas of chemistry, as reflected in their average mark which is about half the maximum mark. The following key chemical ideas appear to be understood by *under* 25 % of the pupils:

- conservation of mass in precipitation reactions, and as a means of predicting reacting quantities;
- the periodic table as a means of predicting properties of compounds, and as a means of predicting formulae; and
- key chemical ideas which appear to be understood by between 25 and 50 % of

pupils are aspects of chemical change and trends down a group of elements in the Periodic Table.

In the second, qualitative part of this study the pupils of the full sample (216) were asked to mention aspects of their chemistry course which they enjoyed, what courses they intended to follow after their GCSE exams, and to give their reasons for making the latter choices.

In general pupils liked the practical work, and disliked "writing ... calculations, formulae, balancing equations, and 'all that stuff on moles'" (p. 709). Only about 10 % of the Salters' pupils (12 out of 124) explicitly commented on the *relevance* of the chemistry course to their lives, while *none* of the non-Salters' pupils made any such remarks, thus revealing "the one very noticeable difference" (p. 709) in the effect of Salters' and non-Salters' courses on pupils.

Salters' pupils said they appreciated the "real life things ... or things outside school" (p.709), that is, the "relevance to their lives of what they had studied." (p. 710). As one pupil put it:

> I have enjoyed finding out about things which will be *useful* in future. Because it's *interesting* I still try to do it even if it is hard (Ramsden, 1997, p. 709).

Finally, about 15 % of the upper and middle ability students mentioned that they hoped to go on to study A-level chemistry. Just over 80 % said they were not choosing science subjects "because they were not needed for their career plans" (p. 709) in the field of business, accountancy, media studies, and arts subjects.

In conclusion, a majority of upper and middle ability students of the sample of students investigated, experienced conceptual difficulties with about half of the key chemical ideas central to high school chemistry, irrespective of whether they followed a Salters' or a non-Salters' science exam course. A minority of the full sample of students said they would go on to study A-level chemistry, while a small minority, only *Salters'* students, said that they were motivated by the *relevant* emphasis of the Salters' Science exam course.

If these conclusions apply to the more able students, what about the less able students? I cannot help remembering here what Francesca Garforth said, having found out how many conceptual difficulties her O-level students in the seventies still had.

> If the able ones are suffering, the less able ones were probably suffering more (G92b).

5.4.5 Discussion

Having discussed my own findings on the experienced curriculum of Metals (1992) and reviewed the findings of some other relevant studies with regard to the experienced curriculum of Salters' Science/Chemistry, I come back to the questions put forward in the introduction of this section. Are students motivated by the kind of contexts and activities provided by the interpreted and taught curriculum? Do they acquire, apply and use the intended content of the unit Metals (1992), as entailed by these contexts and activities, and as interpreted by the teacher?

Inspection of Figure 5.17 below shows that all studies indicate an overall *positive* *effect* of the context- and activity-based Salters' Science course on students' motivation, with only Ramsden (1997) reporting a relatively small effect. The enhancement of students' motivation has been attributed by Ramsden (1992) to an improvement of the general classroom atmosphere. In the classroom-based case study, reported on in this chapter, I found some *specific* CTS contexts motivating and enabling students to learn some relevant and useful concepts, that is, to acquire some CTS concepts and transfer them to similar CTS contexts (local transfer). Because these selected contexts originate from everyday life, they are perceived by students as worthwhile or meaningful. Students are therefore clearly focused on the activities that explore these relevant contexts from which chemical-societal concepts such as corrosion are developed, and which are needed in order to make sense of those contexts. Students work on these activities, individually or in groups, showing improved practical skills in the process.

Secondly, many of the difficulties pupils have in understanding PC concepts, as found in the case study on Metals (1992), are also found in other studies, especially in the comparative study of Ramsden (1997). The exception here is Borgford (1992) who does not report any learning difficulties.

