6 Beyond current school chemistry: Perspectives on chemistry at school

In this chapter, I will summarize the answers with regard to the research questions formulated in Chapter 1 of this thesis, as listed in Figure 6.1 (reproduced from Figure 1.5). First, I summarize and discuss the answers to the first three research questions, which are related to the structure of the current school chemistry curriculum (6.1). Second, I summarize and discuss the answers to research questions five and six, which are related to attempts to escape from the structure of the current school chemistry curriculum (6.2). Third, based on my research findings, its implications, and my explanations of them, I will formulate a number of recommendations for reforming the currently dominant school chemistry curriculum, thereby answering research questions four and seven on the conditions of escape (6.3). While discussing the answers given to my research questions in previous chapters, I will point to the most important implications of the research findings, and give functional explanations of the curriculum phenomena found. Finally, I will give some suggestions for further research by looking back and reflecting on the research reported in this thesis (6.4).

Figure 6.1 Research questions

1. What is the structure of the current school chemistry curriculum?
2. Why is this structure the way it is?
3. Is this structure a desirable structure?
4. What are conditions for escape?
5. To what extent does the Salters' Chemistry curriculum escape from this structure?
6. Why is it so hard to escape from this structure?
7. How can attempts to escape from this structure be more successful?

6.1 Curriculum analysis of current school chemistry

In this first section, I summarize and discuss the answers reached in this thesis for the first three research questions (Figure 6.1) that are related to the structure of the currently dominant school chemistry curriculum. Thus, I will give the main characteristics of what I called Dominant School Chemistry (6.1.1), explain its properties and relationships in terms of Kuhn's functional theory of scientific education (6.1.2), and discuss the appropriateness of the current function of Dominant School Chemistry (6.1.3).

6.1.1 Dominant School Chemistry

We started (De Vos et al., 1991; De Vos, 1992) by answering the question: What is the hidden structure of school chemistry? The initial answer was a hypothesis on the *Coherent Conceptual Structure of School Chemistry Curriculum* (De Vos et al., 1994), which was tested in the form of *Ten Statements* (Figure 1.4) by way of a semi-structured survey of an International Forum of twenty-eight researchers and developers in chemical education, and of a Dutch Forum of twenty-two researchers and developers in chemical education (see sections 1.2.2 and 1.2.3).

The *problem of structure* was initially taken by us as a problem of the hidden *conceptual* structure as present in school chemistry curricula, and described in terms of chemical concepts and their structural relationships. In the course of the analysis of the International Forum responses, the problem was reformulated in terms of three substructures: the substantive, philosophical, and pedagogical structures of the school chemistry curriculum (see Figure 1.1). The problem thus became one of characterizing the three specific substructures composing *the currently dominant school chemistry curriculum*, and of characterizing their specific relationship.

For the sake of analysis and discussion in this Chapter, I will first give a summary of the most important characteristics found for the substantive, philosophical, and pedagogical structure of the currently dominant school chemistry curriculum. Second, I will discuss the relationships of the school chemistry curriculum as a whole. Together, this will constitute my answer to the first research question: *What is the structure of the current school chemistry curriculum?*

Substantive structure of current school chemistry

The currently dominant substantive structure of the school chemistry curriculum is not only built around, but also often starts from, corpuscular concepts. Compared to Coherent School Chemistry (see section 1.2.2), the *structural* relationships of Dominant School Chemistry are partly implicit, incomplete, and incoherent, as I have analyzed in Chapter 2 and summarized in Figure 6.2 below. It is important to note that the choice for a substantive structure of school chemistry in terms of corpuscular theory has implications for the nature, scope, and sequence of related concepts developed in the curriculum, choices which also reflect views on the philosophy and pedagogy of chemistry.

Figure 6.2 Substantive Structure of Dominant School Chemistry

Categories	Specifications based on International Forum responses
Chemical concepts	– chemical (pure) substances and their properties, elements, simple reactions – stoichiometry, balanced equation, formulae – taxonomy of substances and reactions – periodic system – atoms, valence and bonds
Chemical relations	- demarcation, mostly implicit, from: common sense, everyday life and society, technology, history/philosophy of science, physics, and research – implicit (partly incomplete) relations among chemical reaction, chemical substance, and chemical element – reaction conditions often implicit, incoherent, and partly incomplete – conditions for existence of substances are presented only as fragments – the relationship of descriptive/systematic chemistry with theoretical/physical chemistry often lacks coherence – corpuscular theory dominates: symbolic notation, balancing equations (number of atoms/charges/electrons)
Chemical techniques	– school laboratory: use of simple reactions, separation techniques

Philosophical structure of current school chemistry

The currently dominant philosophical structure of the school chemistry curriculum, based on my analysis of the IF response (section 2.2.2), consists of the following foundations of science: *scientism*, *positivism*, *reductionism*, and *predictability and control*. Figure 6.3 lists these foundations together with views on the methodology of science. Further listed foundations of chemistry: primacy of chemical theories/concepts, dominance of physics, and a corpuscular curriculum emphasis and views on the methodology of chemistry as present in Dominant School Chemistry.

Figure 6.3 Philosophical Structure of Dominant School Chemistry

CATEGORIES	SPECIFICATIONS BASED ON INTERNATIONAL FORUM RESPONSES
Foundations of science	• scientism (pure, certain, neutral) • positivism • reductionism • predictability and control
Methodology of science	• no uncertainty of conclusions: interpretation always correct, reified account, models as facts • positivism of physics
Foundations of chemistry	• primacy of chemical theories/concepts • emphasis on physical chemistry and physics • corpuscular orientation: atoms/molecules/atomic structure as basis for stoichiometry, formulae, and equations
Methodology of chemistry	• systematization of substances and reactions • description of patterns in properties of substances and reactions (periodic table)

Pedagogical structure of current school chemistry

The currently dominant pedagogical structure of the school chemistry curriculum, based on my analysis of the IF response (section 2.2.2), has as its main characteristics the teaching and learning of science as a series of propositions and algorithms, and the initiation and preparation of future chemists (see further Figure 6.4).

Figure 6.4 Pedagogical Structure of Dominant School Chemistry

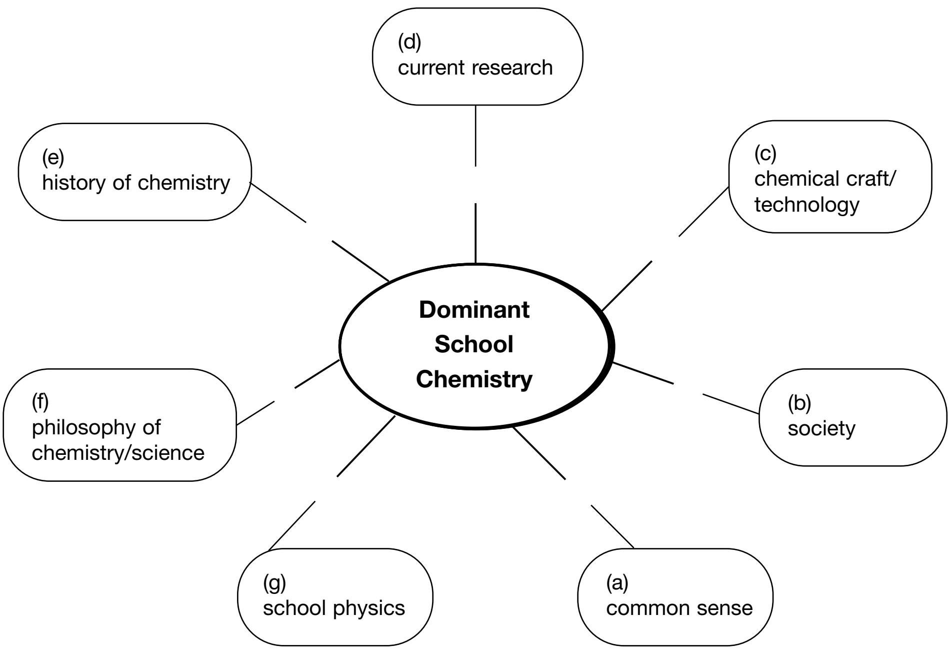
CATEGORIES	SPECIFICATIONS BASED ON INTERNATIONAL FORUM RESPONSES
Aim	• initiation and preparation for university chemistry/future chemist • learn systematization of chemical information: learn explanation/prediction of properties, formulae, valency, and bonding by applying simplified corpuscular rules
Teaching Approach	• established standard items of dogma: theoretical propositions and algorithms are conveniently reproduced within the limitations of school role play illustrating what professional chemists do
Learning Approach	• rote learning of propositions and algorithms (distinctions, facts, definitions, theories, techniques)

Curriculum structure as a whole

The specification of the separate substructures of Dominant School Chemistry leads to the question of the *relationship* between the specific substantive, philosophical, and pedagogical substructure that together were found to comprise currently dominant school chemistry curricula.

As argued in Chapter 2, Dominant School Chemistry must be taken as a *rigid* combination of a specific substantive structure based on *corpuscular theory*, a specific philosophical structure, which I called *educational positivism*, and a specific pedagogical structure involving *initiatory and preparatory training* of future chemists. This first general feature, its *rigidity*, characterizes the *internal* structure of dominant school chemistry. We also found (section 2.4.1) a second general feature of Dominant School Chemistry, namely its *isolation*, which characterizes its external relations, or rather, the lack of them, with the environment (see Figure 6.5).

Figure 6.5 Sevenfold Isolation of Dominant School Chemistry



The International Forum response to our probe (*Ten Statements*) gave credence to our idea about the resistance to reform of the currently dominant curriculum structure. As we saw in section 2.2.2, IF respondents mentioned some alternative school chemistry curricula, such as Nuffield or Salters' Chemistry, as having been proposed, trialled, and to some extent implemented. The structure of these curricula can be taken as a combination of a different conceptual or substantive structure, of certain views on teaching and learning (pedagogical structure), and of certain views on chemistry and/or science (philosophical structure). According to International Forum respondents, the alternative school chemistry courses usually have only a marginal impact on the currently dominant school chemistry curriculum. The reforms of Dominant School Chemistry appear to be neither systemic nor sustained, and the traditional structure of school chemistry is therefore largely retained, i.e., it resists reform. The so-called ‘consistency’ analysis (section 4.1.3) of the Salters’ Chemistry curriculum based on interview and document analysis and my classroom based research and subsequent consistency analysis (section 5.1.4) of the unit Metals amply confirmed this, as I have described in Chapters 4 and 5.

Whereas we recognized both variations in the pedagogical structure, such as different approaches to teaching and learning, and variations in philosophical structure, such as different views on chemistry and/or science, IF members made the valuable additional point that *variations in the substantive* structure of school chemistry have been proposed and tried as well. At least three such substantive structures have been incorporated in school chemistry curricula: one centered on substances, one centered on corpuscula, and one around chemical reactions (section 2.2.2).

We found that the *prevailing* substantive structure of school chemistry is a structure based on corpuscular theory. Thus, contrary to our initial hypothesis, *all* three substructures of school chemistry curricula must be considered as *variable.* This increases, of course, the number of curriculum structures, taken as combinations of chosen substructures, that are possible for a secondary chemistry curriculum. It appears that one of these structures, the currently dominant curriculum for school chemistry, a rigid combination of substructures, has had extensive implementation (Figures 6.1, 6.2 and 6.3). Other curriculum structures with an emphasis on processes/skills or society/technology have been given, at most, a small niche in the curriculum landscape (see section 3.2).

Schwab (1978, p. 229) poses an important prior question that should be posed before asking any question about the structures peculiar to specific disciplines which might be employed in science curricula.

> What relevance may the structure of the disciplines have for the purposes of education? Why should the curriculum maker or the teacher be concerned with the structure of the disciplines with which he or she works?

The answer to these questions will further increase the number of curriculum structures that are possible, and relevant for a secondary chemistry curriculum, taken as combinations of chosen substructures. Depending on the chosen pedagogical and philosophical structure, the substantive structure needs to undergo a fundamental change in content as well (Van Aalsvoort, 2000, p. 60).

The curriculum structure represented by our initial hypothesis on Coherent School Chemistry contains a *substantive* structure built around the chemical reaction concept (see Figure 1.3). Its most important structural feature consists of three reaction conditions which must be fulfilled in order for a chemical reaction to take place, namely (i) conservation of chemical elements; (ii) decrease of chemical or Gibbs energy, and (iii) kinetic instability (De Vos et al., 1991, 1994).

As became clear from the International Forum response, our hypothesis on Coherent School Chemistry, in particular its reaction-chemical emphases must be regarded as an *idealization* of school chemistry. In other words, our hypothesis has to be seen as a *construction* on the basis of our content analysis of a number of representative textbooks and syllabi *in the light of* our views on chemistry, philosophy of science, and pedagogy (section 1.2.2). This means that the *reaction-chemical* substantive structure contained in Coherent School Chemistry is neither realized nor probably intended in the current school chemistry curriculum.

The corpuscular substantive structure, on the other hand, is often part of the intended curriculum, but is as a rule only incompletely realized in the currently dominant school chemistry curriculum at the level of the formal, the taught, and the learned curricula.