Thus, pupils have difficulty understanding chemical concepts such as oxidation, reactivity series, alloy/mixture, formulae, chemical reaction/change (see also section 5.3.4). These are all *pure* chemistry concepts, and as such, part of the currently dominant school chemistry curriculum as described in Chapter 2. This is a kind of school chemistry particularly relevant for future chemistry students, usually a minority of the population of the pupils following science or chemistry lessons, and referred to as "hard core college prep chemistry" by the American teacher in Borgford's study.

None of the studies reviewed mention *specific* examples of PC concepts which are introduced but which are not really needed to make sense of CTS contexts, such as the chemical concepts I found in my case study on Metals (1989, 1992), like oxidation, reactivity series, compound, and formulae. Deliberately *not* introducing such PC concepts would be consistent with design criterion two, *relevance,* and design criterion three, *context-led development of concepts,* and could lessen or perhaps avoid a number of the conceptual difficulties of pupils mentioned above. Finally, the Salters' Science course appears to benefit mostly the more able or high-achieving 14-16 year old students, just as a traditional science course would do. On the other hand, the less able or average 13-14 year old students are relatively more motivated by, and derive greater enjoyment from, the Salters' Science course, perhaps because the course communicates to them a non-traditional emphasis in terms of the usefulness of science and its relationship to real life.

This brings us back to the relationship between the quality of the provided curriculum, as characterized in this chapter (sections 5.1-5.3) on the basis of my research, and the quality of the Salters' Science curriculum as experienced by students, based on other research (section 5.4). Thus, with regard to the enhancement of the motivation of the average student, the formal curriculum of Salters' Science, as exemplified and taught by the chemical unit Metals (1992), appears to be largely realized. As for the average student's conceptual understanding, this is largely achieved for a number of CTS concepts such as corrosion and rust and its prevention, but rather weakly for many PC concepts introduced in the unit Metals (1992).

This seems a remarkable conclusion, given that the analysis above has shown that the unit Metals (1989) is not developed (5.2), interpreted (5.3.1), or taught (5.3.2.) fully in accordance with design criterion two, *relevance*, and design criterion three, *context-led*

Figure 5.17 Summary findings experienced curriculum *

STUDY PROBE	GENERAL MOTIVATION BY CONTEXT	SPECIFICALLY MOTIVATED BY CTS CONTEXTS	LEARN, ACQUIRE AND TRANSFER CTS CONCEPTS	LEARN PC CONCEPTS	POST GCSE STUDY CHOICE OF STUDENTS
Van Berkel: Questionnaire sample of 12 students (section 5.4.1)	Eight students	Yes, relevant contexts are effective	Yes, but only with familiar situations	—	Science (7) Not science (5)
Van Berkel: Classroom observation (section 5.4.2)	Yes, on the whole	Yes, relevant contexts	Yes, e.g. corrodibility order	Some difficulties and confusion	—
Evaluation of ca. 200 schools (section 5.4.3)	Yes, enjoyable	Yes, by useful contexts	—	At least basic concepts	—
Nicolson (1991): Comparative study schools (76 out of 207)	Increasing numbers of entries	—	—	—	Choice students for A-level increases 30%
De Gier (1992): Questionnaire (22 pupils)	Yes, enjoyable; impact on daily life	Yes, relevant	—	Some difficulties and confusion	—
Borgford (1992): Case study (100 students)	By CTS contexts, labs, and activities with *function*	Yes, role play transport and labs	—	Concern of teacher; yes, general achievement	—
Ramsden (1992): Questionnaire/ statistical study (124 pupils)	Yes, on the whole equally for girls and boys	Boys more than girls by practicals; usefulness	—	no correlation enjoyment with interest	—
Ramsden (1994): Case study: 11 teachers on their pupils (15 – 16)	Yes, consensus, general classroom atmosphere	Variety, maybe; no specifics	No specifics	No specifics	—
Ramsden (1997): Comparative study (84 able students)	—	About 10% of students	Not probed	Considerable conceptual difficulties	15% chose chemistry

* The symbol (–) indicates that this topic is not probed in this study.

development of concepts. Thus, in view of the relatively low CTS/PC ratio provided by the teacher, it is surprising the extent to which the new characteristics of the Salters' Science foundation unit Metals comes across in students' motivation and learning. It is also interesting that the new CTS emphasis of the curriculum seems to appeal to students regardless of the label put on the curriculum unit used: chemistry, science, or maybe even engineering. In brief, students perceive the CTS content of Metals (1992) as "worthy of study", that is, as motivating and meaningful to learn. At this point Ramsden' s query: "If it's enjoyable, is it science?" again comes to mind.

Apparently, students are able to perceive and experience that they have been offered *something* different from what they would have expected from previous school experience, their expectations perhaps being based on science lessons in the first two years or on an image of science communicated to them at home or by the media. That they enjoyed, found useful, and became interested in the units of the Salters' Science Foundation course such as Metals could mean that *what* they actually enjoyed is indeed different from a traditional or normal science course. Perhaps these pupils did experience to a certain extent an *alternative* science course developed, interpreted, and taught with an emphasis on everyday life, and technological and societal aspects of science as much as on purely scientific aspects,

In view of this, increasing the CTS/PC ratio of the developed, interpreted and taught Salters' Science units such as Metals (1989), in accordance with design criterion two, *relevance*, and consistent with design criterion three, *context-led development of concepts*, is likely to increase pupils enjoyment, motivation, and understanding even more. In Aikenhead's terms (5.1.4), this would mean providing pupils with a SCIENCE ALONG WITH STS CONTENT course rather than with a SCIENCE THROUGH STS CONTENT course.

5.5 Conclusions

In this section, I summarize the findings of the consistency analysis of the Salters' Science unit Metals (1989; 1992), point to *relationships* among these curriculum findings, and to the findings of the curriculum analysis performed on the Salters' Chemistry course in the previous, complementary, chapter (5.5.1). Subsequently, the curriculum findings of Chapters 4 and 5 are discussed and explained in terms of my theoretical curriculum framework (5.5.2).

5.5.1 Analysis of unit Metals and Salters' Chemistry

First, I will summarize the findings of the analysis of the formal curriculum of the *chemical* component of the Salters' Science Foundation course as exemplified by the unit Metals (1989), that is, the findings of the analysis of its operationalization in the lessons of the unit by the developers (section 5.2), its realization in the classroom by the teacher (section 5.3), and in the learning by the pupils (section 5.4). The distinctive curriculum levels – the visionary, written, formal, interpreted, taught, and experienced levels – have enabled me to categorize the curriculum findings in terms of these curriculum levels, and will enable me here to point to relationships among the different curriculum levels, and to explain these curriculum findings and relationships in terms of my theoretical curriculum framework.

Formal and written curriculum

The consistency analysis of the central design criteria two and three, *relevance* and *context-led development of concepts*, of the Salters' Science approach, performed at the level of the *lessons* of the unit Metals (1989), shows that more PC content and less CTS content has been developed than is consistent with these two central design criteria. Thus, the CTS/PC ratio of the *written* curriculum of the unit Metals (1989) at the level of the lessons of the unit is substantially smaller than the CTS/PC ratio of the formal curriculum. See for the latter the content analysis of the *unit as a whole* on the basis of the overview of the unit and the key teaching points of the lesson plan of Metals (1989) as given by the developers (Figures 5.6 and 5.7). As a consequence, a *tension* surfaces in a number of lessons of the unit Metals (1989) between overdeveloped PC content and underdeveloped CTS content.

Written, interpreted and taught curriculum

Secondly, the analysis in section 5.3 showed that the teacher deleted some CTS contexts and added some PC concepts, choices inconsistent with design criteria two and three, *relevance* and *context-led development of concepts* (Figures 5.15 and 5.16). Hence, compared to the *written* curriculum of the unit, the CTS/PC ratio has decreased substantially further, both for the *interpreted* curriculum and for the *taught* curriculum of Metals (1992). Consequently, in the process of teaching Metals (1992), at least in some lessons of the written unit, the tension between overdeveloped PC content and underdeveloped CTS content increases (as mentioned above) to become somewhat larger.