Comments and criticisms of the members of the International Forum on the *Ten Statements* amounted to a refutation of the core statements of our initial hypothesis on Coherent School Chemistry (section 2.2.2). This led to a thorough revision in the light of these criticisms, and to a detailed description in terms of my curriculum categories of the currently dominant curriculum for school chemistry, briefly called Dominant School Chemistry.[1] The revised formulation of the central claims of the core statements taken together constitutes the central core of the currently *dominant* structure of the school chemistry curriculum (Figure 6.6).

Figure 6. 6 The Core of Dominant School Chemistry

Statement 1	All current school chemistry curricula belonging to the dominant version are being taught and learned as propositions and algorithms to students seen as future chemists.
Statement 2	All current school chemistry curricula belonging to the dominant version have a corpuscular theoretical focus on chemical substances and their properties.
Statement 3	All current school chemistry curricula belonging to the dominant version deal with the explanation and systematization of chemical information largely in terms of corpuscular theory.
Statement 8	All current school chemistry curricula belonging to the dominant version make a distinction between a level of phenomena and a level of corpuscula. The introduction of corpuscular theory in books and classroom is neither consistent nor accurate, and hence not effective.
Statement 9	All current school chemistry curricula have a dominant substantive structure, based on corpuscular theory, which is rigidly combined with a specific philosophical structure, that is, educational positivism, and a specific pedagogical structure, that is, initiatory and preparatory training of future chemists.

To sum up, the answer to the first, empirical research question, *What is the structure of the current school chemistry curriculum?*, is given by the description of the substantive, philosophical, and pedagogical structure of Dominant School Chemistry, as summarized in Figures 6.3, 6.4 and 6.5, and by the relationships of the school chemistry curriculum as a whole, summarized in Figures 6.5 and 6.6.

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1 The response of a Dutch Forum (DF) of twenty-two researchers and developers in chemical education led to a similar result (see Chapter 2, notes 3 and 6).

6.1.2 Functional explanation of structure of Dominant School Chemistry

The main properties of the separate substructures: corpuscular theoretical basis, educational positivism, and preparatory training, and of their relationships: rigidity and isolation, raise the question of *why* these properties and relationships hold for the structure of the dominant school chemistry curriculum. This leads to the second, theoretical research question: *Why is this structure the way it is?*

In section 2.4 we established the remarkable similarity of these properties and relationships of Dominant School Chemistry to those of Normal Science Education, a concept based on Kuhn's theory of scientific education. The latter concept led us to the concept of Normal Chemistry Education, which is applicable to both the tertiary and secondary curriculum levels. The basic function of Dominant School Chemistry is, therefore, to prepare students for further study along normal scientific lines and to start initiating them into the current paradigm of chemistry already at the secondary level.

Kuhn's functional theory of scientific education

It is clear from Kuhn's writings that the pedagogy of training normal scientists has an overriding influence on the form and content of the pre-professional curriculum (section 2.3). Historical research of science curricula, too, has shown that from the close of the 19th century, the secondary science curriculum has emulated the same 'academic' model which the university curricula of the natural sciences has followed, according to Kuhn, at least since the beginning of the 19th century.[2]

Kuhn (1970c, p. 237) underpins his theory of the dynamics of science, which includes the process of scientific education, by a rather abstract *functional* argument. I will presently substantiate his argument for the process of scientific education at the secondary school level, but first I give Kuhn's general argument for his theory of the dynamics of science:

> If I have a theory of how and why science works, it must necessarily have implications for the way scientists should behave if their enterprise is to flourish. The structure of my argument is simple and, I think, unexceptionable: scientists behave in the following ways; those modes of behavior have (here theory enters) the following essential functions; in the absence of an alternate mode *that would serve similar functions*, scientists should behave essentially as they do if their concern is to improve scientific knowledge (italics Kuhn).

Let me now apply this reasoning to Kuhn's theory of the dynamics of science education. Kuhn *describes* in his work the "modes of behavior" that scientists have institutionalized to train or teach their students. As we saw in Chapter 2, Kuhn describes these "modes of behavior" in terms of teaching through textbooks and exemplars ("behave in the following ways"). The exemplars are described "as problems *closely* modeled in method and substance upon those through which the *text* has led" (Kuhn, 1977a, p. 229) students

2 This educational model for academic science education was first institutionalized in 19th century Germany (Fuller, 2000). After this, it found its way to other European countries and the United States. At the turn of the nineteenth century the academic model was extended, one could also say exported, to secondary schools by university professors and academically oriented school teachers (Schwab, 1942; Layton, 1973; Just, 1989; Homburg, 1993).

in the first place. Those "modes of behavior" – "here theory enters" – have the *function* to develop students' puzzle-solving competence needed in order to function later as normal scientists. Since scientists' "concern is to improve scientific knowledge" as related to their paradigm, scientists should continue to train their students this way "in the absence of an alternate mode *that should serve similar functions*" (Kuhn, 1970c).

Assuming for the moment, with Kuhn, that this argument applies to normal science education at the tertiary level, the question is now whether it also applies to science education at the secondary level: should secondary science education *serve similar functions*? First of all, it must be noted that the function of science education at the secondary level is not, and has not been, as clear-cut as that for the tertiary level (see section 3.2). Science educators all over the world, including many IF and DF members (2.2), have come to regard the function of science education at the secondary level as more and more being *different* from that at the tertiary level. Thus, a first initiation and preparation of students as researchers in normal science is certainly not regarded as the only function, or even as the most important one at the secondary level. In terms of Roberts (1988), there is more that *counts as science education* at the secondary level than just the traditional emphases on Solid Foundations and Correct Explanations. A number of curriculum emphases other than the traditional ones have been, and are currently, explored in the secondary science curriculum (see Fig. 3.5 & 3.6).

For example, what is more and more considered by many science educators as the most important aim is *the initiation and preparation of students into a science and technology based society and culture* (see also section 3.2.4). Students in secondary education are not to be seen primarily as producers of science ("to improve scientific knowledge"), but rather as consumers of science (Schwab, 1962; Millar, 2002). These kinds of aims should therefore define the nature and form of a more general, citizen-oriented science education at the secondary level to a much greater extent than that for which the extrapolation of Kuhn's theory of scientific training to the secondary level seems to allow.

Reversing this reasoning about the function of the school science curriculum leads to the conclusion that a different function of science education at the secondary level requires, in Kuhn's terms, a different "mode of behavior", that is, a different institutional organization of science education, not specialist but general science education. This implies that a new science curriculum structure must be devised, explored, and tested in the design room and the classroom in order to fulfill this new function. It implies a different role for science teachers in providing such a general education, a role for which they must be prepared in pre-service and / or in-service teacher training. While Kuhn's analysis is focused on the practice of the community of normal science researchers, a similar analysis of community practices could also be performed on other science practices. Different chemical practices demand that different roles be taken by practitioners, and appeal to different kinds of knowledge and procedures (see also subsection 6.4.4 below).

Functional explanations

The curriculum phenomena summarized in section 6.1.1 above, that is, the properties and relationships of Dominant School Chemistry, can be explained in terms of Kuhn's theory about the function of scientific education. A choice for a specific pedagogical structure determines to a great extent the choice for a specific substantive structure and entails as well a choice for a specific philosophical structure. In line with Kuhn's reasoning these relationships have a *functional* nature. The pedagogical *aim* of any chemistry curriculum in the end determines the form and content chosen for the course. Conversely, a specific substantive structure often implies a choice for a specific pedagogical structure and for a specific philosophical structure. In brief, a change in function implies a change in structure, and vice versa.

Let me begin with the aim and the teaching and learning approaches of the *pedagogical structure* of Dominant School Chemistry (Figure 6.3). Its aim, initiation, and preparation for university chemistry and/or the future chemist, is in the end influenced by the need to sustain and strengthen the current paradigm of chemistry. A tradition of normal science creates the need and provides the *means*, namely a disciplinary matrix or substantive structure, to train future normal scientists. It is this need that determines the aim, which in turn determines the form and substance of the science curriculum that novices will have to undergo at the university. The pre-professional curriculum entails a clear and coherent message for university teachers and students alike, namely, that the received curriculum is about training to solve conceptual and instrumental *normal science problems* by way of exemplars in textbooks and laboratory books derived from the current paradigm. In Chapter 2, I argued that Dominant School Chemistry must be regarded as a form of Normal Chemistry Education, since the former has almost all its characteristics in common with the latter. Students at school are taught established or standard items of dogma and learn to reproduce, often by rote, propositions and algorithms on the basis of textbooks and exemplars. The puzzle solving abilities they acquire will set a number them, i.e. those who will in the future form the professional community, on their way as scientists in the paradigm of normal science. In brief, Dominant School Chemistry must be regarded as the first stage of this pre-professional curriculum.

The *substantive* structure of Dominant School Chemistry based on corpuscular theory reflects, albeit incompletely, the first stage of the current paradigm of chemistry into which secondary chemistry students are initiated. Even more so than for university students, the research front remains invisible for them until the last stages of their graduate training, that is, if students choose to study chemistry at the university (cp. section 1.1.3).

Our initial hypothesis was that the *hidden structure* of the current school chemistry curriculum was captured by the properties and relationships of Coherent School Chemistry (section 1.1.2 and Figure 1.3). Instead, the International Forum survey showed that the structure of the currently dominant school chemistry curriculum had to be characterized by the properties and relationships of what I have called Dominant School Chemistry. The IF responses revealed most clearly the components of the pedagogical and substantive structures of Dominant School Chemistry, while the components of the philosophical structure remained partly implicit (Figure 6.2).

It is not only the nature of this *philosophical structure* (educational positivism), but also its *function, which* remains partly *implicit*. In that respect, it is very interesting that Kuhn describes both the philosophical assumptions underlying Normal Science Education and the *implicit* function of these assumptions. Students, Kuhn says, receive a steady picture of science as being one of progressively accumulating results arrived at by time-honored methods (textbook image of science). However, both the genesis and conceptual change, which lead to these results, are made invisible by the textbooks used. The function of the image of science as presented by the textbook, Kuhn stresses repeatedly, is to enlist and sustain the motivation of students aspiring to become scientists, and to build up the confidence they need to solve successfully the often difficult puzzles of normal science. Kuhn frankly admits that the textbook image of science is a highly *misleading* picture, but as we have seen in Chapter 2, he defends and explains this distortion of the nature of science by appealing to its pedagogic function. Likewise, the function of the philosophical structure of Dominant School Chemistry, that is, to induce students into a form of paradigm-led puzzle-solving, is served by its implicit or hidden character.

It is clear that any major reform of school chemistry should involve the analysis and criticism not only of the incorrect philosophical assumptions entailed by educational positivism, but also of its *hidden function* which is related to the pedagogic aim of training future chemists or scientists.

Rigidity and isolation of Dominant School Chemistry

The currently dominant school chemistry curriculum has been characterized, in Chapter 2, by a *rigid* relationship 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.

It might be objected that rigidity, to a certain extent, is not necessarily a negative property because it could also give stability and perhaps even coherence to a curriculum. As noted in section 1.2.1, one of the defining characteristics of a structure is that it persists during change and that it is stable and retained in time and place. Thus, the remarks from IF members to the effect that the traditional school chemistry curriculum has implied a certain conceptual structure combined with a certain pedagogical and an (often) implicit philosophical structure, in a combination retained during change, can also be interpreted in a positive way.

The question is when does stability turn into rigidity in the sense of becoming an obstacle to a necessary reform of a curriculum? In order to prevent this from occurring, or if necessary, to counter it, the reasons for stability of the existing curriculum structure of school chemistry must first be explicated and analyzed. If unwittingly or uncritically accepted as *given*, a stable structure is in danger of becoming a rigid structure, that is, a structure dogmatically adhered to by those who use it. Rigidity formed in this way tends to hinder or exclude reforms. That becomes a problem when the situation changes, that is, with regard to new functions which science education at the secondary level agrees to fulfill, and also often with regard to its current function. Functional stability can thus turn into dysfunctional stability, that is, rigidity.

The rigidity of Dominant School Chemistry manifests itself most clearly in situations of change, namely, as a *resistance* to radical reforms attempted in school chemistry. Thus, after the process-oriented curriculum waves of the 1960s and 1970s had passed, many evaluations concluded that a traditional, academically oriented curriculum structure had largely been retained, although change had seemed necessary. More recent reforms, but now along STS lines, have led in some cases to similar sobering evaluations, for example, Joling et al. (1988) and Van Aalsvoort (2000) for the Netherlands, and Millar and Osborne (1998) for the UK.

A structure, to properly fulfill its function, is to a certain extent *per definition* demarcated or insulated from its environment, and for that reason severs at least some of its relationships with the environment (section 2.4.1). Insulation is thus a useful property as long as it is demonstrably functional or effective. However, the property of insulation can have a negative connotation. The analysis of the IF responses showed that the currently dominant school chemistry curriculum is isolated from seven dimensions: common sense and everyday life, and from society, history and philosophy of science, technology, school physics, and current chemical research (Figure 6.4). As a result chemical education at the secondary level is not open to reforms, that is, to the fulfillment of other functions, which require different combinations of substructures. If it were, it could lead to different modes of teaching and learning chemistry, for example to a citizenship-oriented curriculum. Because of its external isolation, the current structure of school chemistry to a large extent does not even fulfill its own set function. In brief, functional insulation has turned into dysfunctional insulation, that is, to the isolation of school chemistry.