The way Metals (1989) was adapted by teachers and interpreted for the supported self-study approach ('Circus') is a good example of putting into action design criterion five, *flexibility*. It shows that the formal curriculum (Metals, 1989) leaves room for a *science as process* interpretation which leads to a different realization of the Salters' Science curriculum in the classroom. The teaching of Metals (1992), within the constraints set by the National Curriculum, also shows some problems in the teaching-learning process with the implementation of design criterion four, *variety of teaching and learning activities*, in that some CTS contexts are deleted, and some PC concepts are added. Further, the emphasis on teaching *routinely* trained scientific skills leads to a diminishing *variety* of teaching activities and a corresponding decrease in student activity, which could be connected with the decreasing CTS/PC ratio.

Taught and learned curriculum

Students appear to appreciate the CTS content offered to them in the taught curriculum (Metals, 1992), apparently more than they would have expected from their previous school experience with science curricula. They perceive in the classroom teaching, as it were, a higher CTS/PC ratio than they would have expected, and they achieve better learning results with the CTS contexts and activities than with the PC concepts. Ramsden (1992) first noted the remarkable *discrepancy* between students' perception of the taught curriculum of Salters' Science in terms of enjoyment and usefulness, and their expectation of a traditional school science curriculum, usually perceived as abstract and irrelevant, while lacking the former qualities.

Visionary, written, interpreted, taught and learned curriculum

It can be seen that Figure 4.4 shows that the CTS/PC ratio is steadily decreasing for the different operationalizations of the visionary curriculum of the Salters' Chemistry course as a whole. In Figure 5.5 the CTS/PC ratio is steadily decreasing for the different curriculum levels of the unit Metals (1987). The latter unit became part of the Salters' Science course as Metals (1989), was interpreted by teachers as Metals (1992), and was subsequently interpreted and taught by a teacher, and experienced and learned by students in the classroom.

As explained in section 5.1.4, this decrease in the CTS/PC ratio can be taken as a measure of the *degree of escape* of the visionary curriculum of Salters' Chemistry from NCE, as embodied by the O-level school chemistry curriculum in England in the 1980s, when it is realized by developers in the designer's room and teachers in the classroom. It shows how the differences between dominant school chemistry and Salters' Chemistry at the level of the visionary curriculum gradually diminish at the consecutive curriculum levels: formal, visionary/written, taught, and experienced levels.

5.5.2 Curriculum findings and relationships

Visionary and written curriculum

The findings summarized above raise the following question: Why have the developers of Metals (1989) not been able to adhere more consistently to the central design criteria of the Salters' approach, *relevance* and *context-led development of concepts*? As argued above, they have increasingly been held back by external constraints, and were probably also influenced by an internal constraint, which derives, as the developers say, from "the structure of school chemistry as we all perceive it" (L92). A specific description of this internal constraint, called *dominant school chemistry,* has been given in Chapter 2, which as I argued there, is a form of Normal Science Education. The external constraints operative on the developers stem mostly from the different versions of the National Curriculum (1989, 1992).

Written and taught curriculum

The findings summarized above raise also another question, namely, why has the teacher of Metals (1992) not been able to adhere more consistently to the central design criteria of the Salters' approach, *relevance* and *context-led development of concepts*? Teachers have, of course, a strong obligation to teach the chemical content required by the syllabus, whether it is taught by way of a traditional textbook or by way of innovative CTS units such as Metals (1989). Teachers often consider as their overriding aim the preparation of their students for tests and examinations which in England must follow, up to Year Eleven (16 year olds), the requirements of the National Curriculum. Thus, bound by these external constraints and, as I argued, also by an internal constraint, teachers can be led to introduce more PC content and less CTS content than consistent with the central design criteria. Both Salters' developers and teachers had to work within the same set of external and internal constraints, but for teachers the pressure to comply with them is greater. After all, teachers are much more directly involved in, and responsible for, a proper preparation of their students for examinations and the stress on PC content and skills that this implies.