The second general feature of dominant school chemistry, isolation, is therefore the opposite side of the coin, the face of which is rigidity. Thus, looking at current school chemistry from the inside reveals a rigid structure, while looking at it from the outside reveals an isolated structure. The narrow and dogmatic focus of current school chemistry excludes a number of other dimensions, which would be worthwhile to pursue in chemistry teaching, certainly for student-citizens and possibly also for student-scientists.

Resistance to reform

The rigid relationship in the currently dominant school chemistry curriculum explains to a large extent why throughout most of the 20th century school chemistry books from different countries look so remarkably *similar*. Because of that rigid internal structure, the dominant school chemistry curriculum has been found to be very *resistant* to change. To save the traditional structure from major reforms, a number of immunizing strategies have, often unintentionally, been used.

- *Optional* topics or units, either society or process oriented, which are not examined are, consequently, most easily evaded by students and teachers.
- STS issues and/or applications of science added *at the end* of chapters of traditional conceptual textbooks are easily skipped by the teacher, certainly when this added content does not form a substantial part of the examined material.
- A more subtle strategy is the addition of contexts or layers, which can extend either to the traditional curriculum as a whole or a major part thereof, leaving the skeleton intact.

Regarding the latter strategy, De Vos and Pilot (2000) have analyzed the acid-base theories present in the currently dominant school chemistry curriculum. In their paper they point out the several theoretical layers, various acid-base theories, which have been added to the initial oxygen-based theory of Lavoisier. The problem is that such a ‘layered’ text often fails to make clear to students which acid-base theory is needed to explain a type of phenomena in a particular context: chemical research, daily life, or historical. As a result, the distinctions and relationships between these various theories are difficult for students to follow. The new layer has as a rule only an incomplete, incoherent, or implicit relation with what went before. A complete, coherent, and explicit addition of a new layer, on the other hand, would not only require changing a major part of the substantive structure, but also the philosophical and pedagogical structures of dominant school chemistry. Such a coordinated replacement is not usually attempted, and consequently the rigid internal structure of dominant school chemistry is largely maintained.

The relationship between resistance to reform and the rigidity of Dominant School Chemistry is that often unintentionally or unwittingly the protection of the rigid combination of substructures in the current school chemistry curriculum, by way of immunizing strategies, results in additions and/or additional layers in the core curriculum of dominant school chemistry.

6.1.3 Beyond Normal Chemistry Education

This brings us to the third research question: *Is this structure a desirable structure?* As we saw in Chapter 2, the current form of Normal Science Education at the secondary level, Dominant School Chemistry, does not properly fulfill its set function, which is to prepare students for future study of chemistry as a science. The reproduction of chemical facts and algorithms replaces the understanding, explanation, and prediction of chemical phenomena. Improving this 'parody' of Normal Chemistry Education so that it would fulfill its function might be possible, but it would still not make Normal Chemistry Education an *appropriate* curriculum for the majority of students who do not aim to pursue their chemical studies further. The point is, that a *new* function – initiating and preparing students for a culture and society in which chemical materials and processes play an important part – requires a new structure for its realization.

Not only does the old structure fail to motivate the majority of students at the secondary level, it also instills in them a dogmatic attitude to science by giving them an incorrect picture of science as one of a steady accumulation of results acquired by a standard method. Further, the addition of a new curriculum emphasis often results in adding a new layer on top of the old structure, which can lead to incoherence and confusion for teachers and students. Clear indications of the latter were seen in the detailed analysis of the written, interpreted, taught, and experienced curriculum of the Salters' Science unit, Metals in Chapter 5. While in the case of student-scientists, these dangers may be alleviated by the latter's experiences in their future 'normal' science practice, in the case of student-citizens these dangers usually persist and can lead to skeptical, relativistic, or even cynical attitudes to science (cp. section 2.4).

The *domain-specific* character of Normal Chemistry Education (NCE), being in essence a training of specialists, appears not very conducive to fulfilling the purpose of a general chemistry education at the secondary level. As argued in Chapter 2, Dominant School Chemistry does not appear to contribute greatly to the development of students' general investigative and critical skills. On the contrary, the practice of the currently dominant school chemistry curriculum, rigid and isolated as it is, leads to verbalism and dogmatism.

The science education community must, therefore, provide an appropriate science education for the 80% or more students who do not intend to pursue their science studies at a higher level, i.e., those who do not want or need to become scientists. An initiation and preparation for culture (HPS) combined with an initiation and preparation for society (STS) seems to be a much more appropriate science education model for the majority of students. Science education at schools exclusively modeled on the initiation and preparation for normal science is not.

Thus, a new function requires a new curriculum structure. It is important that the new curriculum instill in students a critical attitude toward the results and methods of science (HPS), and that it enable them to critically appraise scientific and technological information in connection with social issues (STS). Curriculum units developed along these lines should be trialled and tested for their effectiveness in learning and for their contribution to the motivation of students.

6.2 The Problem of escape

I first summarize the curriculum findings that constitute an answer to empirical research question 5: *To what extent does the Salters' Chemistry curriculum escape from this structure*? This question concerns the extent to which an STS oriented project such as Salters' Chemistry manages to escape from the structure of the currently dominant school chemistry curriculum. This has been done by looking at the Salters' Chemistry course as a whole (section 6.2.1) and by looking at the level of the lessons of one chemical unit of the Salters' Science course, Metals (section 6.2.2).

Second, I analyze these curriculum findings in relation to Dominant School Chemistry, its properties, and its relationships, and give an explanation of the curriculum findings in terms of Kuhn's functional theory of scientific education, thereby answering the theoretical research question 6: *Why is it so hard to escape from this structure*? (section 6.2.3).

6.2.1 Curriculum findings on the Salters' Chemistry Course

The curriculum reform intended by the developers of the Salters' Chemistry course is taken here as an attempt to escape from Dominant School Chemistry. Put in terms of Schwab's curriculum substructures, the developers tried to realize this by devising a series of units of an STS course, which would constitute a radical new combination of a pedagogical, philosophical, and substantive substructure, and replace the current rigid combination of substructures summarized above.

Visionary curriculum compared with designed curriculum of the Year Three course

Having decided to develop a radically new school chemistry course, a major concern of the developers was whether the context-based Year Three course would show what they called a recognizable sequential order. This concern was reinforced by the existence of the external constraints embodied in the "Common 16+" examination system. The Year Three course was positioned in this exam system as a transitional, but also as a foundational course (Figure 4.1).

This meant that the developers felt they had to take into account not only the needs of the majority of average students, as originally intended, but also the needs of the minority of students who were about to take O-level examinations. However, in the trial phase the Year Three course was still focussed mainly on the needs of average students.

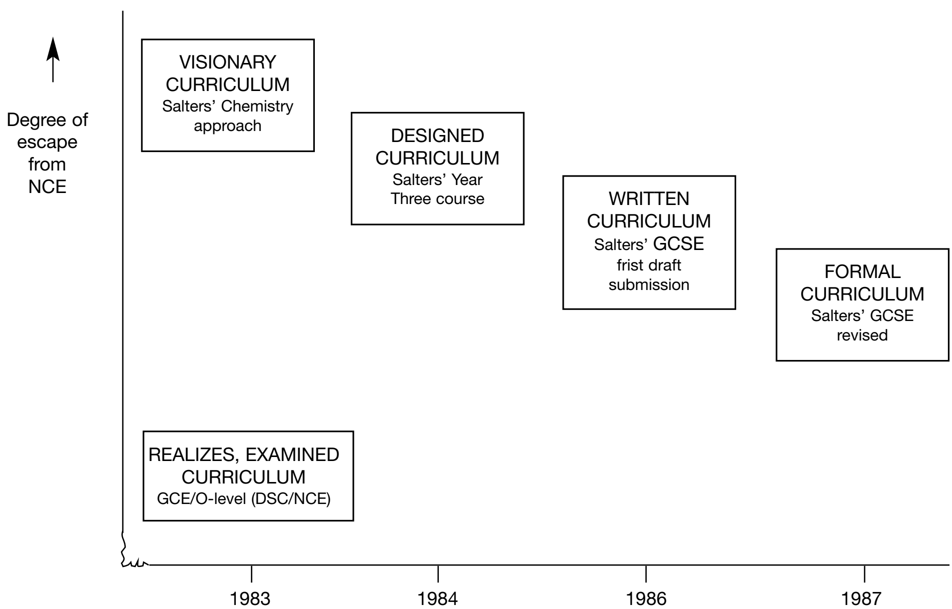
The units of the course were developed using a view on school chemistry, which centered on the ideas of relevance and use, and by starting the lessons with daily life contexts. The developed units contained what they called an agreed-on selection of chemical concepts organized, as they said, on a fairly logical basis as in the units Metals and Transporting Chemicals.

Thus, while designing the units of the Year Three course, the developers *matched* their vision to the realities of external constraints as well as to their perceived concerns, to what I have called internal constraints. This resulted in a designed curriculum, which differed in some respects from the original visionary curriculum (Figure 4.3). The added focus on the needs of future O-level students, a change in pedagogical structure, led to a greater emphasis on explanations and chemical concepts, a change in philosophical structure. The idea of *no preconceptions* as a first design criterion gave way to the selection of a logically organized sequence of chemical concepts, that is, a change in substantive structure. The realized curriculum of the Salters' Chemistry Year Three course, therefore, did not escape as fully from the structure of the dominant school chemistry curriculum as envisioned by the visionary curriculum (see Figure 6.7, reproduced from Figure 4.4).

As we saw in Chapter 4, this was a first manifestation of the important relationship that governs the transformation of the several curriculum levels in the process of development of the Salters' Chemistry course, and which (Goodlad (1979) called:

> … the *slippage* from any ideal formulation to what reaches the student, or of working backwards from what the student perceives to what the formal curriculum intended for him or her (Goodlad (1979, p. 64; italics mine).

Figure 6.7 Process of development of the Salters' Chemistry course (same as Figure 4.4)



Year Three course compared with the first draft of the GCSE exam course

The Salters' Chemistry GCSE examination course, the first draft of which was submitted to the Schools Examination and Assessment Council (SEAC) in 1986, had to conform to the constraints set by the GCSE examination system (section 4.5.2). This meant that the developers had to take into account not only the needs of average students, but also those of future A-level chemistry students. These external constraints reinforced the role of the internal constraint operative during the process of development. At this stage, this internal constraint took the form of what the developers called "the structure of chemistry as we all perceive it" (L92). This constraint was used to organize, in a logical order, the chemical concepts developed from the chosen contexts and applications.

The examination course, first trialled with students of average ability, was later also trialled with students of high ability. It was found to be suitable for the full ability range. The chosen emphasis on relevance and use had to concur for the examination course with the external demands formulated in the National Criteria for Chemistry. The resulting first draft of the exam course did contain a *slightly reduced* selection of chemical content, concepts, and relationships, which were needed for the chemical explanations of the chosen contexts in the lessons of the units of the course. This was in accordance with design criterion three, *context-led development of concepts*. As with the Year Three course, the selected laboratory techniques were applied as much as possible to relevant, familiar materials, in accordance with design criterion two, *relevance*.

Again, there were some changes accompanying the transformation of the curriculum levels involved (Figure 6.7), There was an added focus on the needs of future A-level students, a change in the pedagogical structure; more emphasis on explanations using chemical concepts, a change in philosophical structure; while the substantive structure was to a large extent now based on "the structure of chemistry as we all perceive it" (see also Figure 4.7). Thus, a comparison of the first draft of the Salters' Chemistry GCSE examination course, with the designed curriculum in the form of the Year Three course, leads to the conclusion that the former course escapes to a somewhat lesser degree from the currently dominant school chemistry curriculum than the latter. In brief, the process of slippage continued during the development of the Salters' Chemistry course.

First draft of the exam course compared with the formal GCSE curriculum

The official constraints of the examination GCSE system, as set by SEAC, forced the developers to add some *abstract* chemical content to the course. Some chemical concepts, such as the Periodic Table and atomic structure, had initially been left out as a consequence of upholding design criterion three, *context-led development of concepts* (Figure 4.5).

It was also clear that a GCSE examination course had to provide education in chemistry both to future citizens and to future A-level science students. The latter students require a sound foundation in theory and processes of enquiry, such as explanation, hypothesizing, and experimenting. Thus, a comparison of the formal curriculum of the Salters' Chemistry course (see Figure 4.7) to the First draft of the Salters' Chemistry GCSE exam course submitted for approval to SEAC shows that this formal curriculum does escape from Dominant School Chemistry to a somewhat lesser degree than the latter curriculum (Figure 6.7).

Comparison of formal and visionary Curricula of the Salters' Chemistry course

Inspection of Figure 6.7 shows that there is a *decreasing degree of escape* going from the visionary to the formal curriculum of Salters' Chemistry. Or, on Goodlad's terms, there is a continuous process of slippage governing the transformation of curriculum levels involved. The increasingly strict external constraints of the educational systems, which the Salters' developers had to meet, combined with the increasingly explicit role of the internal constraints they used in the developmental process, form the mechanism causing the decreasing degree of escape.

As we saw in Chapter 4, the developers initially attached much importance to design criterion one, *no preconceptions,* in guiding the selection of traditional content to be put into a new relevant chemistry course for 13 -16 year olds. For the Year Three course, this meant:

> You must *not* be influenced by your thoughts of what we always do with the third year or your thoughts of what we have covered before we arrive in the fourth year. (G92a:15)

Analysis of the interviews of developers and the documents produced show that it is very difficult for developers to adhere consistently to this first design criterion, during the development of actual curriculum units in a given educational system. Notwithstanding their strongly avowed intention not to use any preconceptions, their internal constraints – a recognizable sequential order, a fairly logical basis, the structure of chemistry as we all perceive it – came to function as successive preconceptions used by them to structure logically the units of the Salters' Chemistry course. By relying on these internal constraints, the developers fell back on their traditional or practical knowledge regarding the selection of chemical content, the ordering of this content and the contexts and activities which would work to put the selected content across to students (pedagogical content knowledge, see section 5.5.2).

To a large extent this probably happened unintentionally or unwittingly. One could therefore say that during the actual developmental practice, developers tended to show what I call a Normal Chemical Education reflex, the effect of which is the often implicit use of the structure of the currently dominant school chemistry curriculum. It is important that this point is recognized, because it should lead to the realization that a new *societal function* of school chemistry requires an explicit and coordinated replacement of the current rigid combination of substructures by a radical new combination of a pedagogical, philosophical, and substantive substructures.

Judging from what developers say in interviews, and from what is stated in formal documents such as the *Salters' Chemistry Syllabus* (1992) and the *Salters' Chemistry course: An overall guide for teachers* (1988), design criterion two, *relevance,* and design criterion three, *context-led development of concepts*, are maintained as design criteria throughout the development of the course. As we saw in Chapter 5, the developers did not manage to apply design criterion two and three consistently throughout a unit (see further in section 6.2.2). The reemergence of the 'structure of chemistry as we all perceive it', as a preconception followed by developers, partly accounts for this.

However, these two central design criteria did play an important role in practice. For example, design criterion three, *context-led development of concepts,* was effective as is shown by the reduced conceptual loading of the draft GCSE course submitted to SEAC. The latter criterion was also articulated in the process of development as the 'need-to-know' principle, that is, the idea of developing only those chemical concepts needed to make sense of chosen contexts. At a later stage the developers referred also to what they called the "drip-feed" approach, that is drip-feeding chemical concepts into the course, for example, by spirally revisiting of qualitatively introduced concepts in different contexts (see also section 4.6.2).

As we noted above in section 5.4.4, this process of drip-feeding chemical concepts was guided more and more by the required concepts, and less by the chosen contexts.

External constraints like the National Curriculum dominated the process to an increasing extent. During the development of the units, another criterion was explicated and articulated, namely, design criterion four, *variety-cum-activity*. The wider use of laboratory techniques, not just with pure chemicals but also with familiar materials, was complemented by several other kinds of activities, such as group work, discussions, and role-play. The increased variety of activities appears to be called forth by the new, relevant emphasis of the chemistry course on coping with everyday materials, applications, and STS issues.

6.2.2 Curriculum findings on the unit Metals (1989)

I will now summarize the findings of the consistency analysis of the application of design criterion two, *relevance,* and design criterion three, *context-led development of concepts*, as used by the developers in the design of the lessons of a unit of the Salters' Chemistry course, Metals (1989).

This consistency analysis has been performed on the eight *lessons* of the unit Metals at the level of the interpreted, taught, and experienced curriculum (sections 5.2, 5.3 and 5.4). The findings give us a detailed picture of the changes in degree of escape from Dominant School Chemistry at the several curriculum levels involved in the process of realizing the unit Metals in the classroom.

In the consistency analysis of the lessons of the unit Metals, I used the ratio between CTS content and PC content as a (relative) measure of the degree of escape from Dominant School Chemistry (section 5.1.4). This made it possible to follow in some detail the transformations of the formal, written, interpreted, and taught curriculum levels of the unit Metals in order to compare these with the PC content of the currently dominant school chemistry curriculum. This ordering allows us to determine the changes in degree of escape at these levels. There appeared to be a substantial decrease in degree of escape moving from the formal to the taught curriculum level of the unit Metals (See Figure 6.8, reproduced from Figure 5.5).

Comparison of formal with written curriculum

The consistency analysis of the lessons of the unit Metals (1989) showed, firstly, that more PC content and less CTS content was developed than was needed, that is, than was consistent with design criteria two and three (Figure 5.13). The CTS/PC ratio, taken as a measure of the degree of escape, decreased substantially in moving from the formal to the written curriculum. The analysis showed, therefore, that the developers did not consistently adhere to design criterion two, *relevance*, and design criterion three, *context-led development of concepts*. In so doing, they went against design criterion one, *no preconceptions*, making it thereby very difficult to uphold central design criteria two and three. While designing the lessons of the unit Metals, the developers *retained* a number of PC concepts traditionally part of dominant school chemistry, that is, concepts developed though not needed to make sense of the selected contexts (see further Figure 5.13).

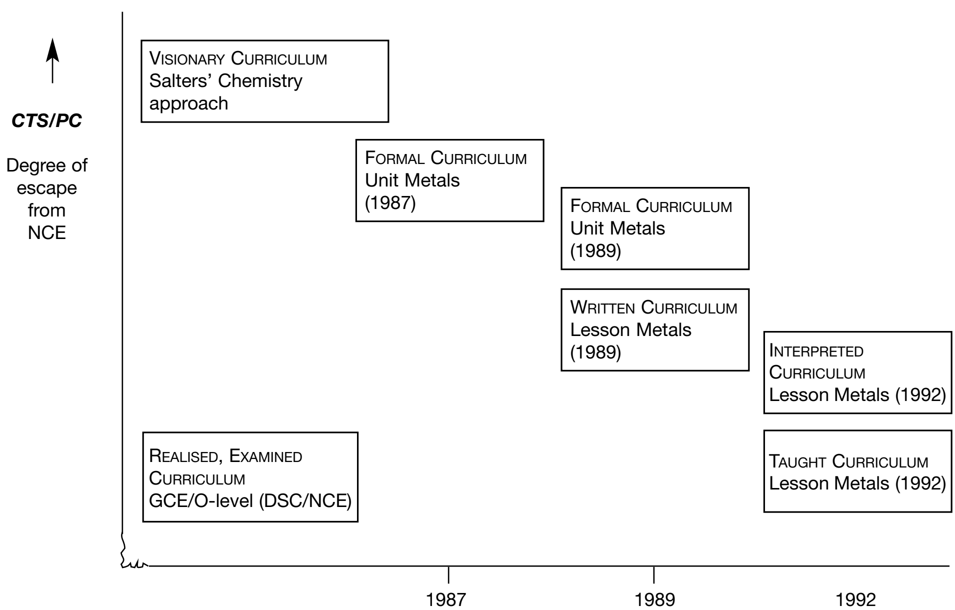
As a result, some lessons of Metals (1989) suffer from a tension between the PC content developed and the CTS content needed. This leads to an important point. The PC-CTS tension present in the substantive structure of the curriculum is connected with a corresponding tension in the philosophical structure, between the cognitive process of explanation on the one hand and the process of application on the other. Further, the PC-CTS tension is also related to a tension in the pedagogical structure, between the aim to train future A-level chemistry students and the aim to educate future citizens in chemical literacy. Such connections can be expected from Schwab's curriculum framework (section 1.3.2).

The concept of normal chemistry education based on Kuhn's functional theory leads to the following explanation. It is predominantly the tension, or dual emphasis in the pedagogical structure, which determines the dual emphasis in the philosophical structure and the PC-CTS tension in the content of the substantive structure. In brief, the change in function determines the change in structure of the curriculum.

As noted above, a combination of increasingly strict external constraints and the increasingly explicit role of internal constraints used by the Salters' developers prevented them from escaping Dominant School Chemistry. In this respect the analysis of the content of the successive formal curriculum units of Metals (1984, 1987, 1989) in section 5.2.8 (Fig. 5.14) is interesting, since it shows the great influence of the traditional structure of school chemistry even in a period *relatively free* from strict external constraints.[3]

Thus, the Normal Chemistry Education reflex manifests itself in all three coordinated curriculum substructures of school chemistry, even under conditions of relatively weak external constraints.

Figure 6.8 Process of development and teaching lessons Metals (same as Figure 5.5)



3 A detailed analysis such as the consistency analysis in chapter 5 of the lessons of Metals (1989), but now of the content of the lessons of previous versions, i.e. Metals (1987) and/or Metals (1984), would confirm, I think, the extent of this influence.

Comparison of designed with interpreted curriculum

As we saw in Figure 5.15 summarizing the interpreted curriculum, PC content was added, though it was not needed, and CTS content was deleted, though it was needed to make sense of the contexts selected. In this process the CTS/PC ratio decreased again. Thus, design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, were not consistently upheld.

Science teachers of the Department of Science of the school where I performed my research, adhered to design criterion five, *flexibility*, by interpreting the curriculum unit Metals (1989) and using an emphasis on teaching scientific processes. Students were thus stimulated to work "as real scientists" in the so-called Circus approach these teachers developed. Design criterion four, *variety-cum-activity*, was correspondingly interpreted by them to give an emphasis to student activities that addressed processes and skills more than relevant contexts. Design criterion one, *no preconceptions*, was in this case replaced by a clear preference for a scientific process approach, a choice probably related to the background of the group of teachers involved and to the impending external changes such as the National Curriculum (section 5.3.2). Thus, internal constraints influenced the interpretation and the subsequent implementation of the curriculum unit Metals (1989), again in combination with external constraints.

Comparison of interpreted with taught curriculum

As we saw in Figure 5.16, the chemistry teacher who taught the unit Metals (1989) added some PC content not needed, and did not teach some CTS content that was needed, to make sense of relevant contexts. This is inconsistent with design criteria two and three, and the CTS/PC ratio therefore decreases further. Within the constraints of the National Curriculum, teaching Metals (1992) to a group of students of low to middle ability led to a teacher-directed approach in which there was little room for discussion of either relevant contexts or for process activities (design criterion four). In this case, the external constraints acting on the teacher clearly prevailed over internal constraints or any preconceptions the teacher had with regard to the teaching of chemistry at this level.

Experienced curriculum

Up to this point I have discussed what at various subsequent levels – visionary, designed, interpreted, taught – is offered to students in terms of changes in the CTS/PC ratio. Students have no prior knowledge of the content or structure of the lessons they are about to receive, let alone of the changes in the CTS/PC ratio. However, depending on the probe or method used we can find out to what extent the relevant CTS emphasis is appreciated or learned by students (sections 5.4.1 – 5.4.4), or alternatively the extent to which the PC content is learned by students through a context- and activity-led approach (Ramsden, 1994; 1997).

All studies reviewed in section 5.4.4 show an overall *positive effect* of the context- and activity-based Salters' Science course on students' motivation, which has been attributed by Ramsden (1992) to an improvement of the *general* classroom atmosphere (see Figure 5.17). More specifically, as I found out in my case-study on Metals (1989), this positive effect on students' motivation can be attributed to some *specific* CTS contexts motivating and enabling students to learn some relevant and useful concepts. Students learn through the CTS contexts of the lessons of Metals (1992 the related CTS concepts such as the relationships and causes of rusting/corrosion and its prevention. That is, they acquire in this way some CTS concepts and transfer them to similar CTS contexts (local transfer).

These findings, as may be expected from a case study, add some interesting detail to the general conclusion above.

Secondly, many of the difficulties students have with understanding PC concepts that were found in the case study on Metals (1992), are also found in other studies. More specifically, the average students' conceptual understanding of CTS concepts introduced in the unit Metals (1992) appears to be better than that for PC concepts.

Finally, none of the studies reviewed, mention *specific* examples of PC concepts which, although introduced in the Salters' Science units, students do not really need to make sense of the CTS contexts as I found in my case study on Metals (1989, 1992), namely chemical concepts such as oxidation, reactivity series, compound and formulae (see Figure 5.13)

6.2.3 Discussion and implications

Students are not only motivated by *specific* CTS contexts, they also learn, through these contexts, the related CTS concepts (such as the relationships and causes of rusting/corrosion and its prevention). This leads to the *prima facie* paradoxical result that students do *perceive* an increased relevance in lessons of the unit Metals (1992), although from the point of view of my research, the CTS/PC ratio steadily decreases from the visionary to the taught curriculum.

This surprising perception of students can be explained by taking into account that students do not compare the lessons they experience with the formal or visionary curriculum, which after all is unknown to them, but instead compare it to what they are accustomed to, or what they expect from previous science lessons at school. Had they been given a unit with more lessons with a clear CTS emphasis and a greater CTS/PC ratio, it seems likely that they might have appreciated such a unit even more.

One could argue that, just as students are led by their prior expectations or preconceptions of school science, to some extent so are teachers and developers. Conversely, one could say that developers, teachers, and students show a certain NCE reflex. Thus, teachers, especially those who have no intimate knowledge of the visionary curriculum as embodied in the five design criteria, might feel they have increased the relevance of their teaching compared to what they did in previous years. However, from the point of view of the results of the analysis, the CTS/PC ratio decreased in the case of teaching the unit Metals. Similarly, those developers who take a weak interpretation of the design criteria, instead of the strong interpretation, as discussed in section 5.1.3, might not feel that they have decreased the CTS/PC ratio in some lessons or units. Instead, they might feel that, compared to the lessons they used to develop, they have increased the relevance of the newly developed lessons or units, which is correct in the light of their interpretation of the design criteria.