Furthermore, teachers may find themselves constrained by the course units they use in their teaching, which for them might contain unexpected tensions between curriculum emphases. The point is, that the interpreted and taught curricula are partly a function of the *written* curriculum. That is, teachers have to interpret and teach the written units *including* any tensions, intended or not, built into their design, in this case the tension between CTS content and PC content.

It appears difficult for a Salters' teacher to deal with this tension between PC content and CTS content. Having chosen to trial or teach units of the Salters' Science course, a Salters' teacher will probably not expect this tension. Because the first design criterion, *no preconceptions*, is not explicitly stated in the units, it will be very difficult for a teacher to be conscious of the role that the preconceptions of developers might have played in the design process or to stay alert to the role the teacher's own preconceptions play in the interpretation and teaching of the written unit to his or her students. Thus, the effects of the tension between CTS content and PC content built into a unit such as Metals (1989) will be felt by the teacher, if at all, only during the actual teaching of the lessons of the unit.

The internal constraint, that is, "the structure of school chemistry as we all perceive it" (L92) can pull teachers away from the new CTS emphasis of the course. This can happen implicitly as in the case of the teacher described above (5.3.3), or sometimes explicitly, as in the case of the science course called the 'Circus' (5.3.2), where teachers gave explicit emphasis to scientific processes, and also added some PC content.

Finally, the actual teaching had to conform increasingly, from 1989 onwards, to the demanding external constraints of the National Curriculum, which gave much more emphasis to PC content than to CTS content. Thus, a teacher's preference for an STS curriculum must be very strong indeed to go against the external *push* of the requirements of the National Curriculum, the *pull* of teacher's own internal constraints, and the *tension* in the composition of the unit as designed by the Salters' developers.

Taught and learned curriculum

Although offered to them with a relatively low CTS/PC content, students (13-14 year olds) are able to perceive the new CTS emphasis of Foundation units such as Metals (1989), and to some extent, too, the tension between this new CTS emphasis and the traditional PC emphasis.

Their perception of this tension could be paraphrased for school science as follows: 'If this is science, then we want it, since it is relevant and useful for us.' However, when students later follow the Salters' Science GCSE exam course and approach their examination, their perception might change as a result of having to study relatively more PS content, while the STS content they favored comes to play a minor role. The examined curriculum, represented by examination papers, might differ from the Salters' Science curriculum as perceived or experienced by pupils in their first encounter of Salters' Science in the transitional Year Three (Nine). Indeed, it will probably be closer to the initial expectation students had of traditional school science.

Visionary, written, taught and learned curriculum

Regarding the written curriculum, the lessons of the unit Metals (1989) treat more PC content than needed for the CTS theme *corrosion*, and seem thereby to address the needs of potential chemists more than the needs of actual citizens. The unit Metals, taken as representative of the Salters' approach, has a dual emphasis, both in content and aim, which as we saw above is not removed during teaching. The greater emphasis put on PC content [Sub], which goes to some extent against the central Salters' design criteria, is related to the greater emphasis on preparing future science students, and future scientists [Ped/A], which is in line with the overall emphasis of the National Curriculum.

As argued in Chapter 2, the currently dominant school chemistry curriculum has to be taken as a rigid combination of a specific substantive structure based on corpuscular theory, a specific philosophical structure called educational positivism, and a specific pedagogical structure involving initiatory and preparatory training of future chemists. This applies not only to the levels of the designed, written, and formal curricula, but also to the level of the visionary, interpreted and taught curricula. The rigid relationship between the substantive structure [Sub], philosophical structure [Phil], and the pedagogical structure [Ped] of school chemistry manifests itself here *at the level of the taught curriculum*, that is, in the teaching approach used [Ped/TA] by deleting some CTS contexts and adding some PC concepts. It also reduces to some extent the variety of teaching methods and activities of students [Ped], and it changes thereby the original STS-oriented substantive and philosophical structures.[60]

Thus, the tension between PC content and CTS content appears related to, and probably stems from, the dual aim of the Salters' Science course, which is to prepare students for future study in chemistry *and* to make chemistry accessible and relevant to all students, the sum of whom are viewed as future citizens.