In a slightly different way this might even apply to those developers who favored a strong interpretation of the design criteria. Since design criteria are being articulated and operationalized *during* the process of development, at the start they are partially *unknown* to the actors involved.

This also explains why it is so difficult for teachers to implement lessons in accordance with the design criteria. After all, they must necessarily rely to a varying extent on their practical knowledge with regard to school chemistry teaching and on the preconceptions entailed by this. The same applies, as we saw, to the developers of the original units. The latter's practical or implicit knowledge[4] with regard to the development of new materials, and their preconceptions about school chemistry entailed by this implicit knowledge, influences their articulation and operationalization of the partially unknown design criteria.

To some extent this is *inherent* in the design criteria approach to development. In this way preconceptions of developers can hold back the implementation of the visionary curriculum, as well as influence the perception of teachers executing the operationalized lessons. Both developers, in their practice of designing new curriculum materials, and teachers, in their practice of teaching those are led by certain preconceptions. In brief, both tend to show a NCE reflex.

It may seem that the degree of escape, as measured by the changes in the CTS/PC ratio, is largely relative to the observer. This can be counteracted, I think, by linking a research project to a development project in order to make explicit in a systematic way all that is involved in the design criteria approach. This would make it less relative and more objective. The purpose of such a developmental research project is thus to explicate, articulate, and if needed, to revise the initially chosen design criteria during the process of development by obtaining during the project at all curriculum levels – visionary, designed, interpreted, and taught – the necessary feedback from the actors involved: developers, teachers, and students.

The case study of the unit Metals, derived from the Salters' Chemistry course, clearly shows the resistance of Dominant School Chemistry, indicated in section 6.1.2 above, to a radical, societally oriented curriculum reform. More specifically, in all three coordinated substructures, and at all curriculum levels of the unit Metals, a *NCE-reflex* manifests itself. The external as well as internal constraints, which are operative during the designing, writing, and teaching of a CTS unit, lead to a NCE reflex, that is, to a *mechanism* which prevents the agents of reform from escaping NCE in the way in which they are intended. This resulted, in the case of the unit Metals, in a PC-CTS tension in the substantive structure of the curriculum unit which, as can be expected, is associated with a tension between the cognitive processes of explanation and application in the philosophical structure, and with a tension between the aims to train future A-level chemistry students and to educate future citizens in chemical literacy in the pedagogical structure.

6.3 A Strategy to escape from Dominant School Chemistry

In this section, I will come back to the three conditions of escape discussed in Chapter 3. Together, these conditions constitute a proposal for a strategy to escape from Dominant School Chemistry (6.3.1). Secondly, I will briefly summarize the curriculum theoretical framework I have developed in this thesis on which the three conditions of escape are based (6.3.2).

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4 Campbell at al (1994, p. 425) remarks, "We built in, to a significant degree, teachers craft knowledge about teaching and learning. See also section 5.5.2, note 60 on pedagogical content knowledge.

Thirdly, I will outline how the developed curriculum framework can be used, in condition one, for the *analysis* of traditional and innovative school chemistry curricula (6.3.3), in condition two, for the *development* of vision and design of innovative school chemistry curricula (6.3.4), and in condition three, for *developmental research* accompanying the process of large scale development of innovative school chemistry curricula (6.3.5).

Thus, in this section I come back to research question 4, *What are the conditions for escape?*, and I will try to answer research question 7: *How can attempts to escape from this structure be more successful?*

6.3.1 Three conditions for escape

The research findings on the structure of current school chemistry, summarized in section 6.1 gave rise to the formulation of the first condition for escape which has to do with the analysis of the structure of the dominant school chemistry curriculum. The discussion of Roberts' concept of curriculum emphasis lead in Chapter 3 to the formulation of two other conditions for escape. The second condition concerns the development of a vision on new school chemistry curricula, while the third condition has to do with the method to escape from Dominant School Chemistry.

The three conditions are not strictly separable, and have to be applied together. The domain specific analysis of the structure of current school chemistry is performed to initiate a systematic reform, which in its turn has to take fully account of the results of the analysis. The three conditions are summarized in Figure 6.9, which is based on Figure 3.10, but for the points on vision and design derived from the analysis of the Salters' design criteria approach.

The research findings on Salters' Chemistry, summarized in section 6.2, show the usefulness of my curriculum theoretical framework in analyzing an innovative school chemistry curriculum by uncovering the phenomenon of *slippage* during the process of development of the Salters' Chemistry course as well as during the process of teaching of the unit Metals. The findings give us a detailed picture of the changes in degree of escape from Dominant School Chemistry at the various curriculum levels involved (Figures 6.7 & 6.8). As argued in Chapters 4 & 5, the developers of the Salters' Chemistry course can be seen as following to some extent condition one and three, and to a larger extent condition two.

As I will discuss below, attempts to escape could be more successful, if large-scale development projects were to adopt and implement these three conditions of escape together. That is, to articulate a new vision while preventing the importation of the old one, and to plan, realize, and test the new vision by developmental research while using the curriculum framework described in section 6.3.2.

Figure 6.9 Three conditions to escape from Dominant School Chemistry

Condition one: *In order to escape, we have to know what to escape from.*

- Perform a domain specific analysis of the nature and structure of the dominant school chemistry curriculum in terms of the framework developed in this thesis, that is, in terms of a combination of the dominant substantive, philosophical, and pedagogical structure.

Condition two: *In order to escape, we have to know what to escape to.*

- Aim towards a coordinated replacement of the currently dominant (rigid) combination of substantive, philosophical, and pedagogical structure of school chemistry.
- Develop and legitimize a new curriculum emphasis for school chemistry, in terms of a new coherent combination of a substantive, philosophical, and pedagogical structure.
- Use the concepts of curriculum emphases and Normal Chemistry Education (NCE) of the framework as instruments to articulate the visionary curriculum in terms of design criteria, that is, a new conjectural vision to be operationalized by the design of prototypes of the teaching material in the designed curriculum.

Condition three: *In order to escape, we have to know how to escape.*

- Be aware of, anticipate and avoid the NCE reflex, or at least deal in time with any difficulties related to the dominant school chemistry curriculum at all curriculum levels, starting at the visionary and designed curriculum.
- Collect evaluation data at all curriculum levels to safeguard the adopted vision, in moving from the visionary, designed, written, formal up to the interpreted, taught, and experienced curriculum levels.
- Check the newly chosen curriculum emphasis, articulated in the visionary curriculum in terms of design criteria, for consistency at all curriculum levels.

6.3.2 Curriculum theoretical framework

The theoretical framework presented in Chapter 1 consists of the substantive, philosophical and pedagogical structure (based on Schwab) which in a coherent combination makes up a curriculum structure, and which pertains to a number of curriculum levels (based on Goodlad). These substructures and levels apply to the curricula of any discipline not just to the curricula of the natural sciences. They form the *formal* part of the theoretical framework (Fig. 6.10).

Both the concept of curriculum emphasis, as elaborated by Roberts and the concept of Normal Science Education as developed in this thesis (based on Kuhn) are specific to the domain of the natural sciences. They form the *material* part of the framework (Fig. 6.12).

Formal part of the framework

If the formal framework is applied to the domain of the natural sciences it is the use of the material part of the framework which guides the researcher, in an iterative process applied to educational documents such as textbooks or syllabi, transcripts of interviews or relevant publications (see 6.3.3), to fill out the categories and subcategories of a curriculum structure at a curriculum level.

Figure 6.10 Formal part of the curriculum theoretical framework

Curriculum levels	**Substantive structure**	**Philosophical structure**	**Pedagogical structure**
Visionary curriculum Designed curriculum Written curriculum Formal curriculum Interpreted curriculum Taught curriculum Experienced curriculum			

In the case of the development of the vision of the Salters' Chemistry curriculum the application of the formal framework guided by the material part of the framework leads to Figure 6.11. The substantive, philosophical, and pedagogical structure are characterized by the headings used in Figures 4.3, 4.5, and 4.7, which give details in terms of the subcategories I used throughout this thesis (Figure 2.2). Based on the curriculum data collected in Chapter 5, the process of teaching of the unit Metals could be represented in a similar figure. These figures offer another, complementary way to represent the processes of development and teaching of innovative school science curricula than the pictures deployed so far, such as Figures 6.6 and 6.7.

Figure 6.11 Formal part of the curriculum theoretical framework applied to Salters' Chemistry

Curriculum levels	**Substantive structure**	**Philosophical structure**	**Pedagogical structure**
Visionary curriculum (Fig. 4.3 gives details)	Familiar materials approach	Relevance and use	Essential chemistry for living; focus on needs less and moderately able students
Designed curriculum (Fig. 4.5 gives details)	A recognizable sequential order	Relevance and use	Essential chemistry for living; future citizens
Written curriculum (Fig. 4.5 gives details)	Structure of chemistry as we perceive it	Relevance and use	Chemical awareness and basis for further study chemistry; Full ability range, including most able
Formal curriculum (Fig. 4.7 gives details)	Logical development of chemical concepts and principles	Relevance, chemistry for industry and everyday life; sources, manufacture and use	Worthwhile, practical, and relevant chemistry Accessible to full ability range of students

In the process of development moving from the visionary to the formal curriculum, the original curriculum emphasis of the Salters' Chemistry course taken as a combination a substantive, philosophical and pedagogical structure is shifting. As shown in detail in Chapter 4 there is, consequently also a shift in the combination of a substantive, philosophical and pedagogical structure comprising the Salters' Chemistry curriculum.
As for the unit Metals, it is shown in Chapter 5, that the CTS curriculum emphasis of the unit is shifting from a Chemistry along with CTS Content (which might contain about 50% STS content and about 50% pure science content) to a Science through STS Content (which might contain about 30% STS content and about 70% pure science content). Although it is to some extent arbitrary, as explained in section 5.1.4, to put exact percentages to the curriculum levels traversed here, there is at least a substantial relative shift in the original curriculum emphasis of the Salters' Chemistry course, and therefore also in the combination of a substantive, philosophical and pedagogical structure which comprises a curriculum. In brief, in my terms Salters' escape from NCE was much less successful than envisioned.
In Roberts terms, the developers started out with a mix of "Everyday Coping, Science Skill Development, and Science, Technology, and Decisions" curriculum emphases and ended with, as Borgford (1992, p. 28) put it: "A unique hybrid of "Everyday Coping, *Solid Foundation*, Science Skill Development, and Science, Technology, and Decisions" curriculum emphases (my italics).

Material part of the framework
Roberts' concept of curriculum emphasis, enables us to characterize science curricula in terms of seven curriculum emphasis, which can be analyzed ("unpacked" as Roberts called it) in terms of the components: view of science, view of society, view the learner, and view of the teacher (see section 3.2.3; Figure 3.6). Or, alternatively, as I have done in this thesis, specific curricula with various emphases pertaining to secondary chemistry education can be analyzed in terms of the substantive, philosophical and pedagogical structure and their subcategories.

The IF research described in chapter 2 shows that the seven curriculum emphasis identified and characterized by Roberts are not equally strongly represented in school chemistry courses. The currently dominant chemistry curricula have what I called a NSE orientation, whereas STS and HPS orientations on school chemistry must be considered as alternative courses having less representation. The dominant NSE orientation of science curricula consists in its purest form of the curriculum emphases *Solid Foundations* and *Correct Explanations*, and in a somewhat weaker form of the curriculum emphases *Structure of Science* and *Scientific Skill Development,* emphases that emerged in the 60s as a result of the curriculum wave (see section 3.4.2). The curriculum emphasis Personal Explanation is HPS oriented whereas the curriculum emphases Everyday Applications and Science/Technology Decisions are STS oriented. The latter three curriculum emphases are still struggling to get a fair place in the curriculum landscape. I have adapted, therefore, Figure 3. 6 *Seven curriculum emphases for science education in terms of four commonplaces* taken from Roberts (1988, p. 45) in the following way. I have put the most dominant NSE type curricula on top and the STS and HPS curricula at the bottom. In these terms the curriculum emphases *Structure of Science* and *Scientific Skill Development* could be considered as a mixture of NSE and some HPS education (see Figure 6.12).

There is considerable overlap between the curriculum components Roberts uses to

Figure 6.12 Curriculum emphases analyzed in components framework (adapted from Roberts, 1988)

Component **Curriculum emphasis**	**Philosophical structure** **View of Science**	**Philosophical structure** **View of Society**	**Pedagogical structure** **View of the learner**	**Pedagogical structure** **View of the teacher**
NSE				
SOLID FOUNDATION	A vast and complex meaning system which takes many years to master.	Society needs scientists.	An individual who wants and needs the whole of a science, eventually.	One who is responsible to winnow out the most capable potential scientists.
CORRECT EXPLANATIONS	The best meaning system ever developed for getting at the truth about natural objects and events.	Society needs true believers in the meaning system most appropriate for natural objects and events.	Someone whose preconceptions need to be replaced and corrected.	One responsible for identifying and correcting the errors in student thinking.
STRUCTURE OF SCIENCE	A conceptual system for explaining naturally occurring objects and events, which is cumulative and self-correcting.	Society needs elite, philosophically informed scientists who really understand how that conceptual system works.	One who needs an accurate understanding of how this powerful conceptual system works.	Comfortably analyzes the subject matter as a conceptual system, understands it as such, and sees the viewpoint as important.
SCIENTIFIC SKILL DEVELOPMENT	Consists of the outcome of correct usage of certain physical end conceptual processes.	Society needs people who approach problems with a successful arsenal of scientific tool skills.	An increasingly competent performer with the processes.	One who encourages learners to practice at the processes in many different contexts of science subject matter.
HPS				
PERSONAL EXPLANATION	A conceptual system whose development is influenced by the ideas of the times, the conceptual principles used, and the personal intent to explain.	Society needs members who have a liberal education – that is, who know where knowledge comes from.	One who needs the intellectual freedom gained by knowing as many of the influences on scientific thought as possible.	Someone deeply committed to the concept of liberal education exposing the grounds of what we know.
STS				
EVERYDAY COPING STS	A meaning system necessary for understanding and therefore controlling everyday objects and events.	Autonomous, knowledgeable individuals who can do mechanical things well, who are entre-preneurial, and who look after them, are highly valued members of the social order.	Needs to master the best explanations available for comfortable, competent explanation of natural events, and control of mechanical objects and personal affairs.	Someone who regularly explains natural and man made objects and events by appropriate scientific principles.
SCIENCE/ TECHNOLOGY/ DECISIONS	An expression of the wish to control the environment and ourselves, intimately related to technology and increasingly related to very significant societal issues.	Society needs to keep from destroying itself by developing in the general public (and the scientists as well) a sophisticated, opera-tional view of the way decisions are made about science-based societal problems.	Needs to become an intelligent, willing decision maker, who understands the scientific basis for technology, and the practical basis for defensible decisions.	One who develops both knowledge of and commitment to the complex interrelationships among science, technology, and decisions.

analyze science curricula and the curriculum components I use in this thesis (see also section 3.3). Roberts' view of science and view of society correspond to the philosophical structure, whereas Roberts' view of the learner and view of the teacher correspond to the pedagogical structure (cp. Fig.1.1). The science concepts selected in the light of the view of science and society (philosophical structure), and in the light of the view of the learner and teacher (pedagogical structure) will result in the corresponding substantive structure.

6.3.3 Condition one: using the curriculum framework for analysis

The following chemistry and science curricula (processes) have been analyzed and categorized in terms of the curriculum framework developed in this thesis (Figure 6.13).

Figure 6.13 Science curricula analyzed in terms of curriculum theoretical framework

Chemistry and science curricula	**Analysis based on specifications from:**	**This thesis**
Coherent School Chemistry	• publications De Vos & Verdonk	Figure 1.3
Dominant School Chemistry	• IF and DF responses	Figures 2.3 – 2.5
Normal Science Education	• publications Kuhn	Figures 2.3 – 2.5
O-level chemistry curriculum (England)	• transcripts interviews developers	Figure 4.2
Developmental process of Salters Chemistry	• educational documents • relevant publications • transcripts interviews developers	Figures 4.4 & 6.11 Section 5.4.4 Chapter 4
Teaching process of the units Metals	• classroom based research • transcripts interviews teacher • student questionnaire	Figures 5.5 & 5.13 Section 5.3 Section 5.4.1

In the process of development of my research framework I used an empirical method for the analysis and categorizations of the specifications taken from the relevant documents or transcripts. Together with two other researchers I analyzed, in the steps described in section 2.1.2, these specifications in an iterative way using labeled, but further undefined categories and subcategories (see Figure 2.2). After having filled out, defined as it were or 'inductively', all the categories and subcategories of the curriculum in question, I arrived at a characterization of the curriculum emphasis, which subsumes the combination of substantive, philosophical and pedagogical structure. In contrast with the inductive method I have used, Roberts (1988) uses what one could call a more 'deductive' method using labeled as well as defined categories: view of science, society, of the learner and of the teacher (see further Figure 6.12). This method of analysis was used by Roberts and Orpwood (1978) with teachers in trying to discern the curriculum emphases of textbooks.[5]

[5] Based on Roberts (1988) and Van Berkel (2000), Westbroek et al. (2000) devised a curriculum framework, which they adapted to Dutch school chemistry education. This framework was used with Dutch teachers in order to clarify and make explicit the curriculum emphasis teachers saw as dominant in the current school chemistry curriculum, and the kind of curriculum emphases they would prefer instead.

The use of the curriculum framework as an instrument of analysis enables us to see differences or similarities between curricula of secondary chemical education. In the case of the IF research, this led to the finding that the currently dominant school chemistry curriculum must be considered as a form of Normal Chemistry Education in the sense of a first initiation and preparation. Furthermore, the finding that Normal Chemistry Education is the dominant emphasis of the current school chemistry curriculum enables us to take Dominant School Chemistry as the *baseline* for comparison with the successive curriculum levels in an innovative developmental and teaching process. The curriculum framework applied to a specific curriculum, such as Salters Chemistry, results in a detailed picture of the transformation of the curriculum structure along the curriculum levels in a developmental process (Fig. 6.6). And, the curriculum framework applied to a specific curriculum unit, such as the unit Metals, results in a detailed picture of the transformation of the curriculum structure along the curriculum levels in a teaching process (Figure 6.7).

In both cases there is visible a steady decrease in the degree of escape from Dominant School Chemistry as a form of NCE (see also Figure 6.11). This pattern of slippage appears to be quite common, especially in large-scale developmental projects (Goodlad, 1979; Van den Akker 1988). In other developmental projects the decrease in the degree of escape from NCE might be much less, though. There could also be a temporary or local increase in going from one level to another. In the transformation from the visionary to the designed curriculum, a group of developers might improve on the explicitness and coherency of the adopted vision by designing a good prototype. Or, in the transformation from the formal to the taught curriculum, a group of teachers could interpret and teach an adopted unit in an improved way by redesigning the unit more in accordance with the design criteria, which articulate of the vision.

In any case, it is the application of the curriculum framework to a specific science curriculum, which will reveal the pattern, which exits in the transformation of the curriculum levels moving from the visionary to the taught curriculum. Performing this analysis in conjunction with the process of development would lead to results, which would enhance the consistency between the products developed at the various curriculum levels. In brief, it would reduce in a systematic way the slippage, and in a more successful escape from NCE. Thus, the curriculum framework can be regarded as a useful instrument which enables the researcher to compare secondary chemistry curricula from different countries at a particular level e.g. at the formal or realized curriculum, and to compare a particular innovative school chemistry curriculum as it is transformed along the different curriculum levels concerned.

6.3.4 Condition two: use of curriculum framework for development

The findings of the analysis of current school chemistry curricula reported in this thesis have implications for the reform of school chemistry (Figure 6.9). The analysis in terms of the curriculum framework makes the structure of *school chemistry* curricula both explicit and specific. This is an important difference with Roberts' framework, which gives general characterizations of *science* curricula in terms of curriculum emphasis 'unpacked' in views of science, society, of the learner and of the teacher.

For example, the characterization of the structure of current school chemistry as a rigid combination of a specific pedagogical structure, a specific philosophical structure, and a specific substantive structure helps to further explicate and specify the analysis or diagnosis performed by Garforth for the O-level chemistry curriculum in use in England in the 1970s. The O-level chemistry curriculum could be identified as a form of Dominant School Chemistry (Figure 4.2).

The analysis of a particular school chemistry curriculum should entail, besides the analysis in terms of the curriculum framework developed here, a supplementary analysis adapted to the local or national situation in terms of the relationships and tensions within and between the pedagogical, philosophical, and substantive substructures of the school chemistry curriculum in question. In this way the analysis will lead to an explicit, specific, and detailed knowledge of school chemistry in a particular educational jurisdiction. The analysis will give developers a list of things that they do want to escape from, and therefore do not want to incorporate in the design of new teaching materials. In brief, it gives developers a specific idea what to escape from.

Furthermore, such an explicit and detailed knowledge will facilitate communication, including critiques among the actors involved in a curriculum project, regarding precisely what the project is trying to escape from. This should concern not only the group of developers and teachers involved but should have already begun in the visionary group. Communication among all these groups must then be facilitated in order to preserve as much consistency as possible. The actors involved in the design and teaching of units incorporating the chosen vision should have, on the one hand, an explicit and specific knowledge of their conceptions with regard to the substructures in current school chemistry, and on the other hand, they should be fully acquainted with the chosen vision as laid down in a set of design criteria.

Also, the actors' awareness of the rigid and isolated nature of school chemistry across the three substructures and at all curriculum levels will tend to prevent, correct, or (at least) control the NCE-reflex, the tendency of developers and teachers to fall back on their explicit or implicit conceptions with regard to the structure of school chemistry. An excellent formulation of this problem has been given by Garforth (1983), one of the pioneer developers of the Salters' Chemistry course.

> It may well be that there is a corpus of knowledge without which no syllabus could be called chemistry. Equally it may be that by our *schooling*, *subsequent training* and *teaching* we cannot see anything different adequately filling the space called chemistry at the school level.

This calls for an appropriate pre-service and in-service training for teachers and developers in order to prevent, correct or control the NCE-reflex (section further 6.4). The problem is complicated by the fact that not everyone will see the need for escape. For example, a Faculty of Science ad hoc Committee on a new STS-oriented science curriculum in Canada stated:

> We believe that science curriculum development should be primarily *the responsibility of professional scientists and teachers educated and trained in science and science education.* It must not be unduly influenced by professional educators whose background and interests are frequently secondary (Panwar & Hoddinott, 1995, p. 508).

It could well be that, because almost everyone involved in chemical education, or in science education for that matter, has been trained as a normal scientist, has been taught, has been teaching, is teaching, or is learning in an NSE tradition, it will remain very hard to see or do “anything different”. In short, it may be very hard to escape from NSE, even if we see the need for escape. As we have seen, the Salters’ developers came to violate, in the process of development, their design criterion one, *no preconceptions,* by invoking the structure of school chemistry as they perceived it. This led to the introduction of chemical concepts not needed to make sense of the chosen curriculum emphasis. Appealing to the implicit or practical knowledge of teachers can lead for example to the uncritical introduction of chemical experiments which are traditionally part of school chemistry courses (see Chapter 5).

In sum, applying the curriculum framework to the analysis of the currently dominant school chemistry curriculum leads to a more explicit and specific characterization of current school chemistry. Paying attention to the mechanism of the NCE reflex, will lead to a more explicit and specific strategy, which includes the necessary preventive and corrective measures (Figure 6.9), to escape from NCE at all curriculum levels and across the three substructures of the curriculum.

Besides having a clear conception of where to escape from, one should also have a strategy that addresses the direction where to escape to, that is, a vision should be developed (Condition two; Figure 6.9). The strategy to escape from NCE implies a strategy to replace the rigid combination of substantive, philosophical, and pedagogical structures of current school chemistry with a new coherent combination of substructures constituting the visionary curriculum. The Salters’ development team chooses to articulate and operationalize their visionary curriculum using a coherent set of design criteria (Campbell, 1994).

In their retrospective analysis the Salters’ Science developers made an important point, namely, that:

> Curriculum development is the process of *discovering* the detailed aims and objectives rather than starting with them (Campbell et al., 1994, p. 420).

They came to see curriculum development as a kind of technological problem solving addressing the needs of potential users (ibid., 421), and they took therefore as their starting point for their development or design of teaching units a coherent set of design criteria (see Chapter 4).

This has two important consequences. First, the design criteria put forward must be articulated and operationalized during the development by way of units embodying the new proposal, and these design criteria may as a result have to be changed during the process. Secondly, at each level of the curriculum’s development, evaluation data must be collected in order to evaluate the effectiveness of the units developed in terms of learning and motivation, and also, if needed, to add to or revise the original set of design criteria. The specific choice made by the Salters’ Chemistry Project was to develop an STS-type of curriculum, which focused on relevant materials and processes and aimed at a chemical awareness for all students. This led to their adoption of design criterion two, *relevance*, and design criterion three, *context-led development of concepts,* with design criterion one, *no preconceptions,* intended as a check to introducing no more chemical concepts than would be needed to make sense of the chosen, relevant contexts.

Curriculum diversity

In general, teams of developers can try to make school chemistry *relevant* by using some of the relationships given in Figure 6.4. Thus, strengthening relationships b, c, and d is useful in STS approaches, while relationships d, e, and f are addressed in HPS approaches. On the other hand, relationships a, d, and g have been used in NCE approaches (Chapter 2).

Formulated in Roberts' theory of science curriculum emphases, Dominant School Chemistry consists of a cluster of three or four curriculum emphases: *Solid Foundation, Correct Explanations, Structure of Science* and *Scientific Skills Development,* which together send a coherent message to teachers and students alike that school chemistry is about training of sound scientific knowledge, processes and skills (see Figure 6.11). At the same time, Dominant School Chemistry *prevents* the communication to the student of other curriculum emphases, emphases which are perhaps more worthwhile. The process-oriented curriculum emphases: *Self as Explainer* and to some extent *Structure of Science* and *Scientific Skills Development* contain the message that school science is about learning to argue and experiment (see Figure 6.5 for the process-oriented dimensions: common sense, history and philosophy of science, and current chemical research). Also, the society-oriented curriculum emphases, Everyday Coping and Science, Society, and Decisions, contain the messages that school science is about using and applying scientific knowledge and methods, or about making decisions on issues involving scientific and technological knowledge, such as the relevant emphasis of the Salters' Chemistry course (see Figure 6.5 for society-oriented dimensions such as everyday life and society, and technology).