It is important to realize that these curricular findings must be attributed to three main causes:

- A *compositional* constraint set by the written units, in this case, a dual emphasis both in content and aim, from which emerges a tension between PC content and CTS context;
- An *internal* constraint of teachers, that is, the preconceptions of teachers with regard to school chemistry as internalized through education, training, and previous teaching practice;
- The *external* constraints of the educational system, here the National Curriculum of England and Wales as operative on teachers during the period in question.

Together these constraints make it very hard for teachers to choose and adhere consistently to a preferred, strong interpretation of the central design criteria of the Salters' approach, certainly when internal and external constraints pull them in the opposite direction.

Developers are caught up in constraints, too. Not only did the developers described in this research have to work under increasingly stricter external constraints in England in the 1990s, they were also influenced by an internal constraint. The latter, the conceptual structure of school chemistry as most of them perceived it, exercises an important but largely implicit influence on developers. The consistency analysis of the unit Metals

60 Generally speaking teachers operate, in these cases, under a rigid combination of specific substantive, philosophical and pedagogical structures. If compared with the concept of pedagogical content knowledge (PCK) as developed by Shulman (1986,1987), one could speak of a combination of pedagogical, philosophical, and substantive knowledge, or more in line with PCK of rigid *pedagogical, philosophical content knowledge* or PPCK. Interestingly, in developing the PCK concept Shulman builds on the work of Schwab (1978).

(1989) in section 5.2 has made this clearly visible. (See also the comparison of the content of the successive units of Metals (1984, 1987, 1989) in relation to the strength of the external constraints as given in Figure 5.14.) Thus, the rigid relationship between the substantive structure [Sub], philosophical structure [Phil], and the pedagogical structure [Ped] of school chemistry manifests itself here at the level of the *designed, written, and formal* curricula, as we have seen in Figures 4.3, 4.7 and 5.7.

Obviously, developers *must* 'match' their visionary or ideal curriculum to the realities of educational practice, but to some extent they end up matching their vision *internally* to the current structure of school chemistry, not withstanding their explicit intention and sincere attempts to get rid of preconceptions with regard to what school chemistry should provide traditionally. We are now in a better position to understand what *matching* a vision or ideal to the realities of educational practice entails for developers and teachers, formulated in terms of the *external, internal, and compositional* constraints.

First of all, it is obvious that both developers and teachers have to 'match' their ideal to the constraints operative in a particular education system, if and when they want to realize and implement the units, produced as visionary/written forms and trialled on a larger scale, and gain the whole acceptance as a national examination course.

Secondly, and less obvious, developers as well as teachers appear to match the envisioned and written curriculum, in their *practice* of developing and/or their *practice* of teaching, to an internal constraint, which I have described (Chapter 2) as *dominant school chemistry*, or the conceptual structure of chemistry as most developers or teachers perceive it.

Thirdly, for teachers working with the 'finished' products of the developmental process – the units of the course, matching also means interpreting and adapting the visionary/written teaching materials, such as the unit Metals, to the realities of their classroom and school, including any *compositional* constraints with regard to a dual emphasis on aims and tensions in the kind of content (PC or CTS) to be taught.

Fourthly, it probably takes several trials and revisions before the set of design criteria are sufficiently articulated to make it possible to claim validly that the units are developed according to the thus 'discovered' and articulated design criteria, while having collected enough classroom-based evidence to back up this claim. So, finally, for developers working with a set of design criteria – the point of which is that they must be articulated and operationalized in the process of development – matching becomes an *inherent* part of the design process.