The seven-fold isolation of Dominant School Chemistry has come about by largely excluding or resisting these HPS and STS curriculum emphases while simultaneously narrowing down the first four academically-oriented emphases to a weak version of NCE that consists of the reproduction or rote learning of facts and theories and of performing experiments mostly by way of recipes. The particular combination of specific substructures found for Dominant School Chemistry thus communicates a very specific message to teachers and students. The analysis in terms of the concept of Normal Science Education gives an edge to the analysis of Roberts in terms of the concept of curriculum emphases in that it singles out a (cluster of) emphases as *dominant* emphases pertaining to school chemistry curricula. This has repercussions for the process of development. After all, a characterization of the currently dominant school chemistry curriculum as rigid and isolated, will point to the NCE-reflex, which can be expected to occur during reform, more specifically during the transformations of the various curriculum levels (see Figure 6.9).

6.3.5 Condition three: use of curriculum framework in developmental research

The recommendations which arise from the application of my curriculum framework to the process development may also contribute to the strategy of developmental research as described by for example Lijnse (1995). As we have seen in Chapter 4, the Salters' Chemistry Project arranged to obtain feedback from students by collecting their opinions on the lessons of new units, at least in the early stage of the development. The Project also collected the opinions of teachers throughout the development. Given the *tentative* character of the design criteria approach, there is a need to increase the severity of the evaluation by collecting data from different kinds of sources and from all curriculum levels involved. For the taught and learned curriculum levels, not only should data consisting of *opinions* of teachers and students be collected, but also data on the *behavior* of teachers and students in the classroom, that is, of the actual teaching and learning activities they exhibit in the classroom.

The latter could be achieved by recording verbal and visual behavior using audio- and videotapes. In short, classroom-based research should complement the evaluation of opinions of the actors involved. The same should be done for the levels of the designed and visionary curricula. It would be most useful to have not only a record of the opinions of the actors involved, that is, of developers of materials and developers of vision, but also to have *a record of their behavior during the processes of designing and deliberation* leading to the developed products (teaching materials and curriculum vision). In this case the study of the behavior would involve: (i) the actual activities exhibited in the "vision-room" such as the deliberations and decisions made that lead to the successive drafts of the vision to be developed and (ii) the actual activities exhibited in the "design-room" such as the design of the first prototypes, their further development and revision, and the deliberations and decisions involved here.

Thus, "vision-room"-based research and "design-room"-based research should complement classroom-based research. The study of the behavior of the actors involved – be it 'vision makers', developers, teachers or students – should complement the analysis of the opinions given in interviews or tests by the actors involved. Finally, as shown in Chapter 5, a consistency analysis should be performed of the adopted design criteria as articulated and operationalized in the developed materials in order to screen or revise the original set of design criteria.[6] In sum, valuable data should be gathered on a newly designed curriculum by performing:

- a *consistency analysis* in order to see whether and to what extent the intended design criteria are consistently realized in the designed curriculum units;

- a *reversed design analysis*, that is, inferring from the actually realized content of the unit (contexts, concepts, and activities) any *tacitly* used design criteria which might have led to unintended, unforeseen, or perhaps unwanted consequences;

- a *redesigned proposal* or scenario for the topic or theme of the unit in light of the performed consistency analysis and reversed design analysis.[7]

Thus, to maximize the necessary feedback and to test the curriculum hypothesis severely, data should be collected from all curriculum levels about the *behavior* of actors during the processes, about the *products* of these processes, and about the *opinions* of the actors involved in these processes and products. In order to be able to use this varied feedback in an optimal way, it is important not to begin the designing of units until *after* the

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6 See Van Berkel (1999) for a consistency analysis and a reversed design analysis performed on the research-based scenario of "teaching an initial particle model" as designed and tested by Vollebregt (1998).

7 This focus on design in developmental research raises the question whether it would be fruitful to regard and explicate these research activities as a form of 'design science' (Van Heffen et al., 2002, p. 13).

systematic evaluation of the visionary level, and likewise, it is important not to start the large scale teaching of draft materials in the classroom until *after* the systematic evaluation of the designed curriculum level.

The recommendations about curriculum analysis, development, and research can briefly be put as follows: articulate a new vision, prevent import of the previously analyzed old vision, and test and control both processes – to escape from and to escape to – by systematic developmental research augmented by consistency analysis (Figure 6.9). Support for the curriculum framework developed in this thesis will depend on its usefulness in terms of analysis, development and developmental research.

6.4 Suggestions for further chemical educational research

During my struggle with the problem of the structure of school chemistry and the problem of escape from current school chemistry (section 1.1.1), I was led to various research themes which I decided at the time not to pursue in more detail than seemed relevant for the research questions (Figure 6.1).

However, on the basis of the theoretical curriculum framework developed in this thesis, it now seems worthwhile to explore further some of these research themes. Accordingly, I discuss the following: first, a research theme in the field of the history of school chemistry curricula (section 6.4.1); second, the relevance of the history and philosophy of chemistry for curriculum analysis and design (section 6.4.2); third, the development and research of the training of chemistry teachers as developers (section 6.4.3); and fourth, some ways to address the consistency and coherency problems of a context-led development of concepts (section 6.4.4).

6.4.1 History of school chemistry curricula

In several places (sections 2.3, 3.2 and 3.3.2) in this thesis, I have used international sources from the history of school science/chemistry curricula to support two important claims I make here: first, that the academic orientation of school science, what I called Normal Science Education (NSE), came to dominate at the end of the19th century, and second, that the curriculum orientation called NSE has resisted several curriculum reforms. As I have argued throughout this thesis, this NSE tradition still prevails today as a *rigid* combination of a specific substantive structure, based on *corpuscular theory*, a specific philosophical structure, *educational positivism*, and of a specific pedagogical structure, *initiatory and preparatory training* of future chemists.

As discussed in subsection 1.1.2, I refrained from embarking on an extensive and detailed historical study of school chemistry curricula. Since our ultimate goal was to contribute to reforms of school chemistry, what we needed was a valid description and analysis of the structure of current school chemistry, but only as detailed as required for that purpose. As De Vos (1991, p. 79) remarked:

> We must constantly keep in mind that our motives are educational, not historical, since the history of chemical education turns out to be just as fascinating as its present. Still, in order to understand the present curriculum and explore possibilities for future developments, we must study the past.

In this context of reform, Wobbe de Vos has given in several places an outline of a history of Dutch school chemistry, the last publication being, before he passed away, De Vos (2002). In our joint paper (De Vos et al. 1994, p. 746), written in the context of my research, he stated that:

> In a historical analysis of chemistry curricula in secondary schools it is interesting to see how (and to try to understand why) various aspects of the structure have been emphasized for some time, only to be overshadowed by others in later years. Developments in chemistry as well as in society in general have had their influences.

Therefore, the educational focus of my thesis has been on *phenomena of curriculum continuity*, not on phenomena of curriculum diversity of school chemistry curricula. Looking back, though, I think it would be worthwhile, on the basis of the curriculum framework I developed, to undertake a more detailed history of Dutch school chemistry. Such a curriculum history could describe in more detail for the Netherlands:

- How and why the academic orientation to chemistry prevailed at the end of the 19th century over the, originally intended, vocational orientation to Dutch school chemistry.
- Why curriculum changes resulting from intended reforms of Dutch school chemistry came to overlay the dominant curriculum emphasis.
- How mechanisms impending change, such as the NSE reflex, operate at the different curriculum levels involved.

Such a historical analysis of the Dutch school chemistry curriculum would reveal to what degree the actual curriculum diversity differs from the intended curriculum diversity. It would also show to what extent the actual curriculum emphases used in the Netherlands match the curriculum emphases as described by Roberts for North America (1982).

6.4.2 Relevance of history and philosophy of chemistry for curriculum design

The actual curriculum diversity revealed by curriculum history (Layton, 1973; Just, 1989; DeBoer, 1991) is often smaller than the intended curriculum diversity. The potential curriculum diversity, the possible new visions on science curricula, is even greater, as was argued by Schwab (1978), for example. These new visions, taken here as a coordinated combination of a specific substantive, philosophical, and pedagogical structure, are nowadays based on the work of science educators, developers, and teachers who are assisted at times by reflective scientists. These visions, however, can also by drawn from sources of the history and philosophy of science, especially with regard to the substantive and philosophical structure of potential new curricula.

The history of chemistry, an established discipline since the1950s, has occasionally been a valuable source to inform science curriculum design (Conant, 1948; Matthews, 1994; Holton, 2003), but as one of the respondents of the International Forum remarked:

I do not know – like Aarons or Hecht in physics – a secondary textbook that shows chemistry as an historical process.

As for the philosophy of chemistry, this field of research has recently (1999) became more firmly established by the publication of its own journal titled, *Foundations of Chemistry*, while an electronic journal, *Hyle* has already been on-line since 1994 (www.hyle.org). Several conferences on the philosophy of chemistry – to which chemical educators attended or were invited – have led to the publication of many papers on important topics in the philosophy of chemistry, while a number of dissertations have appeared and recently a number of books on the philosophy of chemistry have also been published.

With regard to my own research, I used Kuhn's philosophy of science to analyze the currently dominant school chemistry curriculum as it came out of the responses of the International Forum (Chapter 2). I have further characterized, in Schwab's terms, Dominant School Chemistry as a rigid combination of a specific substantive structure, based on *corpuscular theory*, a specific philosophical structure, *educational positivism*, and a specific pedagogical structure, *initiatory and preparatory training* of future chemists. The rigid and isolated nature of Dominant School Chemistry as a form of Normal Chemistry education, has, as I have argued, its origin in the narrow and insulated nature of Normal Science/Chemistry, as described by Kuhn. In brief, the scientific practice of Normal Science is at the origin of the educational practice of Normal Science education.

Both the responses of the International Forum (Chapter 2), and Roberts historically informed educational analysis, have pointed to the existence of (partially realized) alternative science/ chemistry curricula having curriculum emphases differing from the dominant school science/ chemistry curriculum. As noted before, a new curriculum emphasis can be seen as a coordinated combination of a specific substantive, philosophical, and pedagogical structure. It is at this point that sources of the history and philosophy of chemistry can support the educational analysis of specific substantive and philosophical structures as contained in an alternative or new curriculum emphasis. For example, the work of the German chemical philosopher Schummer (1996) on the representation of dynamical relationships in chemistry could be used to elaborate the reaction-chemical emphasis of the "Coherent Conceptual Structure of the Chemistry Curriculum" as proposed by De Vos et al. (1994). The combined efforts of chemical educators and chemical philosophers might thus lead to a further elucidation and elaboration of the reaction-chemical curriculum emphasis, and the subsequent design and trial of such an (advanced) chemistry course. For another example of the relevance of history and philosophy of chemistry for curriculum design, see section 6.4.4.

Members of the International Forum (Chapter 2) made the valuable additional remark that variations in the substantive structure of school chemistry have been proposed and tried. At least three such substantive structures have been incorporated in school chemistry curricula: one centered on substances, one centered on corpuscula, and one around chemical reactions (section 2.2.2). Erduran and Scerri (2002, p. 20) make the same claim, while arguing for "the inclusion of philosophical perspectives in the chemistry curriculum" over and above these three emphases on chemical content. They mention as an example, the "Acids & Bases Curriculum" in which the main emphasis is of a philosophical, or rather epistemological nature, namely: "to engage students in the process of model generation, evaluation and revision" (ibid., p. 21).

Thus, curriculum diversity can be further increased by choosing alternative philosophical structures but also by choosing alternative substantive structures from the wider field of chemistry, taken as a set of chemical practices or activities in society of which the purely scientific research activities form only one subset (Fensham, 1984; Hoffmann (1995). An example of the latter type of curriculum (section 3.2) is the elementary chemistry curriculum of Van Aalsvoort (2000), a curriculum that is oriented in the chemical practice of making chemical products in conformity with chemical, technical, and societal norms. Needless to say, the pedagogical structure has to change as well. Only then can we say that we deal with:

> A fundamental change.. [which].. consists of an alteration of aims, contents and teaching strategies in concert, due to their being founded in a different representation of reality (Van Aalsvoort, 2000, p. 60).

6.4.3 Training chemistry teachers as developers

In Chapter 4, I have shown that the development team of the Salters' Chemistry project did not fully escape from the traditional O-level chemistry curriculum, the embodiment of normal chemistry education (NCE) in England in the 1970s (Figure 4.2). The larger part of the development team consisted of creative chemistry teachers (temporarily seconded to the Salters' Chemistry project as developers), as well as experienced developers and textbook writers, most of them still teaching in the classroom. In addition in Chapter 5, I have shown in detail to what extent a teacher, congenial to the Salters' approach while in the process of interpreting and teaching the unit Metals of the Salters' science course, did not escape from the substantive structure of NCE (Figures 5.5 and 5.16).

Apparently, it is a problem for both developers and teachers to escape from NCE while designing and teaching units of an alternatively conceived chemistry curriculum. The problem of escape, therefore, has to be faced, for both developers and teachers, at the visionary and designed curriculum levels as well as at the levels of interpreted and taught curricula. This is particularly important now, since in new curriculum projects of the 21st century the role of teachers as developers is seen to be of paramount importance for the success of the kind of reform the project sets out to achieve. Examples of such curriculum projects are Millar and Osborne (1998) on projects to be initiated beyond the year 2000 in the UK; Nentweg et al. (2002) on their "Chemie im Kontext" (Chemistry in Context) project in Germany; Driessen and Meinema (2003) on "Chemie tussen context en concept, ontwerpen voor vernieuwing" (Chemistry between context and concept, a design for renewal), the report which forms the basis for the "Nieuwe Scheikunde" Project (New Chemistry Project) in the Netherlands.

This means that we have to provide chemistry teachers with training, in-service as well as pre-service, which aims to enhance teachers' competence to design, develop, and teach new chemistry curricula. During these processes teachers should be aware of the constraints in order not to succumb to the NCE reflex. The three conditions to escape from Dominant School Chemistry, applied to teachers as developers, take the form of the following recommendations for further research (see also Figure 6.9).

Recommendations for further research on teacher training

Condition 1: *In order to escape, teachers have to know what to escape from.*

Develop and research a teacher training course on traditional, alternative and potentially possible chemistry curricula conceived in terms of curriculum levels (Goodlad), curriculum substructures (Schwab), and curriculum emphases (Roberts). Before assuming their role as developers, teachers should be made aware in this training course of their starting position with regard to their knowledge, skills, and attitudes in the curriculum landscape of their country.

Condition 2: *In order to escape, teachers have to know what to escape to.*

Develop and research the content of a teacher training course, including an effective teaching strategy, which aims to empower teachers with competencies to select, envision, design, interpret, and teach newly devised curriculum units.[8] Curriculum units should, after analysis in the design room and trials in the classroom, be revised or redesigned in accordance with the adopted design criteria, which constitute the new curriculum vision.

At a later stage these piloted teacher training courses might lead to a full-blown teacher training course on “Science Curriculum, Design and Development” to be integrated in the regular pre-service training of science teachers.

Condition 3: *In order to escape, teachers have to know how to escape.*

Perform a developmental research project on *Training Teachers as Developers*, which accompanies a large-scale curriculum developmental project such as the “Nieuwe Scheikunde” Project (Driessen & Meinema, 2003).

In the first phase of this project teams of teachers are formed who act as developers and are coached by a chemical educator. The teacher teams will design and develop pilot units on the basis of the context-led approach envisioned by the project. This is an excellent opportunity to perform design-room-based research on the design and development processes. In this way chemistry teachers learn to enhance their competencies to design, develop, and teach new chemistry curricula.

Furthermore, the chemical education researcher participating in this research project will be able to explicate, elucidate, and elaborate the adopted design principles, possibly into a design heuristic or a set of design procedures, needed to realize the envisioned curriculum effectively in the classroom. The results of the developmental research performed in this way might lead the development team to go back to the ‘design room’, or even back to the ‘vision room’, in order to adjust the originally adopted design criteria constituting the new curriculum vision. The findings of the first cycle of the developmental research project on “Training Teachers as Developers” is then used as input for the next cycle. The newly chosen curriculum emphasis is thus checked for consistency at all curriculum levels, from the visionary and designed curriculum up to the taught and experienced curriculum level.

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8 For research on effective teaching strategies for teacher training courses see Janssen and Verloop (2004) and Stolk et al. (2004).

6.4.4 Problems with context-led development of units of a chemical course

In this final subsection I discuss, first, the *problem of consistency* of a context-led development of a chemical *unit*, and, second, the *problem of coherency* of a context-led development of a chemical *course*. I also outline some practical and theoretical ways to approach the problems of unit consistency and curriculum coherency and suggest some further research.

Problems of consistency of a context-led development of a chemical unit

As we saw in Chapter 4 (and in more detail in Chapter 5) in the analysis of the unit Metals the developers introduced more chemical content (PC content) than needed to make sense of the chosen CTS contexts, which centered around the theme corrosion. As a consequence, the CTS content, as entailed by the CTS contexts, had to give way to traditional PC content. As argued in Chapter 5, these findings are inconsistent with design criterion three, *context-led development of concepts*, which the developers expressed in the Salters Chemistry Syllabus as follows:

> ... chemical generalizations, principles and explanations are only introduced as and when they arise naturally from or when needed in the work on these 'everyday' substances (SLB, p. 1).

In subsections 4.6.2 and 5.2.3, I referred to this problem of unit consistency as the *tension between chemical content and context*, the main problem I discussed in Chapter 5. We also came across a second problem, namely, the *tension between the process of inquiry and the chemical context,* that is, a strong unit emphasis on context development can lead to a certain lack of evidential teaching with regard to the conceptual development. A third tension, *between chemical content and process*, became manifest in the first curriculum wave in the 1960s when many developmental projects tried to address science taken as a process of inquiry, while often holding on to more traditional science content than needed to make sense of the selected context of inquiry and the scientific processes entailed in this (section 3.2).

While developing and teaching any unit with a non-traditional curriculum emphasis, there is a danger that too much traditional content is, explicitly or implicitly, appealed to because of, what I called, the operation of the NSE reflex (section 3.4).

In terms of Roberts' concept of curriculum emphasis we could say in general, that it turns out to be very difficult to develop science units in which two or more curriculum emphases are addressed effectively at the same time. Attempts to do so, be they explicitly or implicitly intended, give rise to the tensions in the curriculum materials mentioned above, and with them to ambiguities and possibly confusion for teachers and students executing them.

In subsection 5.2.8, I suggested that the problem of unit consistency, the *tension between chemical content and context*, could be dealt with in a practical way by attempts to redesign the unit in more strict conformity with the design principles, which articulate the original vision of the developers (see also Van Berkel, 1999).

In brief, based on the consistency analysis performed during and after the development of a unit, there should follow the consistent redesign of the unit, alongside the usual tests for effective teaching and learning of the newly developed unit.

In view of the growing number of context-led developed science courses and projects the problem of unit consistency and the problem of course coherency discussed below deserve theoretical attention as well. The second generation of context-led developed science courses is about to take off (Millar & Osborne, 1998; Nentweg et al., 2002, Driessen & Meinema, 2003). Reflection and research on the first generation of context-led developed science courses such as the MAVO project (Joling at al., 1988), PLON (Wierstra, 1990; Kortland, 2002), Salters Science (Bennett & Holman, 2002) and ChemCom (Sutman et al., 1992) can hopefully lead us to make changes in our development projects, where previously we failed (Aikenhead, 1997). For instance, Bennett and Holman (2002, p. 181) reflect on the Salters Science projects as follows:

> The major challenge still lies ahead: to develop a curriculum for chemical and scientific literacy that meets the needs of all students, *the generalists as well as the future specialists*. The curriculum for chemical and scientific literacy represents the next logical step for context-based movement, yet it requires a fundamentally new approach. It is not a matter of asking what contents can be used to illustrate *a pre-existing body of scientific knowledge*. It is necessary to ask what science explanations and ideas students need to make sense of for their future live in a world dominated by science – *and to exclude rigorously anything that does not meet these selection criteria* (my italics).

In line with the findings of my research, it is my contention that in future context-based development science projects two things are essential to bear in mind (the first of which we have already discussed above). That is, to focus fully consistently on the chosen curriculum emphasis, and beware of developing, explicitly or implicitly, a mix of curriculum emphases Roberts (1988) in which very often the operation of the NSE reflex counteracts the realization of the newly chosen curriculum emphasis. Secondly, to focus in a fully consistent way on the needs of future citizens as generalists, and beware of addressing, explicitly or implicitly, the needs of a mix of future citizens and future science specialists in which, as we saw, the needs of the latter tend to prevail. From now on we should focus on "...learners as future citizens who will be consumers (Millar, 2002. p. 11).

In terms of Schwab, this amounts to the replacement of the prevailing *rigid* combination of a concept-led substantive, philosophical, and pedagogical structure aimed at the preparatory training of future scientists, with a new *coordinated* combination of a consistent, *context-led* substantive, philosophical, and pedagogical structure aimed at the general science education of future citizens.

Furthermore, questions about what we mean in a theoretical sense by the term *chemical context* and the term *chemical concept* need to be addressed as well. In a recent paper Bulte et al. (2004) have discussed a new theoretically based approach to context-led development of chemical units. Following the chemical philosopher Psarros (1998), chemical contexts are taken as what the authors call *authentic chemical practices*. Each chemical practice, they say, embeds a certain kind of question, which is answered by the practitioners of the authentic chemical practice while using appropriate knowledge and procedures contained in that chemical practice.

Different chemical practices embody different issue-knowledge and procedures. Simulating or 'mimicking' those authentic chemical practices for educational purposes leads to the design of educational materials by which students are motivated to explore this type of questions using appropriate knowledge and procedures with regard to the issue involved in the unit. Examples of chemical practices mentioned by Bulte et al. (2004) are: quality control of products, chemical inquiry, chemical modeling, and chemical design. The first two practices have been developed, trialled, and researched (Westbroek et al., 2004; Westbroek, 2005; Van Rens et al., 2003; Van Rens 2005), while using the methodology of developmental research (Lijnse, 1995), the first one in combination with the problem posing teaching approach (Klaassen, 1995).[9]

It is to be hoped that the prototypes of these authentic chemical practical units will inform and influence the large scale developmental project in the Netherlands, *Nieuwe Scheikunde* (Driessen & Meinema, 2003), a project which, as we saw, is also based on a context-led approach to development of a chemical curriculum.

The knowledge and procedures of chemical practices can be researched in an empirical or naturalistic way by observing or interviewing the practitioners of the authentic chemical practice (Prins et al., 2004). Another way to explicate the kind of knowledge and procedures of these authentic chemical practices is by making use of sources of history and philosophy of chemistry (see subsection 6.4.2 above). The expertise from the field of the history and philosophy of chemistry can be used to explicate what could be called *the logic of* these chemical practices, such as the logic of quality control of substances (conform to an international set of quality norms), the logic of chemical inquiry, the logic of chemical modeling, and the logic of chemical technological design.[10] Such logic of chemical practices could inform the consistent development of teaching materials, and thereby underpin the chemical competencies to be taught by chemistry teachers and to be acquired by students. This would constitute a much needed enrichment of the currently taught competencies of explaining and puzzle solving, competencies which have received up to now the most attention from science educators and, to some extent also from philosophers of science, in their explication of the logic of explanation (Hempel, 1965) and the logic of puzzle-solving (Kuhn, 1970). Also the logic of application, and its relation to the logic of explanation, would deserve more attention from science educators. If fully explicated, the logic of application could contribute to the consistent development of applications-led or context-led science courses mentioned above.

Problems of coherency of a context-led development of a chemical curriculum

Having developed chemical units with a consistent chemical context, chemical emphasis, or an authentic chemical practice, the problem arises, regarding the curriculum order or structure in which these various consistent chemical units must or should be put. In other words, we have to face the problem of the coherency of a context-led development of a chemical curriculum composed of different consistent, context-led units without the usual, explicit or implicit, appeal to the traditional conceptual structure of school chemistry. We have seen that the Salters' developers faced this problem in the end by appealing to: "what we perceive, what we all perceive to be *the structure of chemistry*" (L92). This should be avoided. As we have seen, the mechanism of the NCE reflex will lead to *slippage* in the processes, which lead from the visionary curriculum to the

9 Another example is Kortland (2001), who uses a *logic of decision* as explicated by philosophers to develop a problem posing approach to teaching decision making about a waste issue.

10 See Roozenburg & Eekels (1996) for an interesting explication of the logic of technological design, on which the Techniek 15+ Project based its use of the technological design cycle (De Beurs et al., 2003).

realized, taught and learned, curriculum in the classroom and as a result to an inconsistent realized curriculum.[11]

Another, theoretical, solution to the problem of curriculum coherency has been put forward by Roberts (1982) who argued for what he called a *balance* of curriculum emphases in a newly developed curriculum. Such a balance would increase the likelihood of engaging more students in the various activities or practices of science by appealing to a broader array of interests, aptitudes, and abilities of the students involved. A consistent development of a curriculum emphasis would avoid the danger of slippage along the curriculum levels involved.

Another, practical, solution to the problem of curriculum coherency would be to leave it to chemistry teachers to select and compose their own chemistry course. This chemistry course would then be adapted to their own educational situation, school, and classroom while being based on the consistent and effective context-led chemical units provided by a project such as *Nieuwe Scheikunde* (Driessen & Meinema, 2003). It is important to realize that this approach to the problem of curriculum coherency assumes that teachers have been able to enhance their professional expertise in terms of teaching and developing teaching materials conceived along the new curriculum emphases, as I stressed in subsection 6.4.3. For biology education, Janssen (2004) discusses a problem posing approach to teaching eight biological perspectives, while developing at the same time a teacher training course for biology teachers so that they can themselves select, develop, and use these biological perspectives as applied to biological issues chosen by their students. Finally, just as with trialling lessons of a unit for consistency, order, and effectiveness, we can also make an informed guess as to the order for the consistent units making up a course, and then test this hypothesis for consistency and effectiveness.

[11] A first proposal to address this problem from the perspective of authentic chemical practices has been described by Bulte at al. (2004